AN INTEGRATED APPROACH TO INTELLIGENT SYSTEMS: INTERIM PROGRESS REPORT

by

S. Shankar Sastry, Anil Nerode, and Zohar Manna

Memorandum No. UCB/ERL M97/25

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ELECTRONICS RESEARCH LABORATORY

College of Engineering
University of California, Berkeley
94720

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The primary output of the MURI project in this period has been conceptual, and foundational research along the following research fronts: (1) Distributed Multi-Agent Control System: Architectures, (2) Hierarchies of Sensing and Control, (3) Specification, Verification and Robustness of Hybrid Systems, (4) Hybrid System Languages, (5) Intelligent Agents for Complex Uncertain Environments, and (6) Soft Computing and Neural Networks. These basic research thrusts are also being integrated and validated on three test beds of relevance to the Army: *Intelligent telemedicine testbed* featuring multi-modal sensor fusion and planning of battlefield telemedicine and telesurgery, Intelligent software agents for machine augmentation of human-centered decision systems interacting with complex sensory data, *Multi-agent helicopter based decentralized control* featuring soft computing paradigms for the control and coordination of the helicopters.

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An Integrated Approach to Intelligent Systems: First Year Progress Report (March 1997)

S. Shankar Sastry, Anil Nerode and Zohar Manna

1. Introduction

The activity on our project has not been underway very long, but it has proved to be an extremely fertile area with a lot of activities, including a 3-day conference at Cornell in October 1996 and a weekly seminar at Berkeley and Stanford, along with numerous exchanges of researchers. The primary output of the MURI project in this period has been conceptual, and foundational research along the following research fronts:

1. Distributed Multi-Agent Control System: Architectures
2. Hierarchies of Sensing and Control
3. Specification, Verification and Robustness of Hybrid Systems
4. Hybrid System Languages
5. Intelligent Agents for Complex Uncertain Environments
6. Soft Computing and Neural Networks

These basic research thrusts are also being integrated and validated on three test beds of relevance to the Army: *Intelligent telemedicine testbed* featuring multi-modal sensor fusion and planning of battlefield telemedicine and telesurgery, Intelligent software agents for machine augmentation of human-centered decision systems interacting with complex sensory data, *Multi-agent helicopter based decentralized control* featuring soft computing paradigms for the control and coordination of the helicopters.

2. Distributed Multi-Agent Control Systems: Architectures

Investigator: Shankar S. Sastry

The bulk of our effort in this area has been in the development of tools for *the architectural design* of multi-agent, distributed control systems with hierarchies of actuation and sensing. Important characteristics of these systems are the tradeoff between individual safety and performance and collective emergent patterns. In our work, we have worked on hierarchical design techniques to guarantee verified safe designs with protocols for coordination and conflict resolution. The resultant systems are hybrid in that they feature the interaction of discrete and continuous control dynamics. The details of the projects represented here are in the areas of

- Programming of Emergent Behaviors
- Hierarchies of Modeling for Sensing and Control
- Architectures with Trade-offs Between Local and Global Decision Making

Generation of Conflict Resolution Maneuvers for Air Traffic Management
Jana Kosecka, Claire Tomlin, George Pappas and Shankar Sastry

We explore the use of distributed on-line motion planning algorithms for multiple mobile agents, in Air Traffic Management Systems (ATMS). The work is motivated by current trends in ATMS to move towards decentralized air traffic management, in which the aircraft operate in ``free flight" mode instead of following prespecified ``sky freeways". Conflict resolution strategies are an integral part of the free flight setting. In [3] a set of predefined coordination maneuvers has been proposed. The purpose of this paper is to extend this set of maneuvers to cover all possible conflict scenarios involving multiple agents. A distributed motion planning algorithm based on potential and vortex fields is used. While the algorithm is not always guaranteed to generate flyable trajectories, the obtained trajectories can serve as qualitative prototypes for coordination maneuvers between multiple aircraft. The actual maneuvers are generated by approximating these prototypes with trajectories made up of straight lines and arcs of circles.

Towards Continuous Abstractions of Dynamical and Control Systems
George Pappas and Shankar Sastry

The analysis and design of large scale systems is usually an extremely complex process. In order to reduce the complexity of the analysis, simplified models of the original system, called *abstractions*, which capture the system behavior of interest are obtained and analyzed. If the abstraction of system can be shown to satisfy certain properties of interest then so does the original complex plant. From a design perspective, the complexity of large scale systems is reduced by hierarchical structures. In hierarchies, systems of higher functionality reside at higher levels of the hierarchy and could be thought of as bstractions of lower level systems. In hybrid systems, discrete abstractions of continuous systems are of great interest. In this paper, the notion of abstractions of continuous systems is formalized.

A Next Generation Architecture for Air Traffic Management Systems
Claire Tomlin, George Pappas, John Lygeros, Datta Godbole and Shankar Sastry
(Technical Report, 21 January 1997)

The study of hierarchical, hybrid control systems in the framework of air traffic management systems (ATMS) is presented. The need for a new ATMS arises from the overcrowding of large urban airports and the need to more efficiently handle larger numbers of aircraft, without building new runways. Recent technological advances, such as the availability of relatively inexpensive and fast real time computers both on board the aircraft and in the control tower, make a more advanced air traffic control system a reality. The usefulness of these technological advances is limited by today's Air Traffic control (ATC), a ground-based system which routes aircraft along predefined jet ways in the sky, allowing the aircraft very little autonomy in choosing their own routes. In this paper, we propose an architecture for an automated ATMS, in which much of the current ATC functionality is moved on board each aircraft so that the aircraft may calculate their own deviations from predefined trajectories without consulting ATC. Within the framework of this architecture, we describe our work in on-board conflict resolution strategies between aircraft, and in deriving the flight mode switching logic in the flight vehicle management systems of each aircraft.

Learning of Complex Motor Actions

We routinely learn to perform complex motor actions such as walking, running, riding bicycles, gymnastics, diving and windsurfing to name a few examples. If one were to write mathematical models of these activities then they would involve complex dynamical equations of multi-body systems (the limbs of the body) interacting with other multi-body systems (the bicycle), subject to non-holonomic conservation laws (the diver or gymnast), and complex aerodynamic, hydrodynamic forces (the windsurfer). For example in our work on diving, we have found that the equations for enough a 10 degree of freedom model of the body (2 trunk + 2 arm + 4 shoulder + 2 hip) produces equations of motion which cover several pages in symbolic form. Thus, these models are not amenable to the methods of classical adaptive control of nonlinear systems as developed in the control literature. Further, the learning is apparently not rule based since we are able to produce control actions for unfamiliar of unencountered circumstances after we have done some basic learning: for example new patterns of winds and waves in windsurfing. Several other characteristics of the motor learning are that at the outset our performance of the actions is jerky and leaves the muscles tense and exhausted, whereas to use a sports metaphor with time, we "relax into the motions". Also, learning is preceded by a period of more or less confused trials before there is a sudden and sharp improvement in the quality of our actions. We have proposed a mathematical model for the learning of these complex motor actions which captures all of these features. The research on this topic involves mathematical analysis of nonholonomic systems as well as learning.

