Morteza Lahijanian

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Research Interests

Dynamics, control theory, game theory, systems, and formal methods with applications in robotics and systems biology, particularly, motion planning, finite abstraction, formal verification, formal synthesis, and hybrid systems.

My research focuses on the employment of formal methods in automatic control (motion plan) generation for dynamical systems under uncertainty to achieve high-level specifications with correctness and completeness guarantees. My Ph.D. dissertation introduces a computationally tractable formal verification and synthesis framework for stochastic systems with applications in robotics. My postdoctoral work revolves around temporal logic (TL) motion planning using sampling-based techniques for complex dynamical systems with large degrees of freedom under various types of uncertainty, resulting in the first TL manipulation planner, the first sampling-based strategy planner, TL partial satisfaction schemes, etc.

Education

09/06-07/12 **Ph.D. in Mechanical Engineering** Boston University

- Advisors: Sean B. Andersson & Calin Belta

01/01-12/04 **B.S. in Bioengineering** UC Berkeley

- Emphasis: Biorobotics & MEMS

Research Experience

12/15-Present **Dept. of Computer Science, University of Oxford** Oxford, UK

- **Research Scientist:** mobile autonomy - safety, trust, and integrity of autonomous mobile robots; enabling a pervasive technology of the future.

09/12-09/15 **Dept. of Computer Science, Rice University** Houston, TX

- **Postdoctoral Research Scholar:** motion planning and control synthesis for complex and uncertain systems from task-level specifications at Kavraki Lab and Computer-Aided Verification and Reasoning (CAVR) group. Collaborators: Lydia E. Kavraki & Moshe Y. Vardi.
  - Developed a theory for partial satisfaction of linear temporal logic specifications in the context of robotics.
  - Designed and implemented (C++) a motion planning framework with optimal satisfaction guarantees for complex dynamical systems with high-level tasks in unknown environments.
  - Developed and implemented (C++) a strategy planning algorithm for nondeterministic hybrid systems with complex dynamics by combining sampling-based techniques with game theoretic approaches.
  - Designed a fully automated framework for optimal policy planning for continuous stochastic systems with temporal goals.
  - Developed a planning algorithm for manipulators with large degrees of freedom and complex tasks

06/08-07/12 **BU Hybrid and Networked Systems Lab** Boston, MA

- **Graduate Research Fellow:** formal approaches to control of stochastic dynamical systems, analysis and control of hybrid systems, and finite abstraction of continuous systems.

- Designed and implemented (MATLAB) a formal verification and synthesis method for continuous stochastic systems.
- Developed and implemented (MATLAB) a synthesis algorithm for Markov models with Probabilistic Computation Tree Logic (PCTL) specifications.
- Developed a finite abstraction technique and a refinement algorithm for stochastic systems.
- Developed and tested a simulator (MATLAB) for an iRobot Create mobile platform equipped with a laser range finder, an RFID reader, and a netbook in an indoor environment.
- Developed a computational framework, experimental setup, and simulation tools (MATLAB) for autonomous cars in a miniature Robotic Urban-Like Environment (RULE).

09/06-07/12 **BU Andersson Lab** Boston, MA

- **Graduate Research Fellow:** symbolic control of probabilistic robots including design of feedback control primitives, finite abstraction of the motion of the robot in the environment, optimization of the probability of satisfying a task specification.
  - Constructed and implemented an observer (MATLAB) for language-driven control systems (systems with symbolic controls). The tool identifies the symbolic string driving the system through observation of its output.
  - Designed feedback control laws (control symbols) for an iRobot Create mobile platform.

01/06-06/06 **NEU Mechanical Engineering Robotics Lab** Boston, MA

- **Research Assistant:** robotic assisted rehabilitation for gait re-training of stroke or other such patients with difficulties in walking and keeping balance.
  - Assisted with the mechanical design, hardware development, and control of a rehabilitation robot.

