PROPOSAL WHITE PAPER

BAA Number 07-036

Title: A Formal Model of Cognitive Computation

Technical Point of Contact: Prof. D. Paul Benjamin
phone: (212) 346-1012
fax: (212) 346-1863
benjamin@pace.edu

Topic 7: Harnessing Complexity in Human-Machine Systems

Overview

We have developed an integrated formal model of computation for cognitive systems, tested it successfully in human-robot interaction, and developed methods of mathematically analyzing its performance. We propose to extend the theoretical basis of this model, to complete its implementation, and to demonstrate its effectiveness in a wide variety of environments and tasks.

Identification of the research and issues

Current military systems are composed of a large number of agents, both human and machine, that act and interact in complex ways. The difficulty of understanding such systems has created a need for new mathematical tools that encompass both computing agents and cognitive agents within one formalism and can analyze the system's performance, dynamics and vulnerabilities.

Encompassing computing agents and cognitive agents within one formalism requires developing a formalism that has cognitive validity yet provides a computational semantics. Such a formalism must be able to model:

Agents that can be either human or machine,
Ensembles of agents,
The use of natural language by agents,
Perceptual processes and action,
Asynchronous operation of agents,
Distributed operation of agents.

We must model perception and natural language if we are to analyze and comprehend properly the actions of the human and machine agents. For example, we must be able to model what is visible to a human or a camera, and we must be able to model the interactions between people, most of which involve natural language. Developing tools to create such a comprehensive model of large systems poses great conceptual and computational challenges.

Proposed Technical Approach

Over the past three years, we have built a cognitive architecture for robotics. This architecture is based on an extension to the RS language, which is a mature programming language for real-time, distributed computation [8]. RS has a formal semantics based on the algebra of port automata [10]. This permits us to analyze and prove properties of our systems [4].

Our architecture, called ADAPT [1,2], uses this formalism to represent itself and everything in its environment as one large dynamical system. This approach lends itself perfectly to the topic of this research program, which is to specify complex systems in a way that is computable and that lends itself to mathematical analysis.

First, we will briefly describe the port automata model and how we are extending it, and how this provides the semantics for modeling a system as a distributed computation. Then we will sketch our implementation of this model within a general cognitive architecture. Finally, we will show how we use this model to analyze the properties of systems containing cognitive agents.

RS is a well-developed formal model of distributed concurrent computation that was originally developed in the mid-1980s and has been used successfully in factory automation [6,7,8]. RS is based on the semantics of networks of port automata. A port automaton (PA) is a finite-state automaton equipped with a set of synchronous communication ports []. Formally we can write a port automaton P as:

$P = (Q, L, X\ \delta, \beta, \tau)$ where

Q is the set of states

L is the set of ports

$X = (X_i \mid i \in L)$ is the event alphabet for each port

Let $XL = \{ (i, X_i) \mid i \in L \}$ i.e., a disjoint union of L and X

$\delta : Q \times XL \rightarrow 2^Q$ is the transition function

$\beta = (\beta_i \mid i \in L)\ \beta_i : Q \rightarrow X_i$ is the output map for port i

$\tau \in 2^Q$ is the set of start states

This formalism is general enough to encompass both legacy computer code and real-time operation of physical devices. For example, a program written in an imperative language such as C or Fortran corresponds in a straightforward way to a finite-state automaton whose states are the value assignments to the variables in the symbol table and whose transition function is given by the program itself.

RS models a physical entity by specifying a network of processes to express its behavior. Building on a set of primitive automata, RS introduces a vocabulary to specify networks of port automata. A network of processes is typically built to capture a specific behavior consisting of perceptual processes linked to motor processes by data communication channels and sequenced using process composition operations.

RS process composition operations are similar to the well-known CSP algebraic process model of [11]. However, unlike CSP, in RS the notation can be seen as simply a shortcut for specifying automata; a process is a port automaton, and a process composition operation is two automata connected in a specific way. Composition operations include sequential, conditional and disabling compositions [8].

Each state in such a process specification can itself be composed of a network of processes. This creates a hierarchy of processes at different spatial and temporal scales. Examples of such hierarchies are provided in [6,7,8].