Control of Nonholonomic Systems with Drift Terms

J.-M. Godhavn, A. Balluchi, L. S. Crawford, and S. S. Sastry

In the present paper non-holonomic systems with drift terms are studied. The discussion is focused on a class of Lagrangian systems with a cyclic coordinate. We present an approach to open-loop path planning in which the system evolution is studied on manifolds of dimension equal to the number of control inputs. A control algorithm is derived and it is applied to the examples of a hopping robot and a planar diver. A similar algorithm is derived for the study of what states can be reached within a given time. An exponentially stabilizing feedback controller is derived for tracking of the planned trajectories. The results are illustrated with simulations.

Learning Controllers for Complex Behavioral Systems
Lara S. Crawford and S. Shankar Sastry
(Technical Report, 3 December 1996)

Biological control systems routinely guide complex dynamical systems through complicated tasks such as running or diving. Conventional control techniques, however, stumble with these problems, which have complex dynamics, many degrees of freedom, and a task which is often only partially specified (e.g., ``move forward fast," or ``execute a one-and-one-half-somersault dive"). To address problems like these, we are using a biologically-inspired, hierarchical control structure, in which controllers composed of radial basis function networks learn the controls required at each level of the hierarchy. Through learning and proper encoding of behaviors and controls, some of these difficulties in controlling complex systems can be overcome.

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3. Hierarchical Sensing and Control

Investigator: Jitendra Malik

A key requirement for hierarchical intelligent systems is their ability to abstract multi-sensory perceptions with labels for the planning layers of the hierarchy, and a capability to have an elaboration of high-level instructions into detailed actions for all the agents.

We consider the example of driving based on visual sensing as a platform for development of a hierachical sensing framework, where acquired information from the sensors is subsequently used for control at different time scales. We have developed the low-level algorithms for extraction of simple measurements necessary for closing the feedback loops of lateral and longitudinal control. We have provided a quantitative analysis of the role of the delay present in the visual system as well as the importance of the measurements at the look-ahead distance for lateral control of the vehicle at various velocities, road curvatures and road conditions.

At the mid and higher levels of sensory-motor control, it is necessary to reason in terms of behaviors of objects (e.g., cars, obstacles). This requires that we be able to group the spatiotemporal information into separate objects. We have chosen to study this problem in its full generality. What makes the grouping problem hard is that while local measurements can be used to assess the probability that 2 pixels belong to the same object, the partitioning of the image stream is fundamentally a global problem. We have devised a new framework for this problem. The proposed framework can be applied to a variety of low and mid level vision cues providing important information for higher level control and symbolic planning of single and multiple agents.

Vision-Based Lateral Control of Vehicles

Robert Blasi, Jana Kosecka, Camillo Taylor, Shankar S. Sastry and Jitendra Malik

Recent interest in highway automation and current advances in real-time image processing provide suitable testbed for employing the visual information extracted from image sequences in the feedback loop of the control system.

The main advantage of vision-based control for steering is that of the availability of information about the road ahead of the car. Not surprisingly this type of information is essential for a driver steering. We investigate the choice of measurements from the road imagery which can then subsequently be used for the design of a controller.

The data extracted from the road is based on the robust detection of lane markers followed by a linear fit at various look-ahead ranges. The main objective of the controller is to maintain the position of the vehicle with respect to the center of the road while maintaining the vehicle's orientation parallel to the road tangent. With a known camera geometry, the offset at the look-ahead distance and the yaw angle of the vehicle with respect to the road can be extracted robustly at 20 Hz with a 150 ms delay. The curvature of the road ahead is estimated using additional information about the yaw rate of the vehicle.

By considering the full dynamical model of the vehicle we look at the choice of the proper lookahead distance, which varies with linear velocity and is affected by quality of the offset estimates. Further we characterize the effect of the delay and the use of the curvature information in the controller design. A thorough analysis of the controller design and closed loop simulations are presented.

Normalized Cuts and Image Segmentation
Jianbo Shi and Jitendra Malik

From the early days of scientific study of human vision, researchers have noticed that a key aspect of human perception is its ability to organize visual data in a concise and stable way. For example, when we drive down a street, we tend to see trees on both sides of the road as grouped together, because of their parallel symmetry and similarity in color. We also tend to see different cars as distinct objects because of their independent motion. The Gestalt school of visual perception described this well using the slogan ``the whole is different from the sum of its parts"—humans prefer to organize visual data in ways that bring out more structure in the data. Computer vision researchers have been struggling for many years to develop algorithms to operationalize this ability.

In this project, we propose a novel approach for solving the perceptual grouping problem in vision. Rather than focusing on local features and their consistencies in the image data, our approach aims at extracting the global impression of an image. We treat image segmentation as a graph partitioning problem and propose a novel global criterion, the normalized cut, for segmenting the graph. The normalized cut criterion measures both the total dissimilarity between the different groups and the total similarity within the groups. We show that an efficient computational technique based on a generalized eigenvalue problem can be used to optimize this criterion. We have applied this approach to segmenting static images as well as motion sequences and found that it gives very good results.

Visual Servoing
Ma Yi, Jana Kosecka and Shankar S. Sastry

The goal of this project is to explore theories and methods of mobile robot motion planning using vision sensor with explicitly taking into account the non-holonomic constraints and the presence of obstacles. Two different classes of schemes will be studied: the open-loop schemes and feedback schemes. In the open-loop schemes, the collision avoidance has been treated as a (optimal in some sense) path planning problem. The conditions of existence of the solution will be studied as the issue of system reachability. We wish to find techniques to constructively give a solution whenever one exists. We will also try to explore algorithms for path planning in some optimal senses (such as minimum energy, or shortest path length). This approach assumes a priori knowledge of the environment.

The feedback schemes are more applicable in partially unknown environments where the information about the obstacles is acquired by available sensors on-line, and consequently, integrated with the lower level control. In the case of non-holonomic mobile robot, the integration of the sensory information, especially the visual sensor, within the control loop has been studied only in very simplified scenarios.

We will explore the use of "artificial potential field" based schemes in design of the feedback control laws for navigation of non-holonomic mobile robots in the presence of obstacles.

