Elmer FEM Webinar Series

CSC, Espoo, Finland
via Zoom
Thursdays
15 EET, 14 CET, 8 ET, 22 JST
Spring 2021

Practical guidelines for the webinar

- For questions that you want answered use the Q&A
  - o Will be addressed at the end of the presentation

- Chat may be used for general discussion
  - o You may write about your application area, geographic location etc.

- The presentation slides will be made available at
  - o https://www.nic.funet.fi/pub/sci/physics/elmer/webinar/

- This webinar will be recorded and will for most parts be available later on youtube

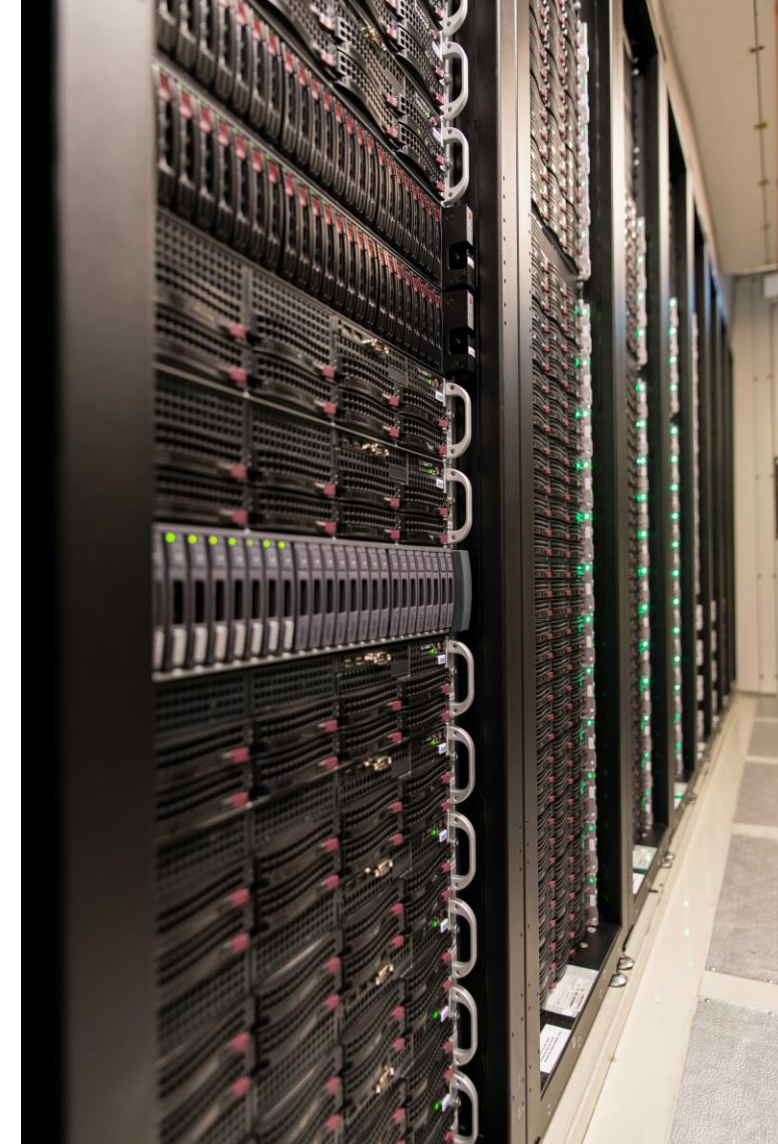# Elmer FEM webinar series - program

- 11.3. Peter Råback & Thomas Zwinger: *Introduction to Elmer & How to teach yourself Elmer*

- 18.3. Peter Råback & Jonathan Velasco*: Overview of capabilities of Elmer - where to go from here?*

- 25.3. Peter Råback & Thomas Zwinger: *Parallel Computing with Elmer*

- 1.4. Juris Vencels: *Elmer-OpenFOAM library*

- 8.4. Eelis Takala & Frederic Trillaud: *Electrical circuits with Elmer with applications*

- 15.4. Mika Malinen: *Solvers for solid mechanics - Recent progress*

- 22.4. Minhaj Zaheer:
  Induction Machine Open-source FEA Computations comparison with Measurement and Commercial FEA

- 29.4. Arved Enders-Seidlitz: *pyelmer - Python interface for Elmer workflow*

- 13.5. Roman Szewczyk, Anna Ostaszewska-Liżewska, Dominika Kopala & Jakub Szałatkiewicz:
  Industrial applications oriented, microwave modelling in Elmer