One of the salient advantages of RS is the mathematical framework that it provides for analyzing system properties. To analyze the properties of a network of processes, it is necessary to calculate how that network changes as time progresses and processes terminate and/or are created. This is the process-level equivalent of the port automaton transition function, combined with the axioms that define port-to-port communication. This Process Transition function can be used to analyze the behavior of RS networks. [4] shows how to build a modeling framework for analyzing the safety and effectiveness of port automata networks. By looking at the internal transitions between port communications, an analysis approach is developed that *removes the combinatoric issues* of looking at an asynchronous combination of system and environment.

This approach has been successfully used in factory automation and mobile robotics. That earlier work used standard planning algorithms for the construction of RS hierarchies to adapt to changing situations. Our current work [1,2] has extended this approach to handling cognitive processes, so that we can model autonomous cognitive agents, both human and machine.

Our approach to producing a formal integrated model of computation and cognition is to implement the RS model within the Soar cognitive architecture [9].

Soar is a cognitive architecture originally developed at CMU and undergoing continuing development at a number of locations, including the University of Michigan and the Information Sciences Institute. Knowledge in Soar is represented as *operators*, which are organized into *problem spaces*. Each problem space contains the operators relevant to some aspect of the system's environment. Newell [9] presents a full presentation of the body of theory and experiment underlying the Soar architecture.

The basic problem-solving mechanism in Soar is *universal subgoaling*: every time there is choice of two or more operators, Soar creates a subgoal of deciding which to select, and brings the entire knowledge of the system to bear on solving this subgoal by selecting a problem space and beginning to search. This search can encounter situations in which two or more operators can fire, which in turn causes subgoals to be created, etc. When an operator is successfully chosen, the corresponding subgoal has been solved and the entire solution process is summarized in a single rule, called a chunk, which contains the general conditions necessary for that operator to be chosen. This rule is added to the system's rule set, so that in similar future situations the search can be avoided. In this way, Soar learns.

Soar provides a comprehensive cognitive model with a full range of cognitive abilities, including perception, deliberative planning, reaction, natural language, learning, and emotion. The cognitive plausibility of this model has been demonstrated on a variety of applications over the past two decades.

Soar’s theory is based on searching and learning in a hierarchy of problem spaces, and the formal semantics of RS consists of a hierarchy of port automata. We have merged these two formalisms in a straightforward way by implementing each port automaton as a Soar problem space. This is done by specifying the state transitions of each port automaton as Soar operators.

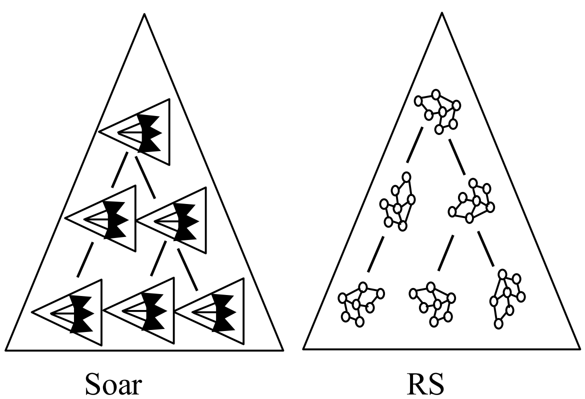

Figure 1. Soar problem spaces implement RS port automata.

Merging RS and Soar in this way combines their strengths. The strengths of RS include its formal mechanism for combining sensing and motion, its ability to reason about temporal behavior, and the ability to reason about processes’ behavior. Its weaknesses are the lack of a synthesis mechanism, and the lack of a model for implementation of cognitive abilities such as learning and language, both of which Soar provides. Also, Soar’s chunking provides a means of collecting parallelisms into groups with a common control need, and of combining the sensory and motor aspects of a computation.

The ADAPT system uses this new approach to represent itself and its environment, including humans. It constructs a network of automata to represent the dynamics, permitting analysis of the properties and possible behaviors of the system. We believe this approach is perfectly suited to the requirements of this research topic. We propose to continue to extend this formalism and its implementation, and to demonstrate its usefulness in a wide variety of contexts.