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4. Specification and Verification of Multi-Agent Hybrid Systems

Investigators: Z. Manna and T. Henzinger

Groups at Berkeley and Stanford worked on various issues dealing with modeling and verifying multi-agent hybrid systems. The pertinent topics appearing in individual contributions include notions of robustness, reliability and performance as well as issues dealing with expressiveness of individual specification languages. In addition to the theoretical contributions the verification tools had been advanced substantially. Current specification languages based on temporal logic have been extended by introducing operators to specify quantities related to system performance, such as the average delay between events. The appropriate efficient algorithms for the automatic verification of reliability and performance properties written in the above temporal languages have been developed. Diagram based methodology has been extended for class of hybrid systems and constitutes the first methodology that is complete for proving general temporal-logic properties of hybrid systems making an important theoretical advance.

The formalism of timed automata has become a standard model for real-time systems, and its extension to hybrid automata has become a standard model for mixed discrete-continuous systems. Yet it may be argued that the precision inherent in the formalism of timed and hybrid automata gives too much expressive power to the system designer. For example, while there is a timed automaton A that issues an event a at the exact real-numbered time t, such a system cannot be realized physically. This is because for every physical realization R_A of A there is a positive real ε, however small, so that one can guarantee at most that R_A issues the event a in the time interval $(t - \varepsilon, t + \varepsilon)$. The discretization of time into units of size ε, on the other hand, may not allow a sufficiently abstract representation of A. We remove the "excessive" expressive power of timed and hybrid automata without discretization, by having automata define (i.e., generate or accept) not individual trajectories, but bundles of closely related trajectories. A bundle of very similar trajectories is called a tube. A tube is accepted by a timed or hybrid automaton if the accepted trajectories form a *dense* subset of the tube. Timed and hybrid automata with tube acceptance are called *robust*, because they are insensitive against small input perturbations (and they may produce small output perturbations). We considerably dampen the hope that robust timed automata can be complemented by proving that, like ordinary timed automata, robust timed automata cannot be determinized (which is the usual first step in complementation). Indeed, the theory of ordinary timed automata turns out to be remarkably *robust* (pun intended) against perturbations in the definition of the automata: our results show that neither the syntactic removal of equality from timing constraints (open timing constraints only)nor the semantic removal of equality (tube acceptance) alter the theory of timed automata qualitatively.

Verification of Performance and Reliability of Real-time Systems
L. de Alfaro

While some systems can be designed to always exhibit the desired behavior, in other cases this guarantee of unconditional correctness is not attainable, due either to the intrinsic unreliability of some system components, or to the randomness of the system environment. As many of these systems play an increasingly critical role in our society (for example, air and rail traffic management systems, and distributed computing systems), there has been a growing interest in methods for the formal specification of their reliability.

Our work extends current specification languages based on temporal logic by introducing operators to specify quantities related to system performance, such as the average delay between events. Moreover, the work presents efficient algorithms for the automatic verification of reliability and performance properties written in the above temporal languages. An earlier technical report also contains a proposal for a system modeling language, based on a probabilistic extension of real-time transition systems. [3]

Integration of Visual, Deductive and Algorithmic Methods for the Verification of Hybrid Systems
L. de Alfaro, A. Kapur and Z. Manna

Diagram-based methodologies for the verification of reactive systems have been successfully used in STeP for some time, and they continue to be an active topic of research (see also next topic). Their advantages include:

- visual representation of the system and its properties
- provision of proof guidance
- effective integration of deductive and algorithmic methods

We have extended the diagram-based approach to the study of hybrid systems. The methodology we propose shares all of the above benefits, and provides a practical visual framework for the verification of hybrid systems. Additionally, our proposal provides the first methodology that is complete for proving general temporal-logic properties of hybrid systems, and constitutes thus an important theoretical advance. [1]

Diagram-based Modular Verification of Systems
L. de Alfaro, Z. Manna and H. Sipma

Our experience with the STeP system is that diagram-based methods are the best available tool for the study of temporal properties of realistic systems. Nonetheless, the types of diagrams currently in use provide only a "flat" representation of a system, and do not scale up well for the study of complex composite systems. In this work, we have extended the diagram-based approach with tools to dynamically decompose a system into modules, study the modules, and compose the resulting module diagrams into a proof of the desired specification. By enabling the decomposition of complex systems into their components, this approach makes it possible for our diagram-based verification methods to scale up. Our proposal also constitutes a generalization of many earlier approaches to modular verification, including the ones based on the assumption-guarantee framework.[4]

Deductive Model Checking
H. Sipma, T. Uribe and Z. Manna

Deductive model checking allows model checking of infinite-state systems, using transformations on falsification diagrams, justified by deductive methods. Like standard model checking, our procedure does not require user provided auxiliary formulas, and allows the construction of counterexamples; the process is guided by the search for such computations. Like deductive methods, it only needs to check local conditions, and allows the verification of infinite-state systems through the use of powerful representations to describe sets of states. We also accommodate the use previously established invariants and simple temporal properties.

Even when the model checking effort is not completed (the general problem is undecidable), the resulting falsification diagram can be used to restrict the search for a counterexample in testing.

A preliminary version of this procedure was presented in CAV'96. It has now been extended with more transformations to make it complete for proving temporal properties over infinite-state systems. [5]

Using HyTech to Synthesize Control Parameters for a Steam Boiler
T.A. Henzinger and H.-Wong-Toi

We model a steam-boiler control system using hybrid automata. We provide two abstracted linear models of the nonlinear behavior of the boiler. For each model, we define and verify a controller that maintains the safe operation of the boiler. The less abstract model permits the design of a more efficient controller. We also demonstrate how the tool HyTech can be used to automatically synthesize control-parameter constraints that guarantee the safety of the boiler. [8]

From Quantity to Quality
Henzinger and O. Kupferman

In temporal-logic model checking, we verify the correctness of a program with respect to a desired behavior by checking whether a structure that models the program satisfies a temporal-logic formula that specifies the behavior. The model-checking problem for the branching-time temporal logic CTL can be solved in linear running time, and model-checking tools for CTL are used successfully in industrial applications. The development of programs that must meet rigid real-time constraints has brought with it a need for real-time temporal logics that enable quantitative reference to time. Early research on real-time temporal logics uses the discrete domain of the integers to model time. Present research on real-time temporal logics focuses on continuous time and uses the dense domain of the reals to model time. There, model checking becomes significantly more complicated. For example, the model-checking problem for TCTL, a continuous-time extension of the logic CTL, is PSPACE-complete.
In this report, we suggest a reduction from TCTL model checking to CTL model checking. The contribution of such a reduction is twofold. Theoretically, while it has long been known that model-checking methods for untimed temporal logics can be extended quite easily to handle discrete time, it was not clear whether and how untimed methods can handle the reset quantifier of TCTL, which resets a real-valued clock. Practically, our reduction enables anyone who has a tool for CTL model checking to use it for TCTL model checking. The TCTL model-checking algorithm that follows from our reduction is in PSPACE, matching the known bound for this problem. In addition, it enjoys the wide distribution of CTL model-checking tools and the extensive and fruitful research efforts and heuristics that have been put into these tools.

