Elmer
Open Source Finite Element Software for Multiphysical Problems

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ElmerTeam
CSC – IT Center for Science

Elmer/Ice advanced course
CSC, 4-6.11.2013
What is CSC?

- Founded in 1971 as a technical support unit for Univac 1108
- Connected Finland to the Internet in 1988
- Reorganized as a company, CSC – Scientific Computing Ltd. in 1993
- All shares to the Ministry of Education and Culture of Finland in 1997
- Operates on a non-profit principle
- Facilities in Espoo, close to Otaniemi campus and Kajaani
- Staff ~200
- Turnover 2009 21,9 million euros
- Currently official name is: ”CSC – IT Center for Science Ltd.”
The volume of data is growing exponentially. To exploit the data for, e.g., drug design, a global, constantly updating IT infrastructure is needed (programs, DBs).
Elmer finite element software for multiphysical and multiscale problems

Figures by Esko Järvinen, Mikko Lyly, Peter Råback, Timo Veijola (TKK) & Thomas Zwinger
Short history of Elmer

1995 Elmer development was started as part of a national CFD program
  – Collaboration of CSC, TKK, VTT, JyU, and Okmetic Ltd.

2000 After the initial phase the development driven by number of application projects
  – MEMS, Microfluidics, Acoustics, Crystal Growth, Hemodynamics, Glaciology, ...

2005 Elmer published under GPL-license

2007 Elmer version control put under sourceforge.net
  – Resulted to a rapid increase in the number of users

2010 Elmer became one of the central codes in PRACE project

2012 ElmerSolver library to be published under LGPL
  – More freedom for serious developers
Developers of Elmer

- **Current developers at CSC**
  - Core Elmer team: Mika Malinen, Juha Ruokolainen, Peter Råback, Thomas Zwinger
  - Accational developers: Mikko Byckling, Sampo Sillanpää, Sami Ilvonen

- **Other/past developers & contributors**
  - CSC: Mikko Lyly, Erik Edelmann, Jussi Heikonen, Esko Järvinen, Jari Järvinen, Antti Pursula, Ville Savolainen, ... 
  - VTT: Martti Verho
  - TKK: Jouni Malinen, Harri Hakula, Mika Juntunen
  - Trueflaw: Iikka Virkkunen
  - Open Innovation: Adam Powell
  - LGGE: Olivier Gagliardi, Fabien Gillet-Chaulet, ...
  - University of Uppsala: Jonas Thies
  - etc... (if your name is missing, please ask it to be added)
Elmer in numbers

- ~500 code commits yearly
- ~230 consistency tests in 4/2013
- ~350,000 lines of code (~2/3 in Fortran, 1/3 in C/C++)
- ~730 pages of documentation in LaTeX
- ~4 FTs used with about half in projects in 2012
- ~60 people participated on Elmer courses in 2013
- 9 Elmer related visits (1 week-2 months) to CSC in 2013
- ~2000 forum postings yearly
- ~20,000 downloads for Windows binary in 2013
- ~50% of CSC’s web page traffic
Elmer is published under (L)GPL

- Used worldwide by thousands of researchers (?)
- Perhaps the most popular open source multiphysical software targeted to end-users
- ~20,000 Windows binary downloads in a year
Elmer finite element software

- **Elmer** is actually a suite of several programs
- Some components may also be used independently
- **ElmerGUI** – Preprocessing
- **ElmerSolver** – FEM Solution
  - Each physical equation is a dynamically loaded library to the main program
- **ElmerPost** - Postprocessing
- **ElmerGrid** – structured meshing, mesh import & partitioning
ElmerGUI

- Graphical user interface of Elmer
  - Based on the Qt library (GPL)
  - Developed at CSC since 2/2008

- Mesh generation
  - Plugins for Tetgen, Netgen, and ElmerGrid
  - CAD interface based on OpenCascade

- Easiest tool for case specification
  - Even educational use
  - Parallel computation

- New solvers easily supported through GUI
  - XML based menu definition

- Also postprocessing with VTK
SERIAL WORKFLOW: VISUALIZATION
ElmerSolver

- Assembly and solution of the finite element equations
- Many auxiliary routines
- Good support for parallelism

Note: When we talk of Elmer we mainly mean ElmerSolver

> ElmerSolver StepFlow.sif
MAIN: ==========================================
MAIN:  E L M E R  S O L V E R  S T A R T I N G
MAIN:  Library version: 5.3.2
MAIN: ==========================================
MAIN:
MAIN: -----------------------
MAIN: Reading Model ... 
... 
SolveEquations: (NRM,RELC): ( 0.34864185 0.88621713E-06 ) :: navier-stokes
: *** Elmer Solver: ALL DONE ***
SOLVER TOTAL TIME(CPU,REAL): 1.54 1.58
ELMER SOLVER FINISHED AT: 2007/10/31 13:36:30
ElmerPost

- Has roots in the FUNCS program
  - written in late 80’s and early 90’s by Juha Ruokolainen

- All basic presentation types
  - Colored surfaces and meshes
  - Contours, isosurfaces, vectors, particles
  - Animations

- Includes MATC language
  - Data manipulation
  - Derived quantities

- Output formats
  - ps, ppm, jpg, mpg
  - animations
ElmerGrid

Creation of 2D and 3D structured meshes
- Rectangular basic topology
- Extrusion, rotation
- Simple mapping algorithms

Mesh Import
- About ten different formats:
  Ansys, Abaqus, Fidap, Comsol, Gmsh,...