Potential Impact on Department of Defense Capabilities

This formalism can specify virtually any kind of system environment. Its ability to represent in a compact and tractable manner a complex arrangment of asynchronous activities is very general, and amenable to large military systems composed of interacting human and machine agents.

The ability of this formalism to represent complex systems at differing levels of description would be very useful to military planners, and the fact that this formalism is computable permits the construction of system simulators for evaluation and prediction.

Potential Team and Management Plan

The team to carry out this work will consist of Prof. Benjamin at Pace University, Prof. Lonsdale of the linguistics department of Brigham Young University, and Prof. Lyons of the computer science department of Fordham University, together with their graduate students. This team already exists and has been working for three years on the robotics application.

Prof. Benjamin and Prof. Lyons will focus on the continued development and extension of the port automata formalism and its implementation in Soar. Prof. Lonsdale will continue to design the design and coding of natural language semantics within the formalism.

The process of managing this interaction is already in place and has been successfully functioning for three years. There is a trac/wiki system at robotlab.csis.pace.edu that includes a code repository. Weekly teleconference meetings are held. We meet in person annually, either at a conference or in a mutual lab visit.

Summary of Estimated Costs

We estimate a total project cost of $900,000 over three years. This breaks down approximately into: $220K for principal investigator support, $245K for graduate student support, $40K for supplies, software and equipment, $30K for travel to conferences, and the rest for benefits and indirect costs.

References

[1] Benjamin, D. Paul, Deryle Lonsdale and Damian Lyons, "A Cognitive Robotics Approach to Comprehending Human Language and Behaviors", Proceedings of the Human-Robot Interaction Conference 2007 (HRI2007), Washington, D.C., March, 2007.

[2] Benjamin, D. Paul, Deryle Lonsdale and Damian Lyons, "Embodying a Cognitive Model in a Mobile Robot", Proceedings of the SPIE Conference on Intelligent Robots and Computer Vision, Boston, October, 2006.

[3] Lonsdale, Deryle, "Modeling Cognition in SI: Methodological Issues," *International journal of research and practice in interpreting*, Vol. 2, no. 1/2, pages 91-117; John Benjamins Publishing Company, Amsterdam, Netherlands, 1997.

[4] Lyons, D., and Arkin, R.C., "Towards Performance Guarantees for Emergent Behavior", (Submitted) IEEE Int. Conf. on Robotics and Automation, New Orleans LA, April 2004.

[5] Lyons, Damian M. and Ronald C. Arkin, "Towards Performance Guarantees For Emergent Behavior", Proceedings ICRA2004.

[6] Lyons, Damian, "Representing and Analyzing Plans as Networks of Concurrent Processes", IEEE Transactions on Robotics and Automation, June, 1993.

[7] Lyons, D.M., "Representing and Analysing Action Plans as Networks of Concurrent Processes", IEEE Transactions on Robotics and Automation, June 1993.

[8] Lyons, D.M. and Arbib, M.A., "A Formal Model of Computation for Sensory-based Robotics", IEEE Transactions on Robotics and Automation **5**(3), Jun. 1989.

[9] Newell, Allen, *Unified Theories of Cognition*, Harvard University Press, Cambridge, Massachusetts, 1990.

[10] Steenstrup, Martha, Michael A. Arbib, Ernest G. Manes, *Port Automata and the Algebra of Concurrent Processes*. JCSS 27(1): 29-50, 1983.

[11] S. Schneider, *Concurrent and Real-time Systems: The CSP Approach*, Wiley, 1999.