Robust Timed Automata
Gupta, T.A. Henzinger, and R. Jagadeesan

We define robust timed automata, which are timed automata that accept all trajectories "robustly": if a robust timed automaton accepts a trajectory, then it must accept neighboring trajectories also; and if a robust timed automaton rejects a trajectory, then it must reject neighboring trajectories also. We show that the emptiness problem for robust timed automata is still decidable, by modifying the region construction for timed automata. We then show that, like timed automata, robust timed automata cannot be determinized. This result is somewhat unexpected, given that in temporal logic, the removal of real-time equality constraints is known to lead to a decidable theory that
is closed under all boolean operations.

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5. Hybrid System Languages

Investigators: A. Nerode, W. Kohn, J. Remmel, S. Artemov and J. Davoren

Topological Semantics for Intuitionistic Logic and Hybrid Systems: A Preliminary Report
Sergei Artemov, Jennifer Davoren and Anil Nerode
(Technical Report, 13 January, 1997)

Decidable Kripke Models of Intuitionistic Theories
H. Ishihara, B. Khoussainov, and A. Nerode
(Technical Report, 4 February, 1997)

One of the recommendations of the original pre-project reviews for the MURI is that all participants get together and decide at the beginning on a common hybrid systems language and common software tools for hybrid systems. The fact is that the tools used by the cooperating groups at Stanford, Cornell, UC Berkeley, and industrial affiliates, meet limited and different objectives and have different semantics. Some are assembly language level, some are block diagram input-out languages, some are purely automata based, some are event driven temporal languages, some are Prolog based, some don't handle differential equations directly for analysis and running simulations, some are good for analysis but not synthesis, some are implementation languages for digital control systems. Working together with compatibility has to be based on common understanding of terms, which in computer science means having a common semantics.

We construct a natural common semantics which meets stability requirements not naturally guaranteed by correctness in existing languages.

We explain this in terms of the Kohn-Nerode methodology. The goal of the Kohn-Nerode hybrid distributed autonomous control architecture is to establish the mathematics and computer science of extracting and checking correctness of digital control programs which claim to enfore performance specifications for such systems. We regard as a key issue assuring that an extracted control program still meets the program specification even if the parameters of the plants controlled and the communication links are not exactly what we think they are; and that we should be able to compute how much error in parameters still keeps us within the program specification. This is a weak necessary condition form of stability. We believe that this has to be part of correctness, needed to write adequate design requirements for sensors, effectors, communication lines, and plant.

If, as many workers have, one turns the whole hybrid system into an automaton by digitizing sensor, effector, plant, and communication line states, and then extracts a digital control program by automata theory, one has no assurance that with small changes in the parameters of the system the program will still meet performance specifications. The same thing often happens if one simply writes every event driven decision in an event driven language as if every value is perfectly known. Further, when one composes get estimates in general for the tolerable error of the composition from that for the parts. If one treats this directly as a numerical analysis problem without discretizing, there is no high-level language expressing this. Many performance specifications have nested quantifier specifications. These arise with liveness and termination, and whenever one sort of firing of an event always or never causes another, etc. Stability under small changes of parameters should be proved for these nested statements as well.

How? A principal research thrust of Nerode-Artemov-Davoren under first year of the MURI is to try to answer this question. We believe we have a satisfactory answer with new semantics tuned to hybrid systems such that programs correct with respect to this semantics have the kind of stability referred to above. This is a new semantics for *all* the languages for hybrid systems. This common semantics for all hybrid languages will allow them to be "mixed and matched". Programs in each language correct in this new semantics can be readily composed , so that calling subroutines compiled in one language into another is just fine. The crudest form of the semantics keeps track of tolerance to errors. They are not named in the language itself. We confine ourselves to describing this semantics.

Warning: hybrid control programs that have been declared correct by current language semantics of current hybrid languages may not be correct in the new semantics.

With some exceptions such as some of Nancy Lynch's work, or piecewise linear plants, they usually have to be reworked using mathematical analysis and rewritten to get programs correct in the new semantics. For the new semantics declares that those programs that cease to obey the performance specification for arbitrarily small changes in some physical parameters are *incorrect*. This semantics sharpens present correctness notions for hybrid systems to give a more engineeringly meaningful notion where correctness involves the analysis of behavior of the differential or variational or other equations obeyed by the physical plants being controlled. We are preparing papers proving that appropriate Kohn-Nerode algorithms for extracting control programs are correct in the new semantics, assuring the form of stability mentioned above. All computer language semantics can be viewed as Scott semantics on an appropriate CPO, just as all mathematics can be viewed as category theory on an appropriate category. That is true here, but as an insight it does not give value; that is, there are no deep theorems to apply.

We explain briefly the new semantics, using Prolog as a control program language. We omit other languages because they take some effort to explain. In the Kohn-Nerode setup a Prolog program is the control program; the input state of the plant fires an atomic statement. The Prolog program computes and terminates. The answer substitution gives the next control law to use. The requirement that an arbitrarily close plant states fire the same input letter plus the finiteness of the input alphabet says that the topology generated by the open sets that fires the input letters is a finite distributive lattice of sets. It generates a finite Boolean algebra. The atoms are a partition of the plant sets. The control automaton cannot distinguish between plant states if they are in the same partition set.

We take it that there are two topologies involved on the plant state space: the usual plant state topology, and the finite topology just mentioned, which is a finite topology representing what the control program can distinguish about the plant states through the sensors. It is natural to say that each Prolog atomic statement *denotes* the open set of plant states that fire it. This open set is a subset of the original plant state space with its original topology and is also in the plant state space small topology. We now apply the Tarski-Rasiowa-Sikorski topological semantics for predicate logic of which Prolog is a part; negation is omitted because it is definable from implication and falsity. Every atomic statement has been assigned a denotation which is an open set in the plant topological space. Define by induction on the length of formulas the denotation of every statement: "and" goes to intersection, "or" to union, "A implies B" to largest open set containing A and disjoint from B, "T" to the whole space, "F" to the empty open set, existential quantifier to the union over instances, universal quantifier to the interior of intersection of instances. In case there are constants naming every partition set and the predicates are about these partition sets, as is the case with our Prolog programs, the universal quantifier reduces to a finite union, and we are dealing with a finite model whose domain consists of the partition sets. A correct statement is one denoting the whole space. Correctness in our sense refers to a specification being satisfied by the Prolog program in the sense of this topology. The statements valid in all such topological models, as the topological space varies, Rasiowa-Sikorski proved are those that are intuitionistically valid. This implies that the rules of inference to be used are the intuitionistic ones only, and that we are talking about intuitionistic validity in a finite model associated with a finite topology when we prove the correctness in our sense of a Prolog program. Programs with input and output letters should be composed so that if an output atomic statement is the input to another such program, the open set denoting the output atomic statement should be a subset of the open set denoting the input atomic statement.