09/05-12/05 **UCSF Surgical Skills Center: Biorobotics** San Francisco, CA

- **Research Assistant:** training novice surgeons through the use of robotic manipulators.
  - Used laparoscopes for acquisition of data and performed Markov modeling of minimally invasive surgery based on tool/tissue interaction and force/torque signatures to evaluate surgical skills.

05/05-8/05 **Centrum Robotiky: VŠB -Technical University of Ostrava** Czech Republic

- **Intern:** development of a rescue robot for fire hazards and earthquake-hit sites.
  - Assisted with the control of a mobile robot, acquisition and analysis of sensor data, image processing, and mapping by neural nets (C++ and MATLAB).

01/05-05/05 **D'Esposito Lab: UCB Cognitive Neuroscience Lab** Berkeley, CA

- **Research Assistant:** understanding age-related changes in prefrontal and parietal networks; a functional study of employing multiple strategies in arithmetic problem solving.
  - Assisted with the fMRI scanning of subjects.
  - Implemented an image processing algorithm and developed a data analysis package in MATLAB.

Teaching Experience

01/13-05/13 **Dept. of Computer Science, Rice University** Houston, TX

- **Co-Instructor:** co-instructed a graduate-level seminar course titled, "Extensive Introduction to MDPs and POMDPs."

10/12-11/12 **Dept. of Computer Science, Rice University** Houston, TX

- **Lecturer:** gave a series of 4 lectures on the topic of probabilistic robotics in a senior-level course titled, "Algorithmic Robotics."

09/09-12/09 **Mechanical Engineering, Boston University** Boston, MA

- **Graduate Teaching Fellow:** dynamics course teaching assistant – 1 semester.

06/07-06/08 **Chelsea High School** Chelsea, MA

- **NSF GK-12 Fellow:** taught 11th and 12th grade physics and enhanced the content of curriculum by developing new modules, designed activities, assisting with labs, and helping students with science fair projects; also provided demos of my research and organized robotic competitions to inspire students to pursue education and careers in STEM. Physics, Control, and Robotics Lesson Plans available at www.bu.edu/gk12/morteza/.

09/06-05/07 **Mechanical Engineering, Boston University** Boston, MA

- **Graduate Teaching Fellow:** fluid mechanics laboratory instructor and course teaching assistant – 2 semesters.

09/05-12/05 **Team-Up for Youth: Coaching Corps (Outreach Program)** Oakland, CA

- **Volunteer Coach:** serving low-income young people and utilizing the potential of children of color by teaching important life lessons like teamwork, leadership, and dedication; also strengthening youth and communities through the power of sports in after school programs.

MENTORING EXPERIENCE

Mentored two graduate students (Matthew R. Maly and Keliang He) on research projects involving motion planning for complex dynamical systems and high degrees of freedom robotic systems with high-level tasks. Both projects have resulted in publications (HSCC'13, ICRA'15).

COMPUTER SKILLS

Software development in C++, MATLAB, Simulink; Open Motion Planning Library (OMPL); Model checking tools (e.g., PRISM, SPOT).

PROJECTS

09/12-09/15 **Dept. of Computer Science, Rice University** Houston, TX

- **Manipulation Planning with Temporal Goals (05/14-present):** in collaboration with Professor Lydia Kavraki, Professor Moshe Vardi, and Keliang He, introduced the first framework that enables manipulation planning with linear temporal logic (LTL) specifications. Resolved the challenge of LTL formulation of manipulation tasks through an original definition for atomic propositions. Addressed the state-explosion problem through a novel abstraction technique and a synergistic multi-layered planning architecture. Algorithms implementation was in C++ within ROS, MoveIt, and OMPL and simulations in Rviz. The framework presented in ICRA'15.