Resume of D. Paul Benjamin

School of Computer Science and Information Systems
Pace University
1 Pace Plaza
New York, NY 10038

benjamin@pace.edu
http://csis.pace.edu/~benjamin
http://csis.pace.edu/robotlab

Education:

Ph.D.	Computer Science - Courant Institute, New York University, 1985
M.S.	Computer Science - Courant Institute, New York University
B.F.A.	Music - Carnegie-Mellon University
M.S.	Mathematics - Carnegie-Mellon University
B.S.	Mathematics - Carnegie-Mellon University

Research Interests:

· Design of cognitive architectures in robotics, focusing on the relationship between perception, problem solving and language
· Application of semigroup and dynamical systems theory to knowledge representation and reformulation, problem solving and learning
· Reformulation and solution of distributed constraint satisfaction problems

Professional Experience:

Pace University, School of Computer Science and Information Systems, 1997 – Present
Professor of Computer Science
Department Chair, 2000 - 2003

Rome Laboratory, Air Force Office of Scientific Research
Visiting Research Professor, 1996 - 1998

Syracuse University, Dept. of Electrical Engineering and Computer Science
Visiting Assistant Professor, 1995 - 1997

Rome Laboratory, Griffiss Air Force Base, Rome, NY
Air Force Office of Scientific Research Summer Research Fellow, 1995

Rome Laboratory, Griffiss Air Force Base, R\ome, NY
Air Force Office of Scientific Research Summer Research Fellow, 1994

Oklahoma State University, Department of Computer Science
Assistant Professor, 1992 - 1995

St. Joseph's University (Philadelphia, Pa.),
Department of Mathematics and Computer Science
Visiting Assistant Professor, 1991 - 1992

Philips Research Laboratory, Briarcliff Manor, NY
Senior Member of Research Staff, 1984 - 1990
Project Leader in Machine Learning, 1985 - 1987

Sponsored Research:

Sponsor: DARPA, “Cognitive Support for Survivability Against Sophisticated Attacks”, contract N00178-07-C-2003, $1.5 million with BBN Technologies, Inc., December, 2006 - June, 2008.

Sponsor: Department of Energy, “Integrating Perception and Action Through Local Symmetries and Invariants”, award number ER 45903, $296,079, September 2001 - August, 2005.

Sponsor: National Science Foundation, “Integrating Formal Methods Tools into the Undergraduate Curriculum”, PI: Prof. Sotorios Skevoulis, Co-PIs: Prof. P. Benjamin and Prof. D. Anderson, Award No. DUE-0126991, $73,423, September, 2002 - August, 2005.

Sponsor: Hudson Valley Center for Emerging Technologies, “Hudson Valley Intelligent Agents Laboratory”, $10,000, 2001.

Sponsor: Air Force Office of Scientific Research / Rome Laboratory, “Pragmatic Approaches to Composition and Verification of Assured Software”, $80,500, with Dr. Shiu-Kai Chin of Syracuse University and Dr. Susan Older of Syracuse University, January, 1998 - December, 1998.

Sponsor: Air Force Office of Scientific Research, “Formal Approaches to Software Design, Planning, and the Design of Secure Systems”, $105,915, Grant No. F49620-93-C-0063, October 1, 1997 - September 30, 1998.

Sponsor: National Science Foundation, “Reformulation of System Theories in Robotics”, $49,678, SGER grant 9696060, August 1, 1995 - March 31, 1998.

Sponsor: Air Force Office of Scientific Research / Rome Laboratory, “Embedding Process and Specification Descriptions within a Categorical Framework for Refinement and Composition”, $76,000, with Dr. Shiu-Kai Chin of Syracuse University, January, 1997 - September, 1997.

Sponsor: Air Force Office of Scientific Research, “Application of Decomposition and Reformulation to Transportation Scheduling”, $103,831, Grant No. F49620-93-C-0063, October 1, 1996 - September 30, 1997.

Sponsor: Air Force Office of Scientific Research / Rome Laboratory, “Application of Process Algebra and Logic'”, $82,613, with Dr. Shiu-Kai Chin of Syracuse University, May, 1996 - December, 1996.

Sponsor: Air Force Office of Scientific Research, “Reformulating Domain Theories to Improve Their Computational Usefulness”, $24,807, SREP grant, January, 1996 - December, 1996.

Sponsor: Air Force Office of Scientific Research, “Transformational Software Design by Decomposition using the Kestrel Interactive Development System”, $24,970, SREP grant, January, 1995 - December, 1995.

Patents Held:

"System for Intrusion Detection and Vulnerability Assessment in a Computer Network using Simulation and Machine Learning", (pending) U.S. provisional patent application Serial No. 60/654,415, 2005, with Pace University.