This gives a hint as to how the same ideas will apply to all other proposed formalisms. We are suggesting that only intuitionistically correct deductions be used (as in Prolog), and that specifications are read the the same way, and can be in full intuitionistic logic. We do not have space to explain why this interpretation guarantees stability in the sense we mentioned of performance specifications with alternating quantifiers in their statement, but it does. We cannot go further here. We refer to the Artemov-Davoren-Nerode paper below for further information.

In addition to the line of research outlined above, which concerns the appropriate logic for specification, reasoning about, and extracting control programs for hybrid systems. Following research directions have been further pursued:

- The work on the mathematics of hybrid systems has continued apace. Its current state is represented by special section invited papers at the engineering conferences CDC96, CACSD96, ISAC96. A main line of research has been the application of Cartan affine connections on manifolds with metric ground form induced by a Lagrangian cost function to extract real time digital control automata. This work is joint with W. Kohn of Sagent Corporation and J. B. Remmel of UCSD and Sagent Corporation.

- Another line of research is into nonmonotonic reasoning systems as a mechanism for treating adaptation and learning, in hybrid systems and in general. An important result is the determination of the recursive complexity of abduction, presented at LICS95, which is being written up in full now.

The wider range of problems in the MURI proposal and the intended Army cooperations will begin in the spring.

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6. Intelligent Agents for Complex, Uncertain Environments

Investigator: Stuart Russell

During the past six months, Russell's group has made progress in applications of {\em probabilistic networks}. Members of the group advanced the state of the art by developing new methods for *learning* in the presence of *incomplete data* (e.g., data with missing values and hidden unobservable variables) [1]. A major computational overhead in learning. To facilitate learning in complex domains, members of the group developed inference algorithms that are especially tuned for the learning task [2]. In addition, the group has initiated research in several applications of probabilistic networks, including scientific discovery (finding genes that are responsible for cancer) and speech recognition. In another line of research, members of the group developed a novel algorithm for probabilistic matching [8] and applied it for matching cars in image sequences from traffic surveillance cameras that view different segments of the same highway. Finally, members of the group developed new *hierarchical decomposition techniques* [8] that allow to perform *decision-theoretic planning* and *reinforcement learning* in large domains that cannot be handled by standard methods.

Investigator: Daphne Koller

During the past six months, Koller's group has made progress in devising frameworks that support the hierarchical decomposition of complex stochastic systems into multiple interacting processes. These include a stochastic extension of interacting finite automata for representing stochastic processes [3] and a stochastic extension to a functional programming language for representing distributions over regular structures such as parse trees [7]. These works lay the foundations for combining methods from the probabilistic network literature to hybrid systems. In another line of research, Koller's group examined the use of higher-level representation languages in learning. In particular, they introduced methods for learning the probabilistic (noise) parameters of general rules [6].

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7. Soft Computing and Neural Networks

Investigators: Leon O. Chua, Walter J. Freeman, Shankar Sastry, and Lotfi A. Zadeh

The research carried out by the MURI investigators working on soft computing and neural networks was concerned with image processing in autonomous vehicle control by means of a cellular neural network, construction of a dynamic model of the olfactory system in vertebrate brains, development of a theory of fuzzy information granulation, design of a hybrid control system for a model helicopter and evolutionary learning methods for robotic behaviors. The group of Prof.~Chua developed the necessary algorithms for the tasks of lane marker extraction and obstacle detection from a stereoscopic by means of the cellular neural network universal machine. Prof.~Freeman and his group found a way to stabilize the attractors of their dynamical KIII model by adding biologically modeled noise to their system. In addition, they devised a novel statistical method to determine the degree of relationship between structures in the brain as well as in their model. The research of Prof. Zadeh focused on the foundations of a theory of fuzzy information granulation and computing with words. The helicopter group has finished the assembly of the model helicopter as well as the flight stand and is now developing a simulation environment on which different control schemes for the helicopter will be tested. The group working on robotic behaviours suggested a novel, flexible genetic coding scheme for the evolutionary design of fuzzy logic controllers. The perception of the robot was improved by a neural network that preprocesses the raw sensor data in order to classifies the environmental situation.

Application of the CNN Universal Machine to Autonomous Vehicle Control
L. O. Chua, and T. Kozek.

The CNN (Cellular Neural/Nonlinear Network) universal machine, a novel, very high speed computing array that utilizes both fast analog and distributed logic types of operation in a fully programmable way has been developed in our laboratory. Due to the unique capabilities of the CNN-UM architecture, low latency and very high throughput operation can be obtained while small area and low power consumption are also achieved. Measurements on the first VLSI test implementations have encouraged us to try to exploit the computing power of these chips in demanding real-time applications such as autonomous vehicle control.

We are currently considering the tasks of lane marker extraction and obstacle detection based on a stereoscopic image sequence. The CNN universal machine is placed into the control loop as an on- or close to sensor image processor to tackle the high data rate output from the sensor device, a task most amenable to CNN implementation. The massive parallelism of the architecture and the speed of dynamic computation provide for a low-latency feature detection and stereo correlation stage which improves greatly the stability of the entire control loop.

Following the structure of the existing DSP-based solution, we have developed the necessary algorithms for this new kind of hardware by transforming the algorithmic steps into a sequence of spatial-temporal dynamic transformations and local logic and arithmetic operations. The patterns of cell interaction (so called CNN templates) have been determined and analogic algorithms have been created for the above two tasks. The algorithms have been verified by software simulation.

Currently, the CNN prototyping system hosting a CNN universal test chip designed earlier at our laboratory is being set up for the in-circuit test of the developed algorithms. Measurements taken on this test bed will provide for a hardware level verification of the concept and will serve as a basis for a later, full-blown implementation of a CNN-UM chip based image processing stage which, however, will require additional resources.

A Model of Biological Construction of Perceptual Patterns to Serve as an Interface between Intelligent Systems and their Environments
Walter J. Freeman

Brains operate by acting into the environment and learning from the consequences of their own, self-paced actions. The actions are constructed within the brain in accordance with the goals that are derived from the basic needs of the body for survival and reproduction. The actions taken depend on the information that is gathered from the environment by directing the sense organs to specific targets, such as predators or prey, and priming the sensory cortices to respond selectively to desired patterns of input. The hypothesis is being tested that the novel actions appearing in trial-and-error search, and particularly the activity patterns in sensory cortices during perception, are the product of chaotic brain dynamics.