- **Sampling-Based Strategy Planner for Nondeterministic Hybrid Systems (01/13-present):** in collaboration with Professor Lydia Kavraki and Professor Moshe Vardi, introduced the first sampling-based strategy planner for systems with disturbances modeled as nondeterministic hybrid systems with complex continuous dynamics. Combined sampling-based techniques with game-theoretic approaches to generate a series of plans and decision choices that increase the chances of success within a fixed time budget. Implemented the algorithm in C++ within OMPL. Results reported in ICRA'14.

- **Optimal and Efficient Stochastic Planning (01/13-present):** in collaboration with Professor Lydia Kavraki and Ryan Luna, developed a top-down, optimal, and fast policy planner for stochastic systems. Reduced the complexity of stochastic planning in continuous space by a novel offline discrete abstraction and online analysis and policy generator. Introduced three re-abstraction techniques to deal with environment uncertainty with varying degrees of detail. Enabled policy generation for complex tasks with maximum probability by extending the framework to accept

temporal logic formulas. Proved asymptotic optimality properties of the framework. Implementation in C++ within OMPL. The approach is detained in three publications (ICRA'14, AAAI'14, WAFR'14).

- **Iterative Temporal Motion Planning in Partially Known Environments with Partial Satisfaction Guarantees (08/12-present):** in collaboration with a team consisting of faculty members, postdocs, and students from Rice U., Cornell U., and Hebrew U., assembled a planning framework for complex dynamical and hybrid systems in partially known environments with linear temporal logic specifications. Developed the theory of partial satisfaction of linear temporal logic specifications. Introduced three quantitative and one qualitative algorithms for partial satisfaction. Designed an innovative abstraction-planning architecture to enable online planning. Algorithms implemented in C++ within OMPL. The methodology detailed in three publications (HSCC'13, AAAI'15, TRO).

09/06-07/12 **Mechanical Engineering, Boston University** Boston, MA

- **Formal Verification and Synthesis for Discrete-Time Stochastic Systems (05/11-07/12):** in collaboration with Professor Sean Andersson and Professor Calin Belta, built a computationally tractable verification and synthesis framework for discrete-time stochastic systems. Developed an abstraction procedure that maps discrete-time stochastic systems to approximate Markov models: interval Markov chains (IMC) and bounded-parameter Markov decision process (BMDP). Constructed model checking algorithms for these models against Probabilistic Computation Tree Logic (PCTL) formulas and a synthesis procedure for BMDPs. Derived an analytical expression for the growth of the abstraction error bound. Designed an efficient refinement algorithm that reduces the uncertainty in the abstraction. Implemented the algorithms in MATLAB. Framework is described in CDC'12 and ITAC'15.

- **Temporal Logic Policy Generation Using Actor-Critic Methods (05/10-09/11):** in collaboration with a team consisting of faculty members, a postdoc, and students at Boston U., successfully reduced the complexity of probabilistic computation tree logic and linear temporal logic policy synthesis for large MDPs by employing actor-critic methods. Introduced learning methods in synthesis algorithms by adapting approximate dynamic programming framework based on a least-square temporal difference of the actor-critic type. Implemented a hardware-in-the-loop simulator in MATLAB. Project reported in CDC'11 and ICRA'12.

- **Temporal Logic Motion Planning with Probabilistic Satisfaction Guarantees (05/08-05/11):** in collaboration with Professor Sean Andersson and Professor Calin Belta, developed a computational framework for automatic deployment of a robot with sensor and actuator noise from a temporal logic specification. Modeled the motion of the robot in the environment as a Markov decision process (MDP) and translated motion specifications to formulas of probabilistic computation tree logic (PCTL). Developed algorithms for the synthesis of MDP policies for different classes of PCTL formulas. Designed feedback control laws and built an experimental platform and a simulator for iRobot Create equipped with lager range finder, an RFID reader, and a notebook in an indoor environment. Implemented the synthesis algorithms and simulator in MATLAB. Results reported in four publications (CDC'09, ICRA'10, IFAC'11, ACC'11, TRO'12).

