



# ISE-416 — Dynamic Programming

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<b>Instructor:</b>	Boris Defourny	<b>Term:</b>	Fall 2018
<b>Office:</b>	Mohler Lab #327	<b>Day:</b>	Monday & Wednesday
<b>Phone:</b>	(610) 758-4250	<b>Time:</b>	12:45pm-2:00pm
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<b>Office hours:</b>	MW 3:50pm-4:40pm or by appointment.	<b>Web page:</b>	<a href="https://coursesite.lehigh.edu/">https://coursesite.lehigh.edu/</a>

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## 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, min-max 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.

### 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 Calendar

The following schedule is indicative only.

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<b>Week</b>	<b>Dates</b>	<b>Topics</b>
1	8/27, 8/29	Discrete-Time Optimal Control 1
2	9/3, 9/5	Discrete-Time Optimal Control 2
3	9/10, 9/12	Supermodularity and Monotone Policies 1
4	9/17, 9/19	Supermodularity and Monotone Policies 2
5	9/24, 9/26	Dynamic Programming Algorithms 1
6	10/1, 10/3	Dynamic Programming Algorithms 2
7	10/8, 10/10	Finite Markov Decision Processes 1
8	10/17	Finite Markov Decision Processes 2
9	10/22, 10/24	Multiarmed Bandits
10	10/29, 10/31	Sampling-Based Solution Methods 1
11	11/5, 11/7	INFORMS
12	11/13, 11/15	Sampling-Based Solution Methods 2
13	11/20	Linear Approximation Architectures 1
14	11/27, 11/29	Linear Approximation Architectures 2
15	12/4, 12/6	Project presentations

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## 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](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 are encouraged to use your laptop during class for the purpose of this course.

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

If you have a disability for which you are or may be requesting accommodations, please contact both your instructor and the Office of Academic Support Services, Williams Hall, Suite 301 (610-758-4152) as early as possible in the semester. You must have documentation from the Academic Support Services office before accommodations can be granted.

### 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 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>