15-884/15-484: Course Information and Syllabus, Computational Methods for the Smart Grid

Zico Kolter
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Course Information

- **Course Number:** 15-884 (PhD), 15-484 (undergraduate), crosslisted as 18-473
- **Instructor:** J. Zico Kolter
- **Lecture:** TR 10:30-11:50, GHC 4101
- **Units:** 12 (15-884), 9 (15-484)

Brief description

Building a sustainable energy ecosystem, and controlling a complex electrical grid to provide this energy, poses one of the largest challenges facing the world. Although energy topics span many disciplines, ranging from power systems to public policy, it is becoming apparent that computational techniques such as simulation, prediction, optimization, and control have the potential to drastically impact virtually all of these areas. This course provides an introduction to recent advances in computational methods applied to sustainable energy and the smart grid; the goal is to provide students with a broad background in state-of-the-art computational methods that repeatedly arise in these domains, such as machine learning, optimization, and control, and to provide hands-on experience applying these methods to real-world domains. In particular, much of the class will use real data from the Pennsylvania electrical grid as a running example, and address issues regarding the prediction, modeling, and control of electricity from existing and renewable energy sources. Although listed in Computer Science, the course is expected to be of interest to students in many departments, including ECE, MechE, CEE, and EPP.

Recommended background

This course is intended for a fairly broad audience: students who are familiar with energy systems but who want to develop a better understanding of computational techniques that can be brought to bear on these problems, or students who may have a strong background in CS but who want to explore applications in sustainable energy systems (or even those who want to learn both). As such, the formal prerequisites for the course are fairly small: you should have some background in linear algebra (Math 341 would be more than sufficient, for example, but certainly less than this is fine), as well as some basic background in programming (homework assignments will be done in MATLAB). I will post linear algebra notes and MATLAB tutorials for those who may need a refresher in these areas. Other than that, I intend to make the course as approachable as possible for students of all backgrounds, since this is an area that overlaps several fields, and thus benefits hugely from students coming from different departments. This difference in backgrounds also motivates the option of both PhD (15-884) and MS (15-484) courses.

Distinctions between the 15-884 and 15-484 classes

This course is listed under both 15-884 and 15-484 and the undergraduate course is also cross-listed under 18-473; these are really the same class: lectures are the same and taught at the same time, basic problem sets and due dates are the same, etc. There are two distinctions between the two levels: 15-884 students will need to complete 1-2 additional homework problems on each assignment (see below), and the final project for 15-884 is significantly expanded and must must have some original research component (the final project for 15-484 can be a survey of existing work, or an advanced programming assignment).

The point of having these two levels to the course, as highlighted above, is to accommodate students of different backgrounds. Some students may already be very familiar with either the computational or energy background covered by the course, and so would benefit from challenging research-level problems. Alternatively, some students may be less familiar with the topics, and so will spend an equal amount of time working on the class even without these extra assignments. Grades will also be computed looking at student performance from each class separately.

Homework and projects

Grades in the class will be based upon four problems sets, assigned every two weeks (60% of the grade, each assignment worth 15%), and a final written project (40% of the grade).

Problem sets will consist of 4-5 questions, usually requiring some mathematical derivation or a programming assignments. In addition, problems sets will have one or two challenge problems, which are required for 15-884 students but optional for 15-484 students; these problems are intended to let students explore more difficult or research-level questions in the area, especially for those who might be more familiar with the material.

The final project for 15-884 consists of an (up to) 5 page written report on an advanced research topic in computational methods for sustainable energy. Any students who are curious about potential research projects are encouraged to talk about possible topics during office hours. **Students may work in teams of two for the final project**, but can also work alone. A short (250 word) project proposal will be due earlier in the semester (due date to be announced in class). The final project for 15-484 can be either a report of the type above (but no original reserach component is required, and the report can be a survey of existing literature), or a final programming assignment that will bring together many of the topics we have discussed in the course.

Homework policy

Working together on homework problems in a group can be one of the most effective ways to learn class material. Thus, **students are allowed and encouraged to discuss and work through homework problems with each other in groups.** However, after you have worked through the problems as a group, **you must complete the final write-up of the problem sets yourself**. This include programming assignments: you may discuss in a group the algorithms you will implement for solving the problems, but the actual code you submit must be written independently.

Homeworks are due at the beginning of class on the due date. However, there are times in the semester when many deadlines coincide and it is difficult to hand in an assignment on the original due date. For this reason **each student has total of five free "late days" that they may use**

throughout the semester. These late days can be distributed amongst the 4 problem sets any way desired: handing in each problem one day late, handing in one problem set five days late and the rest on time, etc. After you spend your five late days, you will receive 20% off per day on any assignment handed in late. **Late days may only be used on the problem sets and project proposal, not the final written project** (to allow sufficient time for grading at the end of the course).

Lecture videos

Videos for all the course lectures will be posted on the class website. You are welcome to take the course even if you cannot attend all (or any, if you so desire) of the lectures in person, but you will be responsible for all the same material and problem sets.

Syllabus

The course will cover several topics on computational approaches to energy systems, including the following. The precise days may change some, given that this is the first time the course is being offered at CMU, but this is a rough outline.

- **Introduction to energy and computation (2 lectures), 8/27-8/29**
  - Overview of challenges in sustainable energy
  - Illustrative examples of computation: wind energy and power markets
  - Basic background on physics of energy
  - Overview of some ongoing research at CMU
- **Brief review of background material (1 lecture), 9/3**
  - Linear algebra
  - MATLAB programming
- **Machine learning for prediction and forecasting (7 lectures), 9/5-9/26**
  - Examples of importance of prediction in energy systems
  - Application: electricity demand forecasting from weather data
  - Linear regression models and least squares
  - Optimization approaches to machine learning
  - Non-linear regression models with explicit feature and kernels
  - Alternative loss functions in regression
  - Application: identifying home appliances with non-intrusive load monitoring
  - Linear and non-linear classification models, logistic regression and support vector machines
  - Evaluating machine learning algorithms
  - Time series prediction, autoregression models
- **Basics of Power Systems (7 lectures), 10/1-10/22**
  - Basics of DC circuits
  - AC Circuits, real/reactive power
  - Generators, three-phase power, power electronics
  - Power flow in AC networks
  - Newton's method for solving non-linear power flow
  - Linearized DC power flow

  - Optimal power flow
  - Power markets and locational marginal pricing

- **Control and planning (8 lectures), 10/24-11/19**
  - Control as optimization
  - Linear quadratic control
  - Application: control of energy storage system
  - Model predictive control
  - Application: control using ML-based predictions and power systems constraints
  - Introduction to discrete control and combinatorial optimization
- **Reserved for guest lectures (2 lectures) 11/26-11/28**
- **Current research directions (2 lectures) 12/3-12/5**