The immediate aim of work in this laboratory is to construct a dynamic KIII model with coupled ordinary differential equations to simulate the operation of one of the sensory ports of the vertebrate brain, that for olfaction. The solutions of the sets of interconnected equations must be chaotic, in order to conform to the performance of the several parts of the olfactory system that is observed by measurements of its EEG and the action potentials of its neurons. The simulated perceptual responses to simulated stimuli are calculated on a digital platform after conversion to difference equations. The parameters are optimized to give aperiodic attractors that simulate the observed brain activity.

One of the problems that has been encountered is that the numerical solutions are unstable, owing to attractor crowding and to truncation errors that manifest the sensitivity to initial conditions of chaotic systems. This has been solved. The attractors are stabilized with biologically modeled additive noise. This KIII model is tested with pattern classification of machine parts, constituting data compression to "accept" or "reject" [1]. Another of the problems is to determine the time-varying level of interdependence between components in the brain, as well as components in the KIII model that is used to simulate brain function. The time series that are measured from EEGs of brains, and from digitized time series during operation of the KIII model, have broad spectra (approaching ``1/f"), aperiodic wave forms, and low to insignificant correlations between them. Linear methods such as cross-spectra, coherence, PCA, and time-lagged correlation have proved to be of little value. Other methods such as estimation of the correlation dimension, Lyapunov exponents, and mutual information have been found to fail over the short time segments in which strong interdependencies are known to occur from biological evidence. A novel statistical method has been devised to determine the degree of relationship between structures as a time function that can be related to the behavior of animals and of the KIII model [2].

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Toward a Theory of Fuzzy Information Granulation and its Application to the Conception, Design and Deployment of Intelligent Systems

Lotfi A. Zadeh

The concepts of granulation and organization play fundamental roles in human cognition. In a general setting, granulation involves a decomposition of whole into parts. Conversely, organization involves an integration of parts into whole. In more specific terms, information granulation (IG) relates to partitioning a class of points (objects) into granules, with a granule being a clump of points drawn together by indistinguishability, similarity or functionality.

Modes of information granulation in which granules are crisp play important roles in a wide variety of methods, approaches and techniques. Among them are: interval analysis, quantization, rough set theory, diakoptics, divide and conquer, Dempster-Shafer theory, machine learning from examples, chunking, qualitative process theory, decision trees, semantic networks, analog-to-digital conversion, constraint programming, Prolog, cluster analysis and many others.

Important though it is, crisp information granulation (crisp IG) has a major blind spot. More specifically, it fails to reflect the fact that in much -perhaps most- of human reasoning and concept formation the granules are fuzzy rather than crisp. For example, fuzzy granules of a human head are nose, forehead, hair, cheeks, etc. Each of the fuzzy granules is associated with a set of fuzzy attributes, e. g, in the case of the fuzzy granule hair, the fuzzy attributes are color, length, texture, etc. In turn, each of the fuzzy attributes is associated with a set of fuzzy values. Specifically, in the case of the fuzzy attribute length(hair), the fuzzy values are long, short, not very long, etc. The fuzziness of granules, granule attributes and attribute values is characteristic of the ways in which human concepts are formed, organized and manipulated.

In human cognition, fuzziness of granules is a direct consequence of fuzziness of the concepts of indistinguishability, similarity and functionality. Furthermore, it is entailed by the finite capacity of the human mind to resolve detail and store information. In this perspective, fuzzy information granulation (fuzzy IG) may be viewed as a form of lossy data compression.

Fuzzy information granulation underlies the remarkable human ability to make rational decisions in an environment of imprecision, uncertainty and partial truth. And yet, despite its intrinsic importance, fuzzy information granulation has received scant attention except in the domain of fuzzy logic, in which fuzzy IG underlies the basic concepts of linguistic variable, fuzzy if-then rule and fuzzy graph. In fact, the effectiveness and successes of fuzzy logic in dealing with real-world problems rest in large measure on the use of the machinery of fuzzy information granulation. This machinery is unique to fuzzy logic.

Recently fuzzy information granulation has come to play a central role in the methodology of computing with words. More specifically, in a natural language words play the role of labels of fuzzy granules. In computing with words, a proposition is viewed as an implicit fuzzy constraint on an implicit variable. The meaning of a proposition is the constraint which it represents.

In CW, the initial data set (IDS) is assumed to consist of a collection of propositions expressed in a natural language. The result of computation -referred to as the terminal data set (TDS)- is likewise a collection of propositions expressed in a natural language. To infer TDS from IDS the rules of inference in fuzzy logic are used for constraint propagation from premises to conclusions.

There are two main rationales for computing with words. First, computing with words is a necessity when the available information is not precise enough to justify the use of numbers. And second, computing with words is advantageous when there is a tolerance for imprecision, uncertainty and partial truth that can be exploited to achieve tractability, robustness, low solution cost and better rapport with reality. In coming years, computing with words is likely to evolve into an important methodology in its own right with wide-ranging applications on both basic and applied levels.

Theory of fuzzy information granulation (TFIG) builds on the existing machinery for fuzzy information granulation in fuzzy logic but takes it to a much higher level of generality, consolidates its foundations and suggests new directions for applications, especially in the realm of intelligent systems. Among other applications are data mining, expert systems, forecasting and decision analysis under uncertainty. Our research is directed both at the development of basic theory and an exploration of its application to the solution of real-world problems which do not lend themselves to analysis by conventional methods.

Helicopter Control based on Soft Computing Techniques

Tak-Kuen John Koo, Frank Hoffmann, Shankar Sastry

The goal of this project is to develop an autonomous aerial robot as a testbed of An Integrated Approach to Intelligent Systems--MURI. The robot would be able to fly autonomous, recognize and locate target object, and perform navigation. A model helicopter is used as the airframe of the robot, which has various flight modes such as hovering, forward/backward flight, sideways flight, vertical climb/descent, etc. At this stage, we have finished the assembly of the model helicopter and the flight stand. A customized micro-controller board is made for controlling the servos of the helicopter and obtaining sensor signals from the joints of the flight stand. Through the serial communication link, the controller can communicate with the host computer in exchanging control and sensor data up to 9600bps.

To develop a suitable control scheme for autonomous flying, a simulation program of the helicopter is under development. The helicopter dynamics in trim [1] and hover mode[3] are derived and will be used for the design of different control schemes. comparison with the model developed in [3] will also be made. Three different control methodologies, including nonlinear control approach, learning approach, and fuzzy control approach, will be investigated.

We are developing a computer vision system for the aerial robot development to perform object recognition and navigation. We are also exploring the possibilities in combining control with vision directly for visual servoing and path planning. For control, in order to obtain informations about position, orientation, velocities, and accelerations in both angular and translational, directions, a Kalman filter will be employed for sensor fusion with the outputs of inertial sensors and GPS.

