Department of
Industrial and
Systems Engineering

200 W Packer Ave
Bethlehem, PA, 18015

LEHIGH
UNIVERSITY

ISE-416 — Dynamic Programming

Instructor:	Boris Defourny	**Term:**	Fall 2019
Office:	Mohler Lab #327	**Day:**	Monday & Wednesday
Phone:	(610) 758-4250	**Time:**	9:20am-10:35am
Email:	`defourny@lehigh.edu`	**Room:**	Mohler #375
Office hours:	Mon 4:15pm-5:15pm or by appointment.	**Web page:**	`https://coursesite.lehigh.edu/`

1 Description

Dynamic Programming is the principal method to reason on a broad variety of control and multistage planning problems. Applications are found in marketing, economics, finance, supply chain, health care, bioinformatics, and robotics. Computational methods often require the use of approximations and sampling, which leads to *Approximate Dynamic Programming* and *Reinforcement Learning*.
This course introduces problems, theory and algorithms of the dynamic programming literature, by addressing the following topics: discrete-time optimal control and Markov Decision Processes, minimax control and Markov games, supermodularity and monotone policies, fixed-point methods and value iteration algorithm, linear optimization methods, sampling-based methods and Q-learning, linear approximation architectures.

2 Course Objectives

The goals of this course are to:

1. Be able to formulate a sequential decision making problem using state variables.
2. Understand Bellman's principle of optimality and be able to adapt it to the context.
3. Be able to solve finite Markov Decision Processes using a variety of exact methods.
4. Understand the theory of supermodular functions on a lattice and how it applies to dynamic programming.
5. Understand the theory of contraction mappings and how it applies to dynamic programming.
6. Recognize problems where the optimal policy has a special structure.

7. Develop capability to make assumptions to simplify the analysis of sequential decision making problems.
8. Use different classes of approximations to simplify computations.
9. Be able to implement algorithms to solve (exactly or approximately) dynamic programming problems.

3 Textbook

This course has lecture notes which I update yearly and distribute chapter by chapter on coursesite during the semester.
The lecture notes are based on the following references:

- W.B. Powell, *Approximate Dynamic Programming: Solving the Curses of Dimensionality*, 2nd Ed.,Wiley, New York, NY, USA, 2011.
- D.P. Bertsekas, *Dynamic Programming and Optimal Control*, Vol. I, 3rd Ed., & Vol. II, 4th Ed., Athena Scientific, Nashua, NH, 2005 & 2012.
- D.P. Heyman and M.J. Sobel, *Stochastic Models in Operations Research*, Vol. II: Stochastic Optimization, Dover, 2003.
- M.L. Puterman*, *Markov Decision Processes*, Wiley, 2005.
- D.M. Topkis*, *Supermodularity and Complementarity*, Princeton University Press, Princeton, NJ, 1998.
- J.M. Harrison*, *Brownian Models of Performance and Control*, Cambridge University Press, New York, NY, 2013.
- H.J. Kushner, P.G. Dupuis, Numerical Methods for Stochastic Control Problems in Continuous Time, Springer-Verlag, New York, NY, 1992.

* J.M. Harrison and A.F. Veinott Jr (who advised M. Puterman and D. Topkis among others) are Lehigh ISE Alumni.

4 Prerequisites

This course assumes a basic training in probability and statistics, linear algebra, and for some aspects, in linear programming and convex optimization. In coding illustrations in class, and in assignments, we use Matlab, but you are also free to use other *interpreted* languages such as python, java, ...

5 Course Site

Material will be posted on course site (`https://coursesite.lehigh.edu/`). Homework assignments and announcements will also be posted on Course Site. Important information will be sent by mass-email via Course Site. Email is the official way of communication for this course, so be sure to check your email often.

6 Course Evaluation

The course evaluation is comprised of the following elements (weights are for indicative purpose, we reserve the right to change them): Participation 10%, Assignments 50%, Final Project 40%.

6.1 Homework

There will be problem sets or computer implementation work for which you are asked to submit your solutions electronically to course site according to the due date. For such assignments you are asked to submit a pdf report, and the code files. Please zip them together when you upload to coursesite.

6.2 Project

There will be no formal final exam. Instead, if you are a PhD student, there will be a research project involving the investigation of a dynamic programming model in your domain of research, preferably a model that you propose. If you are a Master's student, there will be an implementation project based on an existing research paper. You can also do the project of the other student category, depending of the scope of the project.
I will determine a good topic with each of you. Suggested lists of topics and papers will be made available on coursesite. A presentation of your final project, with slides, will take place on the last week of class. You will have additional days to polish your written report, based on the feedback and requests you receive during your presentation.

