Advanced Optimization Techniques for Communications and Signal Processing

Second Quarter, Course 2008 - 2009

Professor

	Email	Office	Tel.
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Time and location of Lectures

Days	Time	Classroom
Thursdays	11:30 - 13:00	Seminar Room, 1st Floor, Instituto de Robótica
Thursdays	13:30 - 15:00	Seminar Room, 1st Floor, Instituto de Robótica

Tutorships

Days	Time	Office
Tuesdays	14:00 - 15:00	Instituto de Robótica

General description of the course

This course is a 5 ECTS Core course that is taught during the second Quarter of every academic year, during the months of January, February, March and part of April.

The focus of the course is to provide a deep study of optimization tools in the context of important problems related to point-to-point and Networked Communications, as well as Signal Processing. On the one hand, these are very useful tools in order to understand, model and analyze correctly real problems and on the other hand, these are also the key tools to design solutions for these problems. The course will cover both classic results and also more recent results.

Main objectives

- Acquire correctly the mentality and language of Optimization.
- Know how to model and formulate real communication and signal processing problems as optimization problems.
- Understand well the underlying theory, concepts and properties related to each of the optimization tools.
- Design, implement and simulate practical (centralized and distributed) algorithms to solve the various optimization problems.
- Analyze the structures/decompositions of problems and solutions, as well as the relationship between different problems

Of course, I also expect you to: be willing to learn, enjoy the class and to be participative!

Prerequisites

You are expected to have knowledge on Algebra, Calculus, Probability and Random Processes, Basic Digital Communications and Matlab Programming. If you don't have a good knowledge on these topics, maybe you should not take probably this course at this moment.

Class material and Web access

- Slides, which will be distributed periodically and posted at http://pizarra.uv.es.
- Homework assignments. Although in-group discussion can be done and is ok, you should try to solve all the problems individually. When preparing the exam, I will assume that you have done all the problems. The general type of problems will not be plug-and-chug, that is, it will require time and thinking, not just applying straightforward or standard methods. Each homework assignment will have also a given due date and no late homeworks will be accepted. Doing the homeworks will be the best possible preparation for the final exam. The homework assignments will be also posted at http://pizarra.uv.es
- Research papers and other complementary material (refreshers, tutorials, papers, etc...), which will be posted at http://pizarra.uv.es.

Project

- Either original research or extensive comparative study between existing solutions
- A list of papers and topics will be provided (students can also propose topics ;))
- Individual projects (2 projects can collectively cover a large problem)
- Presentation during last week of Quarter
- Project report due last day of class (both content and presentation will be evaluated)
- There will be several project progress meetings to interact

Final Exam

There will be a Final exam during the last week of class. The set of problems and questions in the exam will be of similar level to the homework assignments.

Grading

The final grade for this course will be calculated as follows:

$$\text{Grade} = 0.2 \times (\text{Homeworks}) + 0.4 \times (\text{Project}) + 0.4 \times (\text{Final Exam}).$$

The grading of the project will be based both on the Report (25%) and on the Presentation (15%).

Approximate Outline of topics

- Introduction, Motivation and Course Overview
- Theory and Algorithms:
  - Convex Sets and Convex Functions
  - Classification of Convex problems: LP, QP, SOCP, SDP, GP

- Convex Optimization and Lagrange Duality
- Pareto Optimization
- Dynamic Programming and Sequential Optimization
- Geometric Programming for Communication Systems
- Gradient Optimization Algorithms
- Interior Point Optimization Algorithms
- Alternating Projections & Composite Mappings
- Decomposition Optimization Methods/Structures and Distributed Algorithms
- Non-convex Optimization

- Applications (interlaced between theoretical lectures):
  - Approximation and fitting
  - Waterfilling solutions
  - Network Flow Problems
  - Statistical Estimation
  - Classification
  - Robust Beamforming
  - Transceiver Design for MIMO Communications
  - Power Control Optimization in Wireless systems
  - Multi-user Maximum-Likelihood Detection and Decoding
  - Code duality between rate-distortion and channel capacity
  - Network Utility Maximization
  - Internet TCP Congestion Control

Bibliography

Unfortunately, there is not a single book covering all the material of the course, thus, we will use several books at the same time. There will be also periodic reading assignments from some of these books.