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Soft Computing Techniques for the Design of Mobile Robot Behaviors
Frank Hoffmann

Soft computing is concerned with the design of intelligent and robust systems, which exploit the tolerance for imprecision inherent in many real world problems. In order to achieve this objective, soft computing suggests a combination of fuzzy logic (FL), neural networks (NN), probabilistic reasoning (PR) and genetic algorithms (GA). Soft computing advocates that the integration of these complementary methodologies, each of them adequate for its specific domain of problems, results in more powerful hybrid methods than using a single method exclusively. In our approach we utilize NN, FL and GA to implement and adapt two basic behaviours of a mobile robot, avoiding collisions with obstacles and reaching an aiming point. A NN preprocesses the data perceived by the ultrasonic sensors in order to improve the detection of obstacles and to provide the robot with more reliable information on his environment.

The behavior of the mobile robot is implemented by means of a fuzzy control rules. Fuzzy logic controllers are suitable for mobile applications, because of their robustness. Their method of approximate reasoning allows them to find suitable control actions, even if the information about the environment is subject to incompleteness, imprecision and imperfection.

Designing controllers for mobile robots by hand becomes a difficult task as soon as the behaviour becomes more complex. In many applications the environment of the robot changes with time in a way that is not predictable by the designer in advance. In addition, the quality of the sensors often forms a boundary of the perception of the environment. These problems limit the utility of traditional model-based reasoning approaches for the design of intelligent robots.

Evolutionary computation provides an alternative design method that adapts the robotic behavior without requiring a precisely specified model of the world. Its adaptive power enables the robot to deal with changes in the environment and to acquire a robust behavior tolerating noisy and unreliable sensor information.

We propose a messy GA for the design of FLCs, which is distinguished by its compact and flexible genetic representation of the fuzzy rule base [1]. Because of the reduced complexity of the fuzzy rule base, the fuzzy controller remains tractable and effective, which enables the GA to solve the optimization task even for more complex control problems. An evolutionary strategy optimizes additional real valued parameters of the robot, such as the orientation of the sensors and the scaling factors for the control input and output [2].

Our experimental results show that the behaviors adapted in a simulation of the robot and its environment can be transferred successfully to the physical world.

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Taming Chaos: Stabilization of Aperiodic Attractors by Noise

Walter J. Freeman, H.-J. Chang, B. C. Burke, P. A. Rose and J. Badler

A model named 'KIII' of the olfactory system contains an array of 64 coupled oscillators simulating the olfactory bulb (OB), with negative and positive feedback through low-pass filter lines from single oscillators simulating the anterior olfactory nucleus (AON) and prepyriform cortex (PC). It is implemented in C to run on Macintosh, IBM or UNIX platforms. The output can be set by parameter optimization to point, limit cycle, quasiperiodic, or aperiodic (presumptively chaotic) attractors. The first three classes of solutions are stable under variations of parameters and perturbations by input, but they are biologically unrealistic. Chaotic solutions simulate the properties of time-dependent densities of olfactory action potentials and EEGs, but they transit into the basins of point, limit cycle, or quasiperiodic attractors after only a few seconds of simulated run time. Despite use of double precision arithmetic giving 64-bit words, the KIII model is exquisitely sensitive to changes in the terminal bit of parameters and inputs. The global stability decreases as the number of coupled oscillators in the OB is increased, indicating that attractor crowding reduces the size of basins in the model to the size of the digitizing step (~10-16). Chaotic solutions having biological verisimilitude are robustly stabilized by introducing low-level, additive noise from a random number generator at two biologically determined points: spatially incoherent noise on each receptor input line, and spatially coherent noise to the AON, a global control point receiving centrifugal inputs from various parts of the forebrain. Methods are presented for evaluating global stability in the high dimensional system from measurements of multiple chaotic outputs. Ranges of stability are shown for variations of connection weights (gains) in the KIII model.

Testing for Pairwise Association Between Two Time Series of Lattice-Valued Markov-dependent I.D. R.V.S.:A Semi-Markov Approach to Contingency Table Analysis

Larry R. Lancaster and Walter J. Freeman

We present a nonparametric test for pairwise (linear or non-linear) association between two bounded lattice-valued time series, with H(O): the sampled univariate time series constitute sample paths of independent, stationary, ergodic, bounded, first-order lattice Markov random walks. Our approach allows us to employ a marginal test on each bin's observed frequency for the purpose of extracting the pattern of bins on the bivariate table which individually fails a test of H(O) as it was stated above. Also, a conservative omnibus test is readily available through the use of an improved Bonferroni procedure. While we use first-order Markov sequences as guiding examples, our approach depends only upon a semi-Markov condition for the marginal univariate processes. As a result, generalization to tests on Markov-dependent sequences of any order may be accomplished. It should be emphasized, however, that the approach we take is computationally intensive and exact, and does not rely on asymptotics. It is thus well-suited only for small sample analysis. Also, the results for the nonparametric numerical tests are highly conservative, apparently as a combined result of our choice of estimators and our reliance on a Bonferroni procedure for the omnibus test.

Evolutionary Design of a Fuzzy Knowledge Base for a Mobile Robot

Frank Hoffmann and Gerd Pfister

This work focuses a learning method which designs automatically fuzzy logic controllers (FLCs) by means of a genetic algorithm (GA). A messy coding scheme is proposed which allows a compact and flexible representation of the fuzzy rules in the genotype. It reduces the complexity and size of the rule base, through which the GA is able to solve the design task even for FLCs with a large number of input variables. A dynamically weighted objective function is proposed for control problems with multiple conflicting goals, which prevents the GA from premature convergence on FLCs that are specialized exclusively in the easier subtasks. In order to achieve a robust control behaviour for a broad spectrum of control states a second GA co-evolves a set of training situations to evaluate the performance of the FLCs. We employed the method to train an FLC, which implements a behaviour of a mobile robot. The robot obtains the task of reaching an aiming point and to avoid collisions with obstacles on its way. It perceives its environment by means of ultrasonic sensors, which provide the measured distances to objects as input to the FLC. The knowledge base of the FLC is learned in a simulation based on a simplified model of thesensors and the environment. The adapted control behaviour is tested afterwards in real world experiments with the mobile robot.

Evolutionary Learning of Mobile Robot Behaviors
Frank Hoffmann

The topic of this work is an evolutionary design method for mobile robot behaviors implemented by means of fuzzy rules. The method is applied to adapt a wall following behavior of a mobile robot. The proposed messy genetic algorithm enables the formation of compact and thereby more efficient rule bases. At the same time, an evolutionary strategy optimizes additional real valued parameters of the sensors and the controller. The robot's perception of the environment is improved by preprocessing the raw sensor data by a neural network.

