CS 4649/7649
Robot Intelligence: Planning

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We discuss algorithms for robots and other complex systems that make intelligent decisions in high dimensional or continuous spaces of options. Intelligent decisions take into account both present and future constraints on the system. The course will cover methods for planning with symbolic, numerical, geometric and physical constraints. Topics will range from classical and stochastic planning to continuous robot domains and hybrid control of dynamic systems.

Learning Outcomes:

Students in the class will achieve the following learning objectives:

1) Understand the common and distinct principles used by decision making algorithms in domains with different types of constraints:
    a. Semantic
    b. Geometric
    c. Dynamic
2) Learn skills for developing new algorithms that solve decision making for each constraint type and combinations of constraints through:
    a. Understanding basic methods in each domain
    b. Learning to locate and utilize existing tools with online resources
    c. Implementing algorithms that take advantage of available tools for solving practical planning problems.
3) Learn to analyze both existing and new algorithms theoretically and empirically by evaluating tradeoffs between:
    a. Completeness
    b. Optimality
    c. Efficiency / Complexity

Requirements:

This course has undergraduate (4649) and graduate (7649) sections. Both sections will participate in three group programming projects related to the three covered aspects of planning. The projects will be graded on algorithm implementation, analysis and results for a total of 60% of the course grade.

Classical Planning	(30%)
Motion Planning	(30%)

In order to expose students to research in planning, the course will also have a final project that makes up 40% of the grade. This project involves the design, implementation and validation of a planning algorithm resulting in a conference-style paper and presentation.

- Robot arm planning and control.
- Planning with abstractions.
- Planning for a novel balancing platform.
- Grasp planning for a robot hand.
- Planning or control projects relevant to ongoing research.

7649 Graduate Projects:

Graduate students will work in groups on a project that is relevant to their research goals. The instructor will provide resources such as robot arm/hand hardware and existing algorithms to support this work. Furthermore, students are welcome to use resources or expand on active projects in their own research labs. Final decisions on topics will be made through discussion with the instructor.

4649 Undergraduate Roles:

Undergraduates will take the role of reviewers for the projects. This will expose them to both the research and peer-review. They will be required to review project proposals, final projects, suggest alternative algorithms and find references that back up their claims. They will be graded based on the thoroughness of their reviews, understanding of the project topics and relevance of located references. Undergraduates are given the option to participate in the projects directly and be graded as graduate students.

Tentative Schedule:

Week 1	Classical Planning Predicate Logic, STRIPS, Frame Problem, Causal-link planning
Week 2	Planning Methods Plan Graph Search, Planning as Satisfiability, Constraint Satisfaction
Week 3	Extensions of Classical Planning Heuristics, Hierarchical Task Networks, Resource Scheduling
Week 4	Grid Based Planning Search Tools, Dijkstra, Dynamic Environments, Plan Refinement
Week 5	Motion Planning for Navigation Cell Decompositions, Trajectory Generation, Potential Fields

Week 6	Math Tools for Motion Review of Kinematics, Collision Detection, Sampling Strategies, Hierarchical Decompositions
Week 7	Planning for Robot Arms Configuration Space, Sampling Based Methods, Probabilistic Roadmaps Random Trees, Sampling Strategies
Week 8	Kinodynamic Planning Planning with Primitives, Planning with controllers
Week 9	Planning With Uncertainty Adaptive Planning, Markov Decision Processes, HMMs
Week 10	Dynamic Domains More MDPs, Controllers, Attractors, Learning Dynamics
Week 11	Bridging Planning and Control Trajectories, Relationships between Dijkstra & LQR
Week 12	Further Topics in Planning Manipulation, Assembly, Navigation Among Movable Obstacles (TBD: based on student projects and interests)
Week 13	Final Project Presentations

Prerequisites:
The course requires CS 1332 for undergraduate CS students. We will assume some familiarity with programming, algorithm design, linear algebra, complexity and statistics. However, we will also provide the necessary references for students to gain this familiarity in limited scope as required for understanding course material.

Students who are not sure whether they have the necessary background are encouraged to contact the instructor. In some cases we will recommend some background reading – in others we will advise the student on courses that would prepare them.

Books (Recommended – Not Required):

"Artificial Intelligence: A New Synthesis," Nilsson
"Artificial Intelligence: A Modern Approach," Russel, Norvig
"Reinforcement Learning" Sutton, Barto
"Principles of Robot Motion", Howie Choset et. al
"Planning Algorithms", Steve LaValle
"Robot Motion Planning", Jean-Claude Latombe

Articles will be posted in accordance with topics (Some Examples):
H. Kautz and B. Selman. *Unifying SAT-based and Graph-based Planning*. IJCAI 1999.

A. Blum and M. Furst, "Fast Planning Through Planning Graph Analysis", *Artificial Intelligence, 90:281--300 (1997).*
H. Kautz and B. Selman. *Unifying SAT-based and Graph-based Planning*. IJCAI 1999.
F. Aurenhammer *Voronoi diagrams: A survey of a fundamental geometric data structure* ACM Computing Surveys, V.23 N.3, 1991.
S. Koenig, M. Likhachev: D*Lite. AAAI/IAAI 2002: 476-483
S. LaValle, J. Kuffner *Randomized Kinodynamic Planning* International Journal of Robotics Research, 20(5):378-400, 2001.
P. Maybeck. "Stochastic Models Estimation and Control V.1" Ch. 1: Introduction
Khatib, O. "Motion/Force Redundancy of Manipulators," Symposium on Flexible Automation

Course Websites:
"Planning and Decision Making", S. LaValle: http://msl.cs.uiuc.edu/~lavalle/cs497/
"Robot Motion Planning," S. Akella: http://www.cs.rpi.edu/~sakella/rmp01/
"Artificial Intelligence Planning" Blythe, Ambite and Gil: http://www.isi.edu/~blythe/cs541/