- Basic Bibliography:
  - S. Boyd and L. Vandenberghe, *Convex Optimization*, Cambridge University Press 2004.

- Complementary Bibliography:
  - D. P. Bertsekas, *Nonlinear Programming*, Athena Scientific, 2nd Edition, 1999.
  - D. Bertsimas, J. N. Tsitsiklis, *Introduction to Linear Optimization*, Athena Scientific, 1997
  - D. G. Luenberger, *Linear and Non-Linear Programming*, Springer, 2003.
  - D. P. Bertsekas, *Network Optimization: Continuous and Discrete Models (Optimization, Computation, and Control)*, Athena Scientific, 1998.
  - D. P. Bertsekas, *Convex Analysis and Optimization*, Athena Scientific, 2003.
  - M. Chiang, *Geometric programming for communication systems*, Foundations and Trends in Communications and Information Theory, vol. 2, no. 1-2, pp. 1-154, July 2005.

- S. Shakkottai, R. Srikant, *Network Optimization and Control*, Foundations and Trends in Networking, vol. 2, no. 3, 2007
- D. P. Bertsekas, *Dynamic Programming and Optimal Control*, Volume I, Athena Scientific, 2007.
- G. L. Nemhauser, L. A. Wolsey, *Integer and Combinatorial Optimization*, Wiley-Interscience (series in discrete mathematics and optimization), 1999.
- L. A. Wolsey, *Integer Programming*, Wiley-Interscience (series in discrete mathematics and optimization), 1998.
- T. K. Moon, W. C. Stirling, *Mathematical Methods and Algorithms for Signal Processing*, Prentice Hall, 2000.
- W. Kocay, D. L. Kreher, *Graphs, Algorithms and Optimization*, Chapman & Hall/CRC Press, 2005.
- Several tutorials and journal papers to be distributed in class.

ADVANCED OPTIMIZATION TECHNIQUES
FOR COMMUNICATIONS & SIGNAL PROCESSING

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Class Project Information

The project of this course is meant to be substantial, involving some combination of independent research, implementation and testing, simulation and verification, and documentation, so you should start as early as possible from now. The project can be either (i) working on an original research problem or (ii) an extensive comparative study between existing solutions. The project needs to be in the general area of Optimization, within the context of applications to Signal Processing, Communications or Networking.

1 Project logistics

- **Project proposal**: Projects are individual, although two projects may tackle a large problem.
- **Project proposal**: You need to decide soon on your project topic, and write a 1-3 page project proposal that should be submitted by **May 1st**, by email to Baltasar.Beferull@uv.es at any time. It should include the topic, some background, a description of the work to be done and references. You can check file *project.pdf* at pizarra.uv.es, folder PROJECTS, in order to get an idea about the format you should follow. You can write it using any tool of your choice (latex, Word, etc...). In case you decide to use latex, I have also included the latex template and the corresponding required files.
- **Project progress meetings**: There will be special office hours to discuss progress and questions on your projects. The meeting dates will be **April 23**, **April 30**, **May 7**, **May 14**, **May 20**, **May 8**, all of them thursdays, from 13:00 - 15:00 and also from 15:00 - 16:45.
- **Presentation**: Each student will give a 30 minute presentation of their project some time during the end of May (the final date will be announced in advance). The presentation should be given in English, no exceptions.
- **Final report**: Each person should submit a hard copy and an electronic copy (send it by email to Baltasar.Beferull@uv.es) of their project report by the same day of the Presentation. The projects should be submitted ideally in the IEEE one-column format, which you can check on the template file *project.pdf* I have uploaded to pizarra.uv.es, folder PROJECTS. You can write it using any tool of your choice (latex, Word, etc...). In case you decide to use latex, I have also included the latex template and the corresponding required files. Please, try to keep the length of the report under 20 pages (including references).
  Additionally, your report and other supporting materials should be assembled into a simple self-contained web site, with a master index.html file with links to the other documents, codes, and other materials. The idea is to post these some time later on the web.

2 Some details

Background and problem description

You must clearly describe the engineering problem, giving the background, describing how the problem is solved now, and what is lacking, or inadequate in how it is done now. For example, current design practice might be ad-hoc, ignore a number of constraints, etc...

