CERI 8315
Computational Methods for Geodynamics
FALL 2024

Instructor: Eunseo Choi

Time and Location: TR, 11:20 - 12:45 am.

Contact: echoi2@memphis.edu

Grades

Pop quizzes (20 %), topical homeworks (50 %), and a term project (30 %).

Office Hours

To be determined.

Course Goal and Objectives

This course aims to enable students to understand the basics of the finite element method, a versatile numerical method for solving partial differential equations in their weak forms. After taking this course, students will be able to use or modify as necessary the existing community modeling codes based on this method for their geophysical research.

To achieve the goal, this course will

1. review the fundamental governing equations in continuum mechanics,
2. delve into the inner workings of the finite element method,
3. provide hands-on experiences with common procedure and useful practices in computational research,
4. ask students to use one of the open-source FEM codes, possibly after modifications, for their term project.

Online Resources and References

No required textbook but parts of the references listed below will be used.

Reference texts[1]

- Continuum mechanics:
  - †Tadmor, E. B., Elliott, R. S., and Miller, R. E. (2012). *Continuum Mechanics and Thermodynamics : From Fundamental Concepts to Governing Equations*. Cambridge University Press, Cambridge
  - Holzapfel, G. A. (2000). *Nonlinear solid mechanics : a continuum approach for engineering*. Wiley, Chichester ; New York

[1] † means that the item is available at the UofM Library.

  - Malvern, L. E. (1977). *Introduction to the Mechanics of a Continuous Medium*. Prentice-Hall, Upper Saddle River, New Jersey

- Fundamental numerical techniques

  - †Quarteroni, A., Sacco, R., and Saleri, F. (2000). *Numerical Mathematics*. Springer-Verlag, New York
  - †Zienkiewicz, O. C., Zhu, J. Z., and Taylor, R. L. (2013). *The Finite Element Method: Its Basis and Fundamentals*. Butterworth-Heinemann, 7th edition
  - †Zienkiewicz, O. C., Taylor, R. L., and Fox, D. (2014). *The Finite Element Method for Solid and Structural Mechanics*. Butterworth-Heinemann, 7th edition

- Geodynamics:

  - Turcotte, D. L. and Schubert, G. (2002). *Geodynamics*. Cambridge University Press, New York, 2nd edition
  - †Schubert, G., Turcotte, D. L., and Olson, P. (2001). *Mantle Convection in the Earth and Planets*. Cambridge University Press, Cambridge

- Computational geodynamics:

  - †Ismail-Zadeh, A. and Tackley, P. (2010). *Computational Methods for Geodynamics*. Cambridge University Press
  - †Gerya, T. (2009). *Introduction to Numerical Geodynamic Modelling*. Cambridge University Press, New York

Online resources

- You can easily find online manuals, tutorials and courses for all the aspects of computational science.

- I recommend the following based on my experiences:

  - How to work on a Linux(-like) system especially when you are new to it:
    `https://developer.ibm.com/technologies/linux/tutorials/`;
    search for tutorials with keywords "LPIC-1" and "exam 1"
  - Lessons on BASH, Python and Git by Software Carpentry:
    `https://software-carpentry.org/lessons/`
  - Programming languages (C, Python, etc) and parallel computing (OpenMP, MPI, GPU etc)
    `https://cvw.cac.cornell.edu/topics`

Term projects

- Students carry out a reasonably small but non-trivial project relevant to the course goal and objectives.

- They should use GitHub to manage their projects and products as sharable and reusable resources.

- Individual topics can be decided based on students' interests and needs.

Course Outline

- Unit 1: A short review of continuum mechanics
- Unit 2: Numerical toolbox - Principles of numerical mathematics
- Unit 3: Numerical toolbox - Interpolation: Lagrange polynomial
- Unit 3: Numerical toolbox - Interpolation: Piecewise Lagrange polynomal interpolation in 2D
- Unit 4: Numerical toolbox - Solving linear equations: Basic stability analysis and direct method
- Unit 4: Numerical toolbox - Solving linear equations: Iterative methods and conjugate gradient method
- Unit 4: Numerical toolbox - Solving linear equations: Krylov subspace methods. Solving non-linear systems
- Unit 5: Numerical toolbox - Approximating function derivatives: Finite difference and interpolation-based approach
- Unit 5: Numerical toolbox - Approximating function derivatives: Orthogonal polynomials and weight functions
- Unit 6: Numerical toolbox - Numerical integration: Gauss and Gauss-Lobatto quadrature formula
- Unit 7: Basic finite element method - Weak forms and variational principles
- Unit 8: Basic finite element method - Walkthrough with the Poisson eq. in 1D
- Unit 9: Basic finite element method - Extension to 2D and 3D
- Unit 9: Basic finite element method - Solving time-dependent PDEs
- Unit 10: Selected Topics
  - Elastic deformation: Static and Dynamic
  - Basic parallel computing
  - Introduction to open-source codes: PyLith, ASPECT, FEniCS, DES3D