- **Observers in Language-Based Control (09/06-05/08):** in collaboration with Professor Sean Andersson, constructed an observer for language-driven control systems. Motivated by settings where language-driven systems (e.g., mobile robots) must cooperate "silently," developed an estimation and detection scheme to identify the symbolic string driving the system through observation of its output. Designed control symbols (feedback control laws) and discrete plans (collection of symbols). Employed Kalman filter in state estimation and m-ary hypothesis testing along with partially observed Markov chain for plant detection. Implemented the observer in MATLAB. Reported the technique in CIS'09.

Awards & Honors

- Best Presenter in the Session at American Control Conference (2011)
- Travel Grant to American Control Conference (2011)
- NSF GRASSROOTS Fellowship (2009)
- NSF Travel Grant to IEEE International Conference on Robotics and Automation (2009)
- NSF-GK12 Fellowship (2007-2008)
- Graduate Teaching Fellowship (2006-2007)
- Federal SEOG Grant Fall (2004)
- UC Spring Grant (2004)
- Cal Grant B (2002-2003)
- Ella Mae & Lawrence R. Quarles Physical Science Achievement Award (2001)
- Arthure E. & Glaydys P. Flum Outstanding Achievement in Physical, Health Science (2001)
- Jack White Engineering Physics Award (2001)

Professional Services

- Served as a program committee member of Combining AI Reasoning and Cognitive Science with Robotics Workshop at the Robotics: Science and Systems Conference (RSS, 2015)
- Served as a reviewer for the IFAC journal Automatica (2014-present)
- Co-organized ExCAPE Robotics Workshop at Rice University (ExCAPE, 2013)
- Served as a reviewer for IEEE Transactions on Robotics (TRO, 2013)
- Served as an external reviewer for Robotics: Science and Systems Conference (RSS, 2013)
- Served as an external reviewer for Symposium on Combinatorial Search (SoCS, 2013)
- Served as a reviewer for IEEE Transactions on Automatic Control (ITAC, 2012-present)
- Served as a reviewer for ACM Conf. on Hybrid Systems: Computation and Control (HSCC, 2011-2013)
- Served as a reviewer for American Control Conference (ACC, 2011, 2012)
- Served as a reviewer for IEEE Int. Conf. on Robotics and Automation (ICRA, 2009-present)
- Served as a reviewer for IEEE Conf. on Decision and Control (CDC, 2009-present)

Publications

Papers currently under review

[1] M. Lahijanian, M. Maly, D. Fried, L. E. Kavraki, H. Kress-Gazit, M. Y. Vardi, "Iterative Temporal Planning in Uncertain Environments with Partial Satisfaction Guarantees," *IEEE Transactions on Robotics*, Jun. 2015. (submitted)

Peer-reviewed journal publications

[1] M. Lahijanian, S. B. Andersson, and C. Belta, "Formal verification and synthesis for discrete-time stochastic systems," *IEEE Transactions on Automatic Control*, vol. 60, no. 8, pp. 2031-2045, Aug. 2015.

[2] J. Wang, X. C. Ding, M. Lahijanian, I. Ch. Paschalidis, C. Belta, "Temporal logic motion control using actor-critic methods," *Int. Journal of Robotics Research*, vol. 34, no. 10, pp. 1329-1344, Aug. 2015.

[3] M. Lahijanian, S. B. Andersson, and C. Belta, "Temporal logic motion planning and control with probabilistic satisfaction guarantees," *IEEE Transactions on Robotics*, vol. 28, no. 2, pp. 396-409, 2012.

[4] S. B. Andersson, D. Hristu-Varsakelis, and M. Lahijanian, "Observers in language-based control," *Communications in Information and Systems (Special Issue Dedicated to the 70th Birthday of Roger Brockett)*, vol. 8, no. 2, pp. 85-106, 2009.

