EECS 469 / ME 495: Machine Learning and Artificial Intelligence for Robotics

Time & Location: 11:00-12:20, TuTh, Tech L150
Office hours: 12:20-13:00, TuTh, Tech M194

Instructor: Prof. Brenna Argall
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Description: A coverage of artificial intelligence, machine learning and statistical estimation topics that are especially relevant for robot operation and robotics research.

Objectives: At the end of this course students will understand the AI and ML topics covered, reason about which is most appropriate to apply various robot problems and be able to implement the chosen technique. Students furthermore will understand the issue of uncertainty and noise in robot operation, and be able to apply tools that mitigate uncertainty.

SYLLABUS

I. Introduction: Crash course in robotics: sensors and sensing, effectors and actuators, probability basics

II. State estimation and uncertainty filters
1. Bayes filters
2. Gaussian filters : Kalman, Information...
3. Nonparametric filters: Histogram, Particle...

III. Artificial Intelligence
1. Search
   1. Uninformed
   2. Informed : Greedy, A*, D*, heuristic functions...
   3. Local/optimizing : gradient descent, hill-climbing, simulated annealing...
2. Planning
   1. Navigational
   2. Motion

IV. Machine Learning
1. Neural Nets : perceptron, multi-layered networks...
2. Genetic Algorithms
3. Instance-based Learning : nearest neighbors, regression (linear, locally-weighted, kernel-based)...
4. Reinforcement Learning : Bellman, Q-learning, T-D learning, actor-critic...
5. Demonstration-based Learning

SCHEDULE

Week 0 : [Sept. 19 - 23]

Topics: Introduction, Bayes Filter, Gaussian Filters
Reading: [Tu] Artificial Intelligence, Ch. 25.1 - 25.3
Probabilistic Robotics, Ch. 2.3 – 2.5
Reading: [Th] Probabilistic Robotics, Ch. 3.1 – 3.3
Alternate UKF description (weblink on canvas)

Additional Resources: Probabilistic Robotics, Ch. 2.2 (for a review of basic concepts in probability)

Week 1 : Filters [Sept. 26 - 30]

Topics: Non-parameteric Filters
Reading: [Tu] Probabilistic Robotics, Ch. 3.4 – 3.5
[Th] Probabilistic Robotics, Ch. 4.1 – 4.3

Additional Resources: Probabilistic Robotics, Ch. 1

Week 2 : AI [Oct. 3 - 7]
Topics: Search, Planning
Reading: [Tu] A* reading (weblink on canvas)
Artificial Intelligence, Ch. 4.1 – 4.2
Artificial Intelligence, Ch. 25.4
[Th] D. Ferguson and A. Stenz, Using Interpolation to Improve Path Planning: The Field D* Algorithm, In *Journal of Field Robotics*, 2006.

Additional Resources: Artificial Intelligence, Ch. 3.4 (for an overview of uninformed search strategies)
Artificial Intelligence, Ch. 4.3-4.4 (search with nondeterministic actions, partial observations)
Artificial Intelligence, Ch. 4.5 (interleaving planning and acting)
A. Stenz, Optimal and Efficient Path Planning for Partially-Known Environments. In *Proceedings of ICRA,* 1994.
S. Koenig & M. Likhachev, Fast Replanning for Navigation in Unknown Terrain. In *IEEE Transactions on Robotic and Automation*, 2002.

Week 3 : AI [Oct. 10 - 14]
Topics: Planning, Cost and Reward Functions
Reading: [Tu] L. Kavraki & J. Latombe, Probabilistic Roadmaps for Robot Path Planning. In *Practical Motion Planning in Robotics: Current Approaches and Future Direction*, 1998.
[Th] J. Bruce & M. Veloso, Real-Time Randomized Path Planning for Robot Navigation. In *Proceedings of IROS*, 2002.

Additional Resources: O. Khatib. Real-Time Obstacle Avoidance for Manipulators and Mobile Robots. In *International Journal of Robotics Research*, 1986.
D. Vail & M. Veloso, Multi-Robot Dynamic Role Assignment and Coordination Through Shared Potential Fields. In *Multi-robot Systems*, 2003

Week 4 : AI / ML [Oct. 17 - 21]
Topics: Cost and Reward Functions, Reinforcement Learning
Reading: [Tu] N. Rattliff *et al.*, Maximum Margin Planning. In *Proceedings of ICML*, 2006
[Th] Reinforcement Learning, by Sutton & Barto (online). Ch. 3

Week 5 : AI / ML [Oct. 24 - 28]
Topics: Reinforcement Learning
Reading: [Tu] Reinforcement Learning, by Sutton & Barto (online). Ch. 4.1-4.4, 5.1-5.6, 6.1-6.6
[Th] J. Kober, *et al*., Reinforcement Learning in Robotics: A Survey. Sections 3-6. In *International Journal of Robotics Research,* 2013**.**

Additional Resources: M. Deisenroth, *et al.*, A Survey on Policy Search for Robotics. In *Foundations and Trends in Robotics*, 2013.