Your formulation

Explain your formulation of the problem (or some part of it, or some simplified variation) as any of the followings: a convex optimization problem (or convex optimization based heuristic), a non-convex optimization problem, a game, etc... Be clear about what the variables and constraints are, and whether the problem is convex, or nonconvex. Is your modeling (formulation) accurate? What constraints and specifications can your formulation handle? Which can you not handle? For which is your method heuristic or approximate? If the problem you formulate is nonconvex, how will you solve it ?, or how will you solve it approximately using convex optimization? If you are not solving the problem exactly, you will need to justify that the method works. This might involve simulation of examples to show the method works well, even if it is not known to be optimal.

Verification

You may need to demonstrate that despite the approximations and simplifications you made in formulating your problem, or in solving your problem (if it is not convex), the end result is still useful (and hopefully good). If your method involves for instance a heuristic for solving a hard (say, combinatorial) problem, then you can consider some cases that are small enough for you to compute the global optimum, which can then be compared to the approximate solutions produced by your method. It might be appropriate to compare the results of your method to existing ones (and hopefully, show an improvement).

Final Outcome

The principal final outcome of the project should be hopefully a preliminary research paper (your technical report), along with all the corresponding supporting material such as (well documented) codes and data.

In order to solve the problem you formulate, you can use standard codes (if your problem can be reduced to a standard problem), or develop your own. If the problem you formulate has structure that can be exploited, and problems with more than 1000 or so variables are of interest, you can develop an efficient implementation that scales your method at least to medium scale problems (many thousands of variables). If appropriate and interesting, you can develop a distributed algorithm for solving your problem using for instance decomposition methods.

We emphasize that your formulation does not have to be a convex optimization problem. If it is nonconvex, however, you could use some convex optimization based methods for solving it, perhaps approximately or heuristically. You could form a relaxation, use a randomized method, use branch and bound (with convex optimization based lower bounds), or repeated linearization/convexification to (approximately) solve your problem. However, it is unacceptable to simply form a nonconvex problem and then approximately solve it using some standard nonlinear programming method or code.

You will implement one or more algorithms. You must decide what to implement, and in addition to developing the code, you must develop documentation, test suites if possible, etc. The goal is to make the software available publicly at some time later. The software can be in Matlab/octave, C/C++, Java, or any other reasonable language. It should be as simple as possible, totally portable. You should avoid, if possible, using anything but public domain or easily used code.

3 Some possible Project Topics

A list of possible topics for your project is provided below. You can also propose your own project; the descriptions below are meant only as broad categories and generic examples. Although I will give you some initial material and/or guidance during the first meeting on **April 23** and some days later, you will need to do also some literature search. If you have difficulties to find some paper, just let me know. Many papers can be downloaded from the web site `http://ieeexplore.ieee.org/Xplore/dynhome.jsp`, the official IEEE web site for journals and conferences, which is accessible for free from Universidad de Valencia.

1. **Optimal Transceiver Design for Multiaccess Communications**
2. **Convex or Non-convex Optimization in Sensor Networks related problems**
3. **Distributed Bio-inspired communication protocols as Decomposition Optimization Methods**
4. **Optimization in Gossip Multi-agent Algorithms**
5. **Convex Optimization in Classification Problems**
6. **Convex Optimization and Games in Cognitive radios**
7. **Optimization in Quantum computation and communication systems**
8. **Optimization in Information Theory and Code Design**
9. **Adaptive Linear Filtering Using Interior Point Optimization Techniques**
10. **Optimization in Broadband ADSL systems**
11. **ML Decoding in Multiuser Communications via SDP Relaxation**
12. **Network Layering as Optimization Decomposition**
13. **Distributed Power and Rate control in Cellular systems**
14. **Distributed joint Congestion and power control in multi-hop networks**
15. **Power Control Games in Cellular Networks**
16. **Non-convex Optimization techniques for Communication systems**
17. **TCP Congestion Control**
18. **Non-convex Network Utility Maximization**
19. **Stochastic simulation for TCP/IP**
20. **Network Embedding**
21. **Image Processing via Convex Optimization**