Peer-reviewed conference publications

[1] K. He, M. Lahijanian, L. E. Kavraki, M. Y. Vardi, "Towards Manipulation Planning with Temporal Logic Specifications," *IEEE International Conference on Robotics and Automation (ICRA)*, pp. 346-352, Seattle, WA, May, 2015.

[2] M. Lahijanian, S. Almagor, D. Fried, L. E. Kavraki, M. Y. Vardi, "This Time the Robot Settles for a Cost: A Quantitative Approach to Temporal Logic Planning with Partial Satisfaction," *AAAI Conf. on Artificial Intelligence*, pp. 3664-3671, Austin, TX, Jan. 2015.

[3] R. Luna, M. Lahijanian, L. E. Kavraki, M. Moll, "Asymptotically Optimal Stochastic Motion Planning with Temporal Goals," *Workshop on the Algorithmic Foundations of Robotics (WAFR)*, pp. 335-352, Istanbul, Turkey, Aug. 2014.

[4] R. Luna, M. Lahijanian, L. E. Kavraki, M. Moll, "Optimal and Efficient Stochastic Motion Planning in Partially-Known Environments," *AAAI Conference on Artificial Intelligence*, pp. 2549-2555, Quebec City, Canada, July, 2014.

[5] M. Lahijanian, L. E. Kavraki, M. Y. Vardi, "A Sampling-Based Strategy Planner for Nondeterministic Hybrid Systems," *IEEE International Conference on Robotics and Automation (ICRA)*, pp. 3005-3012, Hong Kong, China, May, 2014.

[6] R. Luna, M. Lahijanian, L. E. Kavraki, M. Moll, "Fast Stochastic Motion Planning with Optimality Guarantees Using Local Policy Reconfiguration," *IEEE International Conference on Robotics and Automation (ICRA)*, pp. 3013-3019, Hong Kong, China, May, 2014.

[7] M. R. Maly, M. Lahijanian, L. E. Kavraki, H. Kress-Gazit, and M. Y. Vardi, "Iterative Temporal Motion Planning for Hybrid Systems in Partially Unknown Environments," *ACM International Conference on Hybrid Systems: Computational and Control (HSCC)*, pp. 353-362, Philadelphia, PA, Apr., 2013.

[8] M. Lahijanian, S. B. Andersson, and C. Belta, "Approximate Markovian Abstractions for Linear Stochastic Systems," *IEEE Conference on Decision and Control (CDC)*, pp. 5966-5971, Maui, HI, Dec., 2012.

[9] X. C. Ding, J. Wang, M. Lahijanian, I. Paschalidis, and C. Belta, "Temporal Logic Motion Control using Actor-Critic Methods," *IEEE International Conference on Robotics and Automation (ICRA)*, pp. 4687-4692, St. Paul, MN, May, 2012.

[10] R. Moazzez Estanjini, X. C. Ding, M. Lahijanian, C. Belta, I. Paschalidis, "Least Squares Temporal Difference Actor-Critic Methods with Applications to Robot Motion Control," *IEEE Conference on Decision and Control (CDC)*, pp. 704-709, Orlando, FL, Dec. 2011.

[11] Cizelj, X. C. Ding, M. Lahijanian, A. Pinto, C. Belta, "Probabilistically Safe Vehicle Control in a Hostile Environment," *Int'l Federation of Automatic Control (IFAC) 18th World Congress*, Milan, Italy, 2011.

[12] M. Lahijanian, S. B. Andersson, and C. Belta, "Controlling an MDP from a PCTL specification," *American Controls Conference (ACC)*, pp. 311-316, San Francisco, CA, Jun., 2011.

[13] M. Lahijanian, J. Wasniewski, S.B. Andersson, and C. Belta, "Motion planning and control from temporal logic specifications with probabilistic satisfaction guarantees," *IEEE International Conference on Robotics and Automation (ICRA)*, pp. 3227-3232, Anchorage, Alaska, May, 2010.