Week 6 : ML [Oct. 31 - Nov. 4]
Topics: Locally Weighted Regression
Reading: [Tu] Elements of Statistical Learning, by Hastie, *et al.* (online). Ch. 2.3, 2.6-2.9
C. Atkeson, *et al.*, Locally Weighted Learning. In *Artificial Intelligence Review*, 1997.
[Th] Elements of Statistical Learning, by Hastie *et al.* (online). Ch. 8.5

Additional Resources: C. Atkeson, *et al.*, Locally Weighted Learning for Control.
In *Artificial Intelligence Review,* 1997.
C. Atkeson & S. Schaal, Receptive Field Weighted Regression.
Tech. Report, ATR, 1997.
S. Vijayakumar & S. Schaal, Locally Weighted Projection Regression : An O(n) Algorithm for Incremental Real Time Learning in High Dimensional Space.
In *Proceedings of ICML*, 2000.
S. Calinon, F. Guenter & A. Billard. On Learning, Representing, and Generalizing a Task in a Humanoid Robot.
In *IEEE Transactions on Systems, Man, and Cybernetics, Part B,* 2007.

Week 7 : ML [Nov. 7 - 11]

Topics: Gaussian Processes, Support Vector Machines

Reading: [Tu] Gaussian Processes for Machine Learning, by C. Rasmussen & C. Williams (online). Ch. 2
[Th] Elements of Statistical Learning, by Hastie, *et al.* (online). Ch. 12.1-12.3

Additional Resources: C. Burges. A Tutorial on Support Vector Machines for Pattern Recognition.
In *Data Mining and Knowledge Discovery*, 1998.
T. Fletcher, Support Vector Machines Explained. 2009

Week 8 : ML [Nov. 14 - 18]

Topics: Neural Nets & Genetic Algorithms

Reading: [Tu] Machine Learning, Ch. 4, 9.1-9.3
[Th] D. Pomerleau, Neural Network Perception for Mobile Robot Guidance.
Ph.D. Thesis, Robotics Institute, Carnegie Mellon University, 1992. Ch. 2

Additional Resources: D. Pomerleau, Neural Network Perception for Mobile Robot Guidance.
Ph.D. Thesis, Robotics Institute, Carnegie Mellon University, 1992. Ch. 3
S. Chernova & M. Veloso, An Evolutionary Approach to Gait Learning for Four-Legged Robots. In *Proceedings of IROS*, 2004.

Week 9 : ML [Nov. 21 - 25]

Topics: Learning from Demonstration

Reading: [Tu] B. Argall, *et al.,* A Survey of Robot Learning from Demonstration.
In *Robotics and Autonomous Systems*, 2009.

Additional Resources: A. Ijspeert & S. Schaal, Movement Imitation with Nonlinear Dynamical Systems in Humanoid Robots. In *Proceedings of ICRA*, 2002.
S. Schaal *et al*., Learning Movement Primitives. In *Proceedings of ISRR*, 2003.
N. Ratliff, Learning to Search: Structured Prediction Techniques for Imitation Learning. Ph.D. Thesis, Robotics Institute, Carnegie Mellon University, 2009. Ch. 2-4

Week 10 : [Nov. 28 - Dec. 2]

Topics: Project presentations

ASSIGNMENTS

Coursework will be largely implementation-based assignments (mini-projects). Assignments should be coded in Matlab, Octave or Python, and an executable version of the code must be submitted with the write-up. Students additionally are expected to keep up with the weekly readings and participate in class.

*Plagiarism, **in reports and code,** will be checked for* and strictly enforced with a zero-tolerance policy. (At best, punishable by a zero on the assignment; at worst, failure of the course and given to the Dean for disciplinary action.)

All homework write-ups should be should be formatted as: Roman 11pt font, single spaced, justified layout, with ¾ inch margins, and submitted as a PDF file.

Assignment 0: (25%)
Objectives: Implement filtering algorithm, analyze performance.
Deliverables (due): Code Part A. (Sept. 30th)
Deliverables (due): Code Part B and Write-up. (Oct. 10th)

Assignment 1: (25%)
Objectives: Implement search/navigation algorithm, analyze performance.
Deliverables (due): Code Part A. (Oct. 17th)
Deliverables (due): Code Part B and Write-up. (Oct. 24th)

Assignment 2: (25%)
Objectives: Implement machine learning algorithm, analyze performance.
Deliverables (due): Approved learning aim, dataset, algorithm. (Nov. 4th)
Deliverables (due): Code Part A. (Nov. 9th)
Deliverables (due): Code Part B and Write-up. (Nov. 16th)

Assignment 3: (15%)
Objectives: Apply partner algorithms to your data, and your algorithms to partner data.
Deliverables (due): Slides. (Nov. 28th)
Deliverables (due): Presentation. (Nov. 29th & Dec. 1st : TBA)
Deliverables (due): Report. (Dec. 2nd)

Assignment 4: (10%)
Objectives: Assess all algorithms, and classmate presentations.
Deliverables (due): Exam, open book. (Dec. 6th, 12-2pm)

All assignments are due at **midnight** (11:59pm for Canvas) on the specified date.

Late policy:
A loss of 10% of credit for every 1 hour late.
More than 9 hours late: 0% credit
Free pass: within 24 hours for full credit, 1 pass per student per quarter

The scale for final grades will not include any plus/minus grades. (A, B, C or F are the only final grade options.)

READINGS

The textbook for the course is a **bound collection of excerpts from 3 different textbooks**, which may be purchased from the bookstore. The contributing books are:

Probabilistic Robotics, by Thrun, Sebastian; Wolfram, Burgard; Fox, Dieter. MIT Press Books, 2006

Machine Learning, by Mitchell, Tom M. McGraw-Hill, 1997

Artificial Intelligence: A Modern Approach, Third Edition, by Russell, Stuart; Norvig, Peter. Prentice Hall /Pearson Education, 2009

There additionally will be assigned reading in the form of scholarly papers and articles, which will be provided via Canvas, as well as online books.