8. Other Activities

8.1 Workshop

The first major MURI activity at Cornell was the Hybrid Systems IV workshop held October 11-14, 1996 by the Mathematical Sciences Institute of Cornell University, with funding for graduate students from the National Science Foundation Intelligent systems program. This workshop will result in the volume of full papers (Hybrid Systems IV, P. Antsaklis, W. Kohn, A. Nerode, S. Sastry, eds., Springer-Verlag LNCS series, to appear in July, 1997). The previous volumes in this series, and it is hoped this one, have been the principal source of information for postgraduates and postdoctoral research fellows in electrical engineering, mathematics, and computer science, who are entering the field. The lecturers and topics were:

W. Kohn (Sagent Corp.)	*Computational Schema for Hybrid Systems: The Continualization Abstract Machine*
S. S. Sastry (University of California, Berkeley)	*Hybrid Control in Air Traffic Management Systems*
A.B. Arehart (Brown University)	*Bumpless Switching Systems*

M. Branicky (MIT)	*A Toolbox for Proving and Maintaining Hybrid Specifications.*
J. Guckenheimer (Cornell University)	*Hybrid Systems and Singularly Perturbed Vector Fields*
M. Broucke (University of California, Berkeley)	*Decidability of Hybrid Systems with Linear Differential Inclusions*
D. Cofer (Honeywell Corp.)	*Reliable Implementation of Hybrid Control Systems for Advanced Avionics*
J.G. Golden (UNDP, Beijing)	*Manufacturing Execution System Implementation (ICAPP)*
O. Strusberg (University of Dortmund)	*Towards Systematic Derivation of Timed and Hybrid Automata from Continuous Models*
T. Johnson (General Electric Corp.)	*Schedule Execution and Error Recovery in Multichannel Digital Video Distribution: A Hybrid Systems Perspective*
M.M. Kokar (Northeastern University)	*Symbolic Reasoning about Noisy Dynamic Systems*
M. Kourjanski (University of California, Berkeley)	*A Class of Rectangular Hybrid Systems with Decidable Reachability.*
C. Martinez-Mascarua, P. Caines (McGill University)	*Macro COCOLOG Control of Hybrid Systems*
P. Caines (McGill University)	*A Theory of Hybrid Hierarchical Control*
D. Godbole (University of California, Berkeley)	*Designing Controllers for Multi Agent Hybrid Systems*
J. Lygeros (University of California, Berkeley)	*Hierarchical, Hybrid Control of Large-Scale Systems*
G. J. Pappas (University of California, Berkeley)	*Abstractions of Dynamical and Control Systems*

D. Probst (Concordia University)	*Integrated Battle Management with Enhanced Modeling and Simulation*
P. Varaiya (University of California, Berkeley)	*The SHIFT Programming Language and Run-time Systems for Dynamic Networks of Hybrid Systems*
M. Broucke (University of California, Berkeley)	*Computable approximations for Hybrid Systems*
D. Seto (Carnegie Mellon University)	*Safe On-line Control Upgrades with the Simplex Architecture-Hybrid Systems*
C. J. Tomlin (University of California, Berkeley)	*Switching through Singularities*
R. Brockett (Harvard University)	*Learning Boolean Expressions via Principal Components*
T. Ushio (Osaka University)	*Control of Chaos in Switched Arrival Systems*
J. Vain (Estonian Academy of Science)	*Program Design for Hybrid Systems*
J.J.H. Fey (Eindhoven University of Technology)	*Control Synthesis for Hybrid Systems*
M. Heymann (NASA Ames Center, Wayne State University)	*Control Synthesis for Class of Hybrid Systems Subject to Configuration-Based Safety Constraint*
V. Gupta (Xerox PARC)	*Robust Timed Automata*
P. J. Mosterman (Vanderbilt University)	*A Theory of Discontinuities in Physical System Models*
S. Mitter (MIT)	*The Embedding of Logic in Mathematical Programming*
J. Hughes (Brown University)	*How Can Hybrid Systems Serve Computer Graphics? A Consumer's View*

J. Chandra (ARO)	*Intelligent Systems: A Strategic Research Objective*
Q. Xu (United Nations University, Macao)	*Derivation of Control Programs: A Heating System*
J. Raisch (University of Stuttgart)	*Timed DES Supervisory Control of Hybrid Systems*
A. Savkin (University of Melbourne)	*Absolute Stabilization of Uncertain Continuous time Systems via Discrete Event Control*
U. Ozguner (Ohio State University)	*Hybrid control Design for an Automated Three-Vehicle Scenario Demonstration*
J. B. Remmel (Sagent Corp.)	*Hybrid Dynamic Programming: Optimization in Hybrid Systems*
A. J. van der Schaft (University of Twente, Holland)	*The Complementarity Formalism for Hybrid Systems*
M. Lemmon (University of Notre Dame)	*Verification of Safe Inter-Event Behavior in Supervisory Hybrid Dynamical Systems*
R. Grossman (University of Illinois at Chicago)	*A Hilbert Space approach to Hybrid Systems Using Formal Dynamical Systems.*

8.2 Berkeley Seminar Series

A weekly seminar is held at Berkeley on Tuesday afternoons. It has thus far featured the following speakers and topics in 1996.

December 5, 1996
Yoav Shoham
Department of Computer Science, Stanford University

November 5, 1996
Luca de Alfaro,
Department of Computer Science, Stanford University
Model-Checking Reliability and Performance Properties of Untimed and Timed Systems

November 12, 1996
Ed Large,
Grasp Laboratory, University of Pennsylvania,
Scaling the Dynamical Systems Approach to Path Planning: Competition among Behavioral Constraints

November 19, 1996
Craig Nevill-Manning,
Biochemistry Department, Stanford University,
Inferring Sequential Structure

November 26, 1996
Matt Ginsberg,
CIRL, University of Oregon
Carbon vs. Silicon: Will machines Ever Think Like We Do?

October 1, 1996
Jean Ponce,
University of Illinois Urbana Champaign / U.C. Berkeley,
On Planning Fixtures, Grasps, and In-hand Manipulation Sequences for Three-Dimensional Objects

October 8, 1996
Nir Friedman,
Department of Computer Science, University of California, Berkeley.
Context-Specific Independence in Bayesian Networks: Representation, Reasoning and Learning

October 15, 1996
Walter J Freeman,
Department of Molecular and Cell Biology, University of California, Berkeley
A Model of Biological Construction of Meaning to Serve as an Interface between an Intelligent System and Its Environments.

October 22, 1996
Christos Papadimitriou,
Department of Computer Science, University of California, Berkeley
Shortest Paths without a Map

October 29, 1996
Stefano Soatto,
Caltech
On Vision Based Control

September 17, 1996
Ruzena Bajcsy,
Grasp Laboratory, University of Pennsylvania.
Dynamic Approach to Robot Path Planning and Control: Competition and Cooperation among Behavioral Constraints

September 24, 1996
Michael Lindenbaum,
Technion, Haifa, Israel.
A Generic Grouping Algorithm and Its Quantitative Analysis