[14] M. Lahijanian, S. B. Andersson, and C. Belta, "A probabilistic approach for control of a stochastic system from LTL specifications," *IEEE Conference on Decision and Control (CDC)*, pp. 2236-2241, Shanghai, China, Dec., 2009.

[15] M. Lahijanian, M. Kloetzer, S. Itani, C. Belta, and S. B. Andersson, "Automatic deployment of autonomous cars in a robotic urban-like environment (RULE)," *IEEE International Conference on Robotics and Automation (ICRA)*, pp. 2055-2060, Kobe, Japan, May, 2009.

Talks and Presentations

[1] Poster Presentation - "Towards Manipulation Planning with Temporal Logic Specifications," *IEEE International Conference on Robotics and Automation (ICRA)*, Seattle, WA, 2015.

[2] Invited Talk - "Bestowing Intelligence upon Robots: Automatic Control Generation from Task-Level Specifications," University of Nevada, Reno, NV, 2015.

[3] Technical Talk - "This Time the Robot Settles for a Cost: A Quantitative Approach to Temporal Logic Planning with Partial Satisfaction," *AAAI Conf. on Artificial Intelligence*, Austin, TX, 2015.

[4] Poster Presentation - "Iterative LTL Planning in Partially-Known Environments with Partial Satisfaction Guarantees," *Workshop on Formal Methods for Robotics and Automation, Robotics: Science and Systems*, Berkeley, CA, 2014.

[5] Poster Presentation - "Asymptotically Optimal Planning for Stochastic Systems with Temporal Goals," *Workshop on Formal Methods for Robotics and Automation, Robotics: Science and Systems*, Berkeley, CA, 2014.

[6] Poster Presentation - "Iterative LTL Planning in Partially-Known Environments with Partial Satisfaction Guarantees," *ExCAPE review meeting*, Philadelphia, PA, 2014.

[7] Technical Talk - "A Sampling-Based Strategy Planner for Nondeterministic Hybrid Systems," *IEEE International Conference on Robotics and Automation (ICRA)*, Hong Kong, China, 2014.

[8] Technical Talk - "Temporal Logic Motion Planning for Complex Dynamical Systems in Partially-Unknown Environments," *ExCAPE Annual Meeting*, Berkeley, CA, 2013.

[9] Workshop Speaker - "Robot Motion Planning Under Uncertainty with Temporal Logic Tasks: from Nondeterministic Discrete Disturbances to Continuous Stochastic Noise," *ExCAPE Robotics Workshop*, Houston, TX, 2013.

[10] Technical Talk - "Iterative Temporal Motion Planning for Hybrid Systems in Partially Unknown Environments," *ACM International Conference on Hybrid Systems: Computational and Control (HSCC)*, Philadelphia, PA, 2013.

[11] Technical Talk - "Approximate Markovian Abstractions for Linear Stochastic Systems," *IEEE Conference on Decision and Control (CDC)*, Maui, HI, 2012.

[12] Technical Talk - "Controlling an MDP from a PCTL specification," *American Controls Conference (ACC)*, San Francisco, CA, 2011.

[13] Technical Talk - "Motion planning and control from temporal logic specifications with probabilistic satisfaction guarantees," *IEEE International Conference on Robotics and Automation (ICRA)*, Anchorage, Alaska, 2010.

[14] Technical Talk - "A probabilistic approach for control of a stochastic system from LTL specifications," *IEEE Conference on Decision and Control (CDC)*, Shanghai, China, 2009.

[15] Invited Talk - "Automatic Deployment of Autonomous Cars with Complex Tasks in an Urban-Like Environment," The University of Tokyo, Tokyo, Japan, 2009.

[16] Technical Talk - "Automatic Deployment of Autonomous Cars in a Robotic Urban-Like Environment (RULE)," *IEEE International Conference on Robotics and Automation (ICRA)*, Kobe, Japan, 2009.