7 Tentative Calendar

The following schedule is indicative only.

Week	**Dates**	**Topics**	**Remarks**
1	8/26, 8/28	Discrete-Time Optimal Control 1	
2	9/2, 9/4	Discrete-Time Optimal Control 2	
3	9/9, 9/11	Supermodularity and Monotone Policies 1	
4	9/16, 9/18	Supermodularity and Monotone Policies 2	
5	9/23, 9/25	Dynamic Programming Algorithms 1	
6	9/30, 10/2	Dynamic Programming Algorithms 2	
7	10/7, 10/9	Finite Markov Decision Processes 1	
8	—, 10/16	Finite Markov Decision Processes 2	Pacing break Oct 14,15
9	10/21, 10/23	Multiarmed Bandits 1	INFORMS Oct 20-23
10	10/28, 10/30	Multiarmed Bandits 2	
11	11/4, 11/6	Sampling-Based Solution Methods 1	
12	11/11, 11/13	Sampling-Based Solution Methods 2	
13	11/28, 11/20	Linear Approximation Architectures 1	
14	11/25, —	Linear Approximation Architectures 2	Thanksgiving Nov 27–29
15	12/2, 12/4	Project presentations	

8 Policies for the course

8.1 The Principles of our Equitable Community

Lehigh University endorses The Principles of Our Equitable Community [`http://www.lehigh.edu/~inprv/initiatives/PrinciplesEquity_Sheet_v2_032212.pdf`]. We expect each member of this class to acknowledge and practice these Principles. Respect for each other and for differing viewpoints is a vital component of the learning environment inside and outside the classroom.

8.2 Electronic Devices

You encouraged to bring your laptop during class for the purpose of this course. This will be especially useful when we code stuff in class together.
Audio or video recording may be done only with the approval of everyone in the classroom. Please let me know in advance if you need to use audio or video recording.

8.3 Accommodations for Students with Disabilities

Lehigh University is committed to maintaining an equitable and inclusive community and welcomes students with disabilities into all of the University's educational programs. In order to receive consideration for reasonable accommodations, a student with a disability must contact Disability Support Services (DSS), provide documentation, and participate in an interactive review process. If the documentation supports a request for reasonable accommodations, DSS will provide students with a Letter of Accommodations. Students who are approved for accommodations at Lehigh should share this letter and discuss their accommodations and learning needs with instructors as early in the semester as possible. For more information or to request services, please contact Disability Support Services in person in Williams Hall, Suite 301, via phone at 610-758-4152, via email at indss@lehigh.edu, or online at `https://studentaffairs.lehigh.edu/disabilities`.

8.4 Academic Integrity

Please consult the material about Academic Integrity available in Course Site. There are many forms of irresponsible behavior that can ruin opportunities for you or for others in this course; there is no room and no excuse for bad behavior. Examples of irresponsible behavior cover a wide range, and include cheating, plagiarism, creating hazards or disruptions, slacking on responsibilities, unfairly exploiting the efforts of others, etc. Further explanation and guidelines on academic integrity at Lehigh can be found on the University Student Conduct System web page `https://studentaffairs.lehigh.edu/node/31` and on the Fostering Academic Integrity at Lehigh University web site `https://studentaffairs.lehigh.edu/content/academic-integrity-resources`. It is firm policy in this course that cheating or plagiarism are unacceptable violations of academic integrity, and will earn an F as the semester grade in the course. Please meet requirements in good spirit, and do your part in advance of deadlines. For example, do not copy data or sections of homework reports from students currently or previously enrolled. While students are encouraged to discuss homework problems together, the final solution should be obtained independently, and the writing of the homework report is an individual responsibility... do not ask for other student's work, and do not share yours with others. Various forms of carelessness or disregard for safety considerations, abuse of

others, compromising opportunities for others, failing to participate in good faith, etc., can also have serious consequences. Appropriate penalties should be expected. Offenders may lose points from their course totals, and serious offenders may be dropped from the course.

8.5 Course Site Material

Material and electronic documents downloaded from course site is for your personal use only. You are not allowed to share material from course site.

8.6 Other Relevant University Policies

Religious Holidays: `https://chaplain.lehigh.edu/`
Lehigh Computer Security: `https://lts.lehigh.edu/services/security`
Lehigh Computer Policies: `https://lts.lehigh.edu/services/library-computing-policies`