12-759: Computational Optimization of Systems Governed by Partial Differential Equations

Fall 2003

Lectures: Mon/Wed 4:30–6:20pm, Porter Hall 07F

Website: `http://www.cs.cmu.edu/~12-759`

Class mailing list: `pde-opt@cs.cmu.edu`

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Description:
This course provides an introduction to the numerical solution of nonlinear optimization problems that are governed by systems of partial differential equations (PDEs), i.e. "simulation-based optimization." The focus of the course is on regularization, variational formulations, finite element approximation, and large-scale solvers for PDE-constrained optimization. Settings covered include inverse problems and parameter estimation, optimal design (including shape optimization), and optimal control. Students will develop numerical implementations and solutions of model problems in each of the classes using a high-level finite element toolkit. Prerequisites include a first course in numerical optimization and a course in finite element methods (equivalent to 12-755), or consent of instructor.

Required work: About six assignments

Text: None required, but several good books worth having are:
Numerical optimization background:

- Jorge Nocedal and Stephen J. Wright, *Numerical Optimization*, Springer-Verlag, New York, 1999

Finite element background:

- Eric B. Becker, Graham F. Carey, and J. Tinsley Oden, *Finite Elements: Volume I, An Introduction*, Prentice Hall, Englewood Cliffs, New Jersey, 1981 (elementary presentation; out of print)
- Claes Johnson, *Numerical Solution of Partial Differential Equations by the Finite Element Method*, Cambridge, New York, 1990 (more advanced presentation; out of print)

Optimal control of PDEs (in particular, flow control):

- Max D. Gunzburger, *Perspectives in Flow Control and Optimization*, SIAM, Philadelphia, 2003.

Inverse problems:

- Curtis R. Vogel *Computational Methods for Inverse Problems*, SIAM, Philadelphia, 2002.

Shape optimization:

- Olivier Pironneau, *Optimal Shape Design of Elliptic Systems*, Springer, Lecture Notes in Computational Physics, Springer, 1983.
- J. Haslinger and R.A.E. Mäkinen, *Introduction to Shape Optimization. Theory, Approximation, and Computation*, SIAM, Philadelphia, 2003.

A snapshot of current research:

- Lorenz T. Biegler, Omar Ghattas, Matthias Heinkenschloss, and Bart van Bloemen Waanders, eds., *Large-Scale PDE-Constrained Optimization*, Springer, Lecture Notes in Computational Science and Engineering, 2003.

Tentative Course Outline

- Sundance introduction
- finite element background
- optimality conditions
  - discrete vs. continuous
  - steady and unsteady
  - linear and nonlinear PDEs
  - distributed, boundary, and finite-dimensional optimization variables
  - parameter estimation, optimal control, and optimal design settings
- numerical algorithms for PDE-constrained optimization
  - sensitivity analysis issues
  - reduced gradient methods
  - reduced SQP methods
  - full space (all-at-once, one-shot)
- inequality constraints
  - optimization constraints
  - state constraints
  - numerical algorithms
- advanced topics (as time permits)
  - regularization of ill-posed inverse problems
  - reduce basis methods
  - shape sensitivities