FINITE ELEMENT PROGRAMMING – MANE 6680
COURSE COMMENTS

The material in this course will be taken from a multiple sources, so there is not a single course text. However, you should have at least one good finite element text. An excellent option is T.J.R. Hughes, *The Finite Element Method: Linear Static and Dynamic Finite Element Analysis*, Dover Pubns., ISBN 0486411818, 2000.

Prof. Mark S. Shephard, 4019 CII, 276-8044, shephard@rpi.edu. The class times are Monday and Thursday, 10-12 and the class will meet in Lally 02. Office hours are Monday 4-5 and Friday 8:30-10. You can stop by other times. Email if you would like to set an appointment for a specific time.

Course handouts are located in folders at https://www.scorec.rpi.edu/~shephard/FEP19/
File with running list of course documents
https://www.scorec.rpi.edu/~shephard/FEP19/Handouts-2019/info-pointers-2019.pdf

Since I will be out for a few classes, we will often go longer than the 75 minutes per lecture.

Course goals:

1. Cover the important components of a finite element analysis program taking a geometry-based perspective. Emphasis will be placed on the parallel implementation of finite element methods.
2. Understand and implement a finite element analysis capability.
3. To carry out a specific project addressing an aspect of finite element programming.

Prerequisites:

1. A finite element analysis course, or sufficient background in finite element methods.
2. A working knowledge of C++ or C. (You can do most of your programming in FORTRAN, however there are libraries you will use that require C or C++ code to interface with.)
3. You must know how to program to take this course. The course will cover concepts, methods and algorithms. It will not cover any programming details.

Grading:

10% Assignment 1 - Mesh database
5% Assignment 2 - Parallel mesh database
5% Assignment 3 - Reordering procedure
30% Assignment 4 - Analysis code
50% Term project (software and write-up)

The course project selected will involve programming some aspect of the finite element method. The project selected must including programming. Since this project represents a major portion of the course, it is important that you begin it as soon as possible. The project you select should have a relationship to your research. Please note that the level of effort involved in this course is such that you only want to take it if the project is of specific value to your research.

FINITE ELEMENT PROGRAMMING

COURSE OUTLINE 2019

1) A geometry-based finite element analysis procedure
   a) Brief review of FEA
   b) Simulation workflow using FEA
   c) FEA frameworks
   d) Geometry and attributes

2) Mesh topology and it relationship to the domain
   a) Mesh entities and mesh topology
   b) Mesh classification
   c) Interface operators for interacting with the mesh using PUMI

3) Introduction to parallel computing
   a) Parallel computers and basic parallel constructs
   b) Data parallel and message passing

4) Meshes in parallel
   a) Supporting meshes in parallel using PUMI
   b) Ordering of unknowns for minimum solution time
   c) Dynamic load balancing unstructured meshes

5) Linear finite element mesh analysis
   a) Element shape functions and their computation
   b) Element equation formation and integration
   c) Construction and solution of global equations by direct solution techniques
   d) Recovery of secondary variables
   e) Parallel FE analysis
   f) Examples of approaches to implementing finite elements

6) Iterative solution methods

4) Time marching and solving nonlinear finite element problems

7) Adaptive finite element techniques
   a) Mesh enrichment schemes
   b) Parallel mesh modification
   c) A posteriori error estimation

8) Automated finite element modeling solutions
   a) Components
   b) Integration with the problem definition
   c) An *h*-refinement system
   d) An *hp*-refinement system
   e) Anisotropic adaptive techniques
   f) Analysis idealization control system

FINITE ELEMENT PROGRAMMING: SOME BOOKS

Regular finite element texts with a reasonable coverage of programming aspects

T.J.R. Hughes, *The Finite Element Method: Linear Static and Dynamic Finite Element Analysis*, Dover Pubns., ISBN 0486411818, 2000.

K.J. Bathe, *Finite Element Procedures,* Prentice Hall, 1996

T. Belytschko, W.K. Liu, B. Moran and K.L. Elkhordary, *Nonlinear Finite Elements for Continua and Structures*, 2nd ed, Wiley, 2014.

J.A., Cottrell, T.J.R. Hughes and Y. Bazilevs, Isogeometric Analysis: Toward Integration of CAD and FEA, Wiley, 2009.

Texts with specific emphasis on the programming of the finite element method

I.M. Smith, D.V. Griffiths and L. Margetts, *Programming the Finite Element Method*, Wiley, 5th Edition, 2014

E. Hinton and D.J.R. Owen, *Finite Element Programming*, Academic Press, 1977

K.J. Bathe and E.L. Wilson, *Numerical Methods in Finite Element Analysis*, Prentice Hall, 1976

G.F. Carey and J.T. Oden, *Finite Elements: Computational Aspects – Vol. 3*, Prentice Hall, 1984

D.J.R. Owen and E. Hinton, *Finite Elements in Plasticity: Theory and Practice*, Pineridge Press, 1980

C.S. Krishnamoorthy, *Finite Element Analysis: Theory and Programming*, 2nd Ed. TATA - McGraw Hill, 1995

Books on C++ and object oriented programming

S.B. Lippman, J. Lajoie and B.E. Moo, *C++ Primer*, 5th Edition, Allison-Wesley, Reading MA, 2013.

B. Stroustrup, *The C++ Programming Language*, 4th ed., Allison-Wesley, Reading MA, 2013.

R. Sedgewick, *Algorithms in C*, *Parts 1-5 (Bundle): Fundamentals, Data Structures, Sorting, Searching, and Graph Algorithms* (3rd ed), Manning Publications, 2001.

P.J. Deitel and H. Deitel, *C++ How to Program* (10th edition), Prentice Hall, 2017.

D.R. Musser, G.J. Derge, A. Saini, *STL Tutorial and Reference Guide*, 2nd Ed., Addison-Wesley, 2012

Object oriented numerical analysis software

M. Daehlen and A. Tveito, Eds., *Numerical Methods and Software Tools in Industrial Mathematics*, Birkhauser, 1997.

E. Arge, A.M. Bruaset, H.P. Langtangen, Eds., *Modern Software for Scientific Computing*, Birkhauser, 1997.

Parallel processing

Peter Pacheco, Parallel Programming with MPI (1st edition), Morgan Kaufmann Publishers, 1997

A. Grama, G. Karypis, V. Kumar and A. Gupta, *Introduction to Parallel Computing* (2nd ed.), Benjamin/Cummings, 2003.

D. Kirk and W. Hwu, *Programming Massively Parallel Processors: A Hands-On Approach*, 3rd ed., Morgan Kaufmann, 2017.

"Introduction to Parallel Computing", https://computing.llnl.gov/tutorials/parallel_comp/

Presentations covering multiple high performance computing hardware and software topics

- 2018 Argonne Training Program on Extreme Scale Computing (ATPESC)
  https://extremecomputingtraining.anl.gov/agenda-2018/
  https://www.youtube.com/results?search_query=ATPESC+2018