"Semantic Encoding and Compression of Database Tables", U.S. Patent 6,691,132, February, 2004, in partnership with Adrian Walker of Reengineering, LLC.

Relevant Publications:

“A Cognitive Robotics Approach to Comprehending Human Language and Behaviors”, with Deryle Lonsdale and Damian Lyons, Proceedings of the Human-Robot Interaction Conference 2007 (HRI2007), Washington, D.C., March, 2007.

“ADAPT: A Cognitive Architecture for Robotics”, with Damian Lyons and Deryle Lonsdale, Proceedings of the International Conference on Cognitive Modeling, (ICCM-2004), Pittsburgh, Pa., July, 2004.

“On the Emergence of Intelligent Global Behaviors from Simple Local Actions, International Journal of Systems Science, special issue: Emergent Properties of Complex Systems, Vol. 31, No. 7, pp. 861-872, 2000.

“Connecting Perception and Action by Associating Symmetries in Vision and Language”, International Journal of Artificial Intelligence Tools, Vol. 8, No. 3, 1999.

“Decomposing Robotic Representations by Identifying Local Symmetries and Invariants”, Proceedings of the NSF Design and Manufacturing Grantees Conference, Mexico, 1998.

“A Decomposition Approach to Solving Distributed Constraint Satisfaction Problems”, Proceedings of the IEEE Seventh Annual Dual-use Technologies & Applications Conference, IEEE Computer Society Press, 1997.

“Transforming System Formulations in Robotics for Efficient Perception and Planning”, Proceedings of the IEEE International Symposia on Intelligence and Systems, Washington, D.C., IEEE Computer Society Press, 1996.

“Behavior-preserving Transformations of System Formulations”, Proceedings of the AAAI Spring Symposium on Learning Dynamical Systems, Stanford University, March, 1996.

“Formulating Patterns in Problem Solving”, Annals of Mathematics and AI, Vol. 10, pp.1-23, 1994.

“Reformulating Path Planning Problems by Task-preserving Abstraction”, Journal of Robotics and Autonomous Systems, 9, pp. 1-9, 1992.

“An Algebraic Approach to Abstraction and Representation Change”, by D. Paul Benjamin, Leo Dorst, Indur Mandhyan, and Madeleine Rosar, in Proceedings of the AAAI-90 Workshop on Automatic Generation of Approximations and Abstractions, Boston, July, 1990.

Curriculum Vitae of Deryle Lonsdale

Deryle Lonsdale, PhD	3186 JKHB
Assistant Professor	Provo, UT, USA 84602
BYU Department of Linguistics & English Language	(801) 422-4067 lonz@byu.edu

1) Professional Preparation:

Undergrad	Faculté Saint-Jean, University of Alberta	BSc 1981	(bilingual)
Grad	Carnegie Mellon	MS (1992), PhD (1997)	Computational Linguistics

2) Appointments: (1998-present) assistant professor, BYU Linguistics; (1990-1997) research/teaching assistant, Carnegie Mellon; (1981-1990) senior computational linguist, project leader and project manager, ALPNET, Inc.

3a) Principal Publications: (ACL = Association for Computational Linguistics)

Benjamin, D. Paul, Deryle Lonsdale, Damian Lyons, “A Cognitive Robotics Approach to Comprehending Human Language and Behaviors”, Proceedings of the Human-Robot Interaction Conference 2007 (HRI2007), Washington, D.C., March, 2007.

Benjamin, D. Paul, Deryle Lonsdale, Damian Lyons, “ADAPT: A Cognitive Architecture for Robotics”, Proceedings of the International Conference on Cognitive Modeling, (ICCM-2004), Pittsburgh, Pa., July, 2004.

Lonsdale, Deryle (2001) An Operator-based Integration of Comprehension and Production; *LACUS Forum XXVII*; pp. 123–132; Linguistic Association of Canada and the United States.

Rytting, C.A. & D. Lonsdale (2001a) An Operator-based Account of Semantic Processing; *The Acquisition and Representation of Word Meaning*; pp. 84-92; European Summer School for Logic, Language and Information, Helsinki.