Mesh manipulation
- Increase/decrease order
- Scale, rotate, translate

Partitioning
- Simple geometry based partitioning
- Metis partitioning
  Example: `ElmerGrid 1 2 step -metis 10`

Usable via ElmerGUI
- All features not accessible (partitioning, discont. BC,...)
Core features of ElmerSolver

**Physical Models**
- Fluid mechanics
- Structural mechanics
- Electromagnetics
- Acoustics
- Heat transfer
- Mass transport
- Free surface problems
- Particle tracking
- Quantum mechanics
- ...

**Numerical Methods**
- Time dependency: steady, transient, harmonic, eigenmode
- Large selection of element types (nodal, edge, face, p-elements)
- Several stabilization methods
- Large selection of direct, iterative and multigrid linear solvers
- Fully supported parallellism
Elmer technical highlights

- A unique modular structure that enables versatility in multiphysics even for end-user
- High level of abstraction – physics neutral library
- MPI parallelism inherently built-in
- Early adaptor in advanced features
  - Iterative methods ~1997
  - GMG & mesh multiplication ~2003
  - Adaptivity ~2004
  - Block preconditioning 2010
  - FETI ~2011
  - Ported on Intel MICs 2012
  - Mortar finite elements for rotating problems 2013
  - ...
Poll on application fields (status 10/2013)

What are your main application fields of Elmer?

You may select up to 5 options

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<th>Votes</th>
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<td>Quantum mechanics</td>
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</tr>
<tr>
<td>Something else (please specify)</td>
<td>12</td>
<td>5%</td>
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Total votes: 221

Submit vote
Microfluidics: Flow and heat transfer in a microchip

- Electrokinetically driven flow
- Joule heating
- Heat Transfer influences performance
- Elmer as a tool for prototyping
- Complex geometry
- Complex simulation setup

MEMS: Inertial sensor

- MEMS provides an ideal field for multi-physical simulation software
- Electrostatics, elasticity and fluid flow are often inherently coupled
- Example shows the effect of holes in the motion of an accelerometer prototype

VMS turbulence modeling

- Large eddy simulation (LES) provides the most accurate presentation of turbulence without the cost of DNS.
- Requires transient simulation where physical quantities are averaged over a period of time.
- Variational multiscale method (VMS) by Hughes et al. is a variant of LES particularly suitable for FEM.
- Interaction between fine (unresolved) and coarse (resolved) scales is estimated numerically.
- No ad hoc parameters.

Plane flow with $\text{Re}_\tau=395$
Most crystalline silicon is grown by the Czochralski (CZ) method. One of the key applications when Elmer development was started in 1995.

CZ-growth: Transient simulation

Parallel simulation of silicon meltflows using stabilized finite element method (5.4 million elements).

Simulation Juha Ruokolainen, animation Matti Gröhn, CSC
Thermal creep in light mills

- Glass container in a very low pressure < 10 Pa
- Each ving has a black and silver side
- When hit by light the light mill rotates with silver side ahead
- The physical explanation of the light mills requires consideration of rarefied gases and thermal creep
- These were studied in the thesis project of Moritz Nadler, University of Tubingen, 2008
Thermal creep in light mills

2D compressible Navier-Stokes eq. with heat eq. plus two rarefied gas effects:

- Maxwell’s wall slip and thermal transpiration

\[ u_x(\Gamma) = \frac{2 - \sigma}{\sigma} \lambda \left( \frac{\partial u_x}{\partial n} + \frac{\partial u_n}{\partial x} \right) + \frac{3\mu}{4\rho T} \frac{\partial T}{\partial x} \]

- Smoluchowski’s temperature jump

\[ T_G - T_W = \frac{2 - \sigma_T}{\sigma_T} \frac{2\gamma}{\gamma + 1} \frac{\lambda}{Pr} \frac{\partial T}{\partial n} \]

Simulation Moritz Nadler, 2008
Cardiovascular diseases are the leading cause of deaths in western countries.

Calcification reduces elasticity of arteries.

Modeling of blood flow poses a challenging case of fluid-structure-interaction.

Artificial compressibility is used to enhance the convergence of FSI coupling.

Simulation of electrical machines

New developments in edge element basis and rotating boundary conditions enable simulation of electrical machines

Magnetic field strength (left) and electric potential (right) of an electrical engine end-windings. Meshing M. Lyly, ABB. Simulation J. Ruokolainen, CSC, 2013.

Iter fusion reactor

- Assumption that 2D dependencies are valid also on a perturbed 3D system
- 3D magnetic fields but no real plasma simulation

Simulation Peter Råback, CSC, 2013
Particle tracker - Granular flow

Simulation Peter Råback, CSC, 2011.
Elmer – Infrastructure for Open Research

Elmer As Infrastructure

Elmer Courses

Elmer Library

HPC

User/Developer/Customer

Company B

Institute C

University D

User/Developer/Customer

Company B

Institute C

University D

GPL modules

propriety modules

Elmer As Infrastructure

Elmer Courses

Elmer Support

Elmer Library

HPC
Most important Elmer resources

- http://www.csc.fi/elmer
  - Official Homepage of Elmer
- http://sourceforge.net/projects/elmerfem/
  - Version control system & Windows binaries
- www.elmerfem.org
  - Discussion forum, wiki & doxygen

Further information: elmeradm@csc.fi

Thank you for your attention!