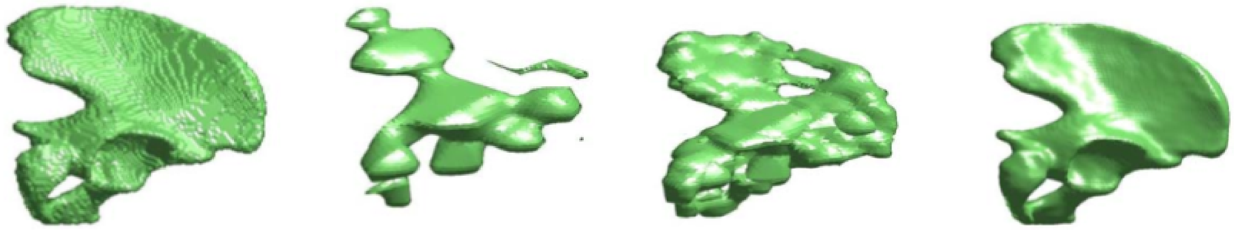
# Fall 2015:
# Computational and Variational Methods for Inverse Problems
# Cross-listed among CSE 397, GEO 391, ME 397, ORI 397



**Unique numbers:** 65207 (CSE), 27174 (GEO), 18559 (ME), 18804 (ORI)

**Lectures:** Monday and Wednesday 9:00–11:00, GDC 6.202

**Website:** `http://users.ices.utexas.edu/~omar/inverse_problems`


**Instructor:** Prof. Omar Ghattas
ICES Office: ACE 4.236A
E-mail: `omar@ices.utexas.edu`
Phone: 512-232-4304
Office hours: after class and by appointment


**Description:** This course provides an introduction to the numerical solution of inverse problems that are governed by systems of partial differential equations (PDEs). The focus of the course is on variational formulations, ill-posedness, regularization, variational discretization, and large-scale solution algorithms for inverse problems. Students will develop numerical implementations for model problems using an inverse problems library, hIPPYlib, along with a high-level finite element toolkit, FEniCS. These implementations will allow us to study the influence of data noise, regularization, the observation operator, the choice of the parameter field, and the nature of the underlying PDE model on the identifiability of the model parameters, as well as facilitating experimentation with different solution algorithms. In addition to the deterministic framework for inverse problems, the course will also provide an introduction to the Bayesian framework and draw connections between the two. Examples will be drawn from different areas of science and engineering, including image processing, continuum mechanics, and geophysics.

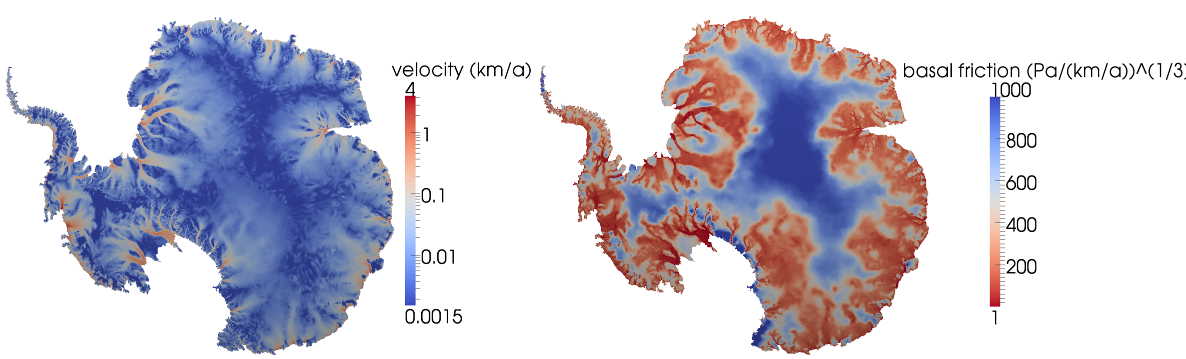
**Prerequisites:** Graduate standing or consent of instructors. Background in numerical linear algebra, partial differential equations, and nonlinear optimization is desirable. However, the required mathematical background will be covered when needed—albeit quickly. A mathematically mature student will be able to acquire from the lectures the necessary mathematical and computational background. If in doubt, contact me.

**Required work:** About six assignments involving a mix of theory, implementation, and computational experiments.

**Collaboration Policy:** Students are encouraged to discuss among themselves the course material and assignments. However, all turned-in material must be the work of the individual student. For further information on the University's Scholastic Dishonesty policy, see `http://deanofstudents.utexas.edu/sjs/scholdis.php`.

**Course Topics**

- introduction and examples of inverse problems with PDEs
- ill-posed problems and regularization
  - theoretical issues
  - different regularization methods
  - choice of regularization parameter
- variational methods, weak forms
- computing derivatives via adjoints
  - steady and unsteady problems
  - discrete vs. continuous
  - linear and nonlinear PDEs
  - distributed, boundary, and finite-dimensional parameters and measurements
- numerical optimization methods
  - line search globalization
  - steepest descent
  - Newton method
  - Gauss-Newton method
  - inexact Newton-conjugate gradient method
- inequality constraints on parameters
- Bayesian approach to inverse problems



## Useful References

No textbook required, but several good references for variational inverse problems include:

**Theory and computational methods for inverse problems:**

- Heinz Engl, Michael Hanke, and Andreas Neubauer, *Regularization of Inverse Problems*, Dordrecht, 2nd edition, 1996. (classic book on regularization of linear and nonlinear inverse problems)
- Curtis R. Vogel, *Computational Methods for Inverse Problems*, SIAM, 2002. (focus on numerical solution methods, applications mainly in image restoration)
- Guy Chavent, *Nonlinear Least Squares for Inverse Problems*, Springer, 2009.

**Numerical optimization background:**

- Jorge Nocedal and Stephen J. Wright, *Numerical Optimization*, Springer-Verlag, 1999. (comprehensive guide)
- C. Tim Kelley, *Iterative Methods of Optimization*, SIAM, 1999. (unconstrained, lots of practical advice, PDF is available online)

**Optimization of systems governed by PDEs:**

- Max D. Gunzburger, *Perspectives in Flow Control and Optimization*, SIAM, 2003. (more general than implied by title)
- M. Hinze, R. Pinnau, M. Ulbich, and S. Ulbrich, *Optimization with PDE constraints*, Springer, 2009. (function-space approach)
- Fredi Tröltzsch, *Optimal Control of Partial Differential Equations: Theory, Methods and Applications*, Graduate Studies in Mathematics Vol. 112, AMS, 2010.
- Alfio Borzì and Volker Schulz, *Computational Optimization of Systems Governed by Partial Differential Equations*, SIAM, 2012.

**Probabilistic approach to inverse problems:**

- Albert Tarantola, *Inverse Problem Theory and Methods for Model Parameter Estimation*, SIAM, 2005. (statistical perspective; freely available on the web)
- Jari Kaipio and Erkki Somersalo, *Statistical and Computational Inverse Problems*, Springer, 2005.