Lonsdale, D. & C. A. Rytting (2001b) Integrating WordNet with NL-Soar; *WordNet and other lexical resources: Applications, extensions, and customizations*; Proceedings of NAACL-2001; pp. 162-164; ACL.

Lonsdale, Deryle (2000) Leveraging Analysis Operators in Incremental Generation; *Analysis for Generation: Proceedings of a Workshop at the 1st International Natural Language Generation Conference*; pp. 9-13; ACL.

Lonsdale, Deryle (1997) Modeling Cognition in SI: Methodological Issues; *International journal of research and practice in interpreting*; Vol. 2, no. 1/2; pp. 91-117; John Benjamins Publishing Company, Amsterdam.

b) Selected Other Publications: (ACL = Association for Computational Linguistics)

i. Skousen. R., D. Lonsdale & D. Parkinson (Eds). (2002) Analogical Modeling: An exemplar-based approach to language; Vol. 10 of *Human Cognitive Processing Series;* 416 pp.; John Benjamins, Amsterdam.

ii. Embley, D.W., D.M. Campbell, Y.S. Jiang, S.W. Liddle, D.W. Lonsdale, Y.-K. Ng, R.D. Smith. (1999) Conceptual-Model-Based Data Extraction from Multiple-Record Web Pages; Data and Knowledge Engineering; Vol. 31; pp. 227-251; Elsevier Science, Netherlands.
iii. Lonsdale, Deryle (2003) Two-level Engines for Salish Morphology; *Proceedings of the Workshop on Finite-State Methods in Natural Language Processing*; pp. 35-42l; European ACL.
iv. (1997) U.S. Patent # 5,677,835: Integrated authoring and translation system.
v. Lonsdale, Deryle (2002) A niche at the nexus: Situating an NLP curriculum interdisciplinarily; *Effective Tools and Methodologies for teaching NLP and CL: Proceedings of the Workshop*; pp. 45-52; ACL.

4) Synergistic activities:

a) I am actively involved in linguistic research in the Native American Salishan language family, particularly Lushootseed (my ancestry includes the Upper Skagit tribe who spoke this language). My publications describe computational linguistic approaches, the first ever undertaken, for these languages: two-level, finite-state morphological engines and categorial grammar/type-logical syntax/semantics parser/generators. (See 3biii above.)

b) I have been active in the development of pedagogy for computational linguistics and natural language processing and have a peer-reviewed article in this area. (See 3bv above.)

Curriculum Vitae of Damian Lyons

DAMIAN MARTIN LYONS

Associate Professor
Department of Computer & Information Science
Fordham University

Professional Preparation:

Ph.D.	9/86	**Computer Science.** University of Massachusetts, Amherst MA.
M.S.	8/81	**Computer Science.** Trinity College, University of Dublin, Ireland.
B.A.I.	6/80	**Electrical Engineering**. Trinity College, University of Dublin, Ireland.
B.A.	6/79	**Mathematics**. Trinity College, University of Dublin, Ireland.

Appointments:

07/02 Present Associate Professor of Computer Science
Director, Robotics & Computer Vision Lab
Dept. of Computer & Information Science, Fordham University
06/01 06/02 Research Department Head, Video & Display Processing Department
Philips Research, Briarcliff Manor NY 10510
10/96 06/01 Principal Member Research Staff
Philips Research, Briarcliff Manor NY 10510
10/86 10/96 Senior Member Research Staff

Philips Research, Briarcliff Manor NY 10510

09/82 09/86 Research Assistant (and Ph.D. candidate)
Laboratory for Perceptual Robotics, University of Massachusetts at Amherst.

06/84 08/85 Instructor, COINS-121 Course
University of Massachusetts, Amherst MA.

1981 1982 Lecturer in Computer Science.
Waterford Regional College of Technology, Ireland

Relevant Publications:

Benjamin, D. Paul, Deryle Lonsdale, Damian Lyons, "A Cognitive Robotics Approach to Comprehending Human Language and Behaviors", Proceedings of the Human-Robot Interaction Conference 2007 (HRI2007), Washington, D.C., March, 2007.

Benjamin, D. Paul, Deryle Lonsdale, Damian Lyons, "ADAPT: A Cognitive Architecture for Robotics", Proceedings of the International Conference on Cognitive Modeling, (ICCM-2004), Pittsburgh, Pa., July, 2004.

D.M. Lyons and D. Pelletier, *A Line-Scan Computer Vision Algorithm for Identifying Human Body Features* in *Lecture Notes in AI #1739* (Eds. A. Braffart et al.)*, Springer Verlag* 2000.

D.M. Lyons, *A Schema-Theory Approach to Specifying and Analyzing the Behavior of Robotic Systems* in: Prerational Intelligence, (Eds. Ritter, Cruse & Dean) Kluwer Academic, Dordrecht/ Boston/ London 2000.

D. M. Lyons and A. J. Hendriks,*Exploiting patterns of interaction to achieve reactive behavior*, Artificial Intelligence February 1995 Volume 73 Issue 1-2.

D. M. Lyons. *Representing and analysing action plans as networks of concurrent processes.* IEEE Trans. Robotics and Automation, 9(3):241-256, June 1993.

D.M. Lyons, and A.J. Hendriks, *Reactive Planning*. Encyclopedia of Artificial Intelligence, 2nd Edition, Wiley & Sons, December, 1991.

Other Significant Publications:

D. M. Lyons. *Discrete-Event Modeling of Misrecognition for PTZ Tracking* IEEE Int. Conf. on Advanced Video and Signal Based Surveillance, Miami FL July 2003.

Brodsky, T.; Cohen, R.; Cohen-Solal, E.; Gutta, S.; Lyons, D.; Philomin, V.; Trajkovic, M. *Visual surveillance in retail stores and in the home.* Invited paper. 2nd European Workshop on Advanced Video Based Surveillance Systems, 2001, Kingston upon Thames, London, UK

Gutchess, D., Trajkovic, Cohen-Solal, E., M., Lyons, D., Jain, A., *A Background Model Initialization Algorithm for Video Surveillance* , Int. Conf. on Comp. Vision, 2001.

Lyons, D., Murphy, T., and Hendriks, A., *Deliberation and Reaction as Decoupled, Concurrent Activities*. ICRA'96 Workshop on Robotic Planning & Execution April 1996

D. M. Lyons and M. A. Arbib, "*A Formal Model of Computation for Sensory-Based Robotics*" IEEE Trans. Rob. Aut., vol. 5, no. 3 (June 1989), 280-293

Synergistic Activities:

- **Program Co-Chair** IEEE Int. Symp. on Assembly & Task Planning, Marina del Ray 1997.
- **Guest Editor** IEEE Trans. Rob. & Aut. Special Issue on Assembly & Task Planning (Feb'96).

- **Technical Committe Chairman** IEEE Rob. & Aut. Soc., Assembly and Task Planning TC, 1992-1996.
- **Chair, Organizing committee** IEEE Int. Symp. on Assembly & Task Planning, Pittsburgh 1995.
- **Program Committees:** AVBS 2003, Multi-Sensor Fusion 2003, Steering Committee IEEE Int. Symp. on Assembly and Task Planning 1998-2000; IEEE Int. Conf. Rob. & Aut. (ICRA) 1997; Intelligent Robots and Systems (IROS) 1997; Multi-sensor Fusion 1996; ISIP'97, BASYS'96, AAAI Spring Symp. on Error Det. in Manf. Sys 1994, Workshop on Comp. Theories of Interact. & Agency 1994; Workshop on Schemas and Neural Networks 1993.

Ph.D. Students Advised:

Thomas G. Murphy, 1996 (co-advisor), Sc.D. Dissertation, University of Massachusetts Lowell, Dept. of Computer Science. Thesis title: An Investigation into the Use of Deliberative Information as a Resource for Reactive System Decision Making.

Collaborators/Co-Authors in last 48 months:

Daphna Weinshall – Hebrew University
Anil Jain – Michigan State University
Eric Cohen-Solal – Philips Research USA
Tom Brodsky – ActivEye Inc.
Paul Benjamin – PACE University

Thesis Advisor: Michael Arbib (USC)