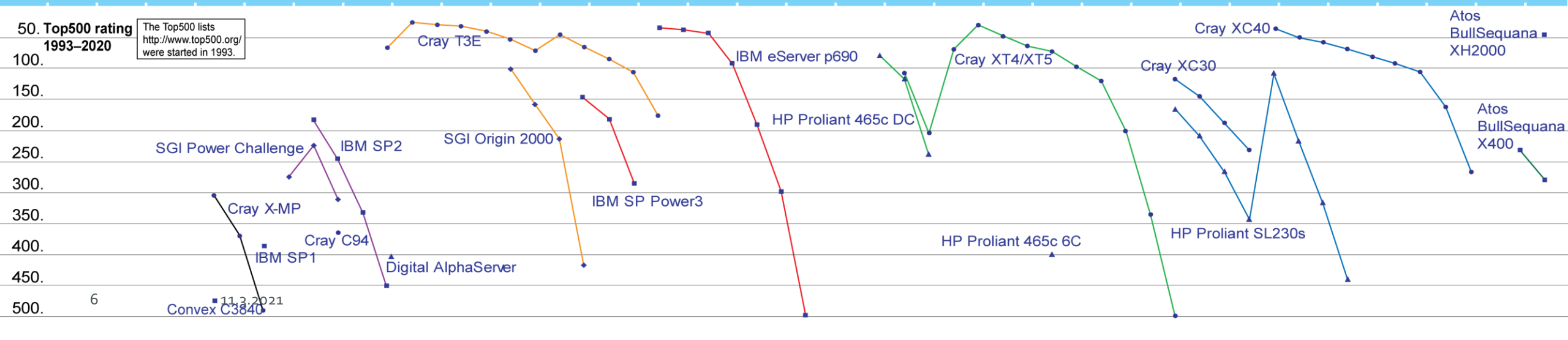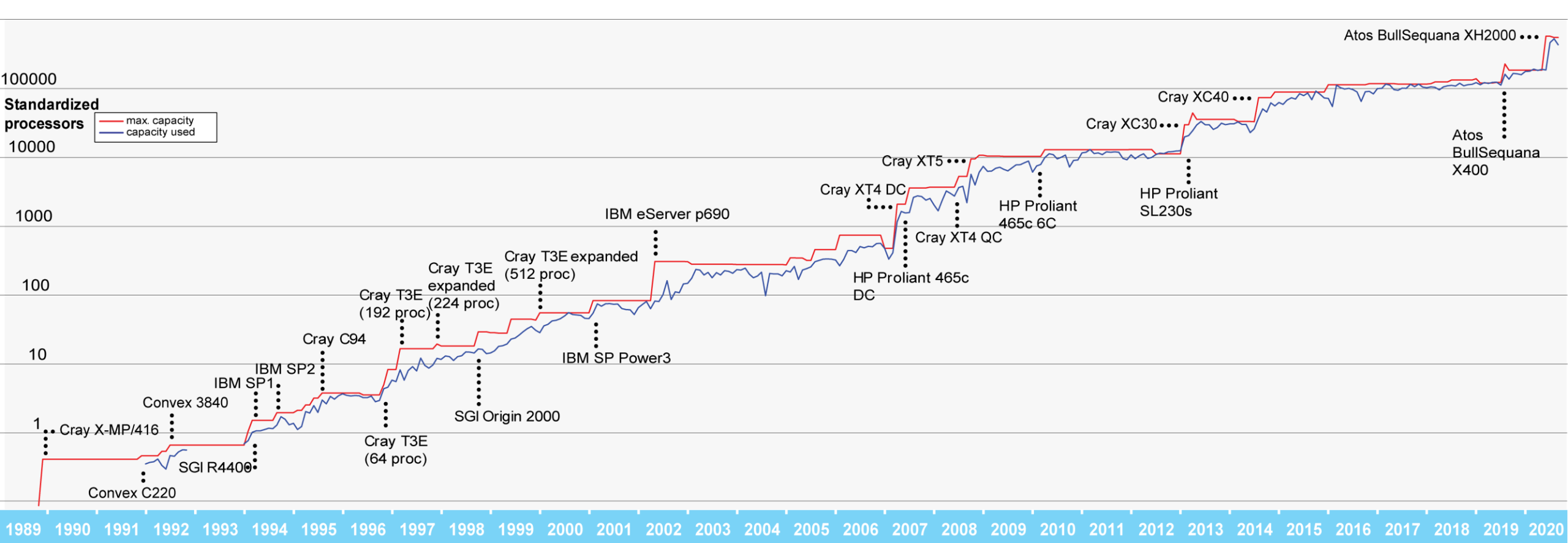- Additional slots available: contact organizers if you're interested!

Outline for today

- Short introduction to Elmer (Peter)
  - Metalevel overview, more details next week…

- Running Elmer on different platforms (Thomas)
  - Linux, Windows, Docker,…
  - Pointers to material

- How to teach yourself Elmer (Peter)
  - Strategies for GUI and CL persons
  - Pointers to material

- Q&A

11.3.2021

CSC – IT Center for Science: http://www.csc.fi

- Non-profit company owned by Finnish ministry of education & the Finnish universities

- Provides information technology and solutions in different areas of expertise
  - Services mainly provided for Finnish academia

- Running the largest computers in Finland already since the 1970's
  - Currently hosting supercomputers Puhti and Mahti (=210,000 cores)
  - Will also host EuroHPC pre-exascale system LUMI

- Elmer was initiated as a finite element code to utilize the power of parallel computing

Standardized processors

— max. capacity
— capacity used

100000

10000

1000

100

10

1

Cray X-MP/416
Convex C220
Convex 3840
SGI R4400
IBM SP1
IBM SP2
Cray C94
Cray T3E (64 proc)
Cray T3E (192 proc)
Cray T3E expanded (224 proc)
Cray T3E expanded (512 proc)
SGI Origin 2000
IBM SP Power3
IBM eServer p690
HP Proliant 465c DC
Cray XT4 DC
Cray XT4 QC
Cray XT5 •••
HP Proliant 465c 6C
HP Proliant SL230s
Cray XC30 •••
Cray XC40 •••
Atos BullSequana X400
Atos BullSequana XH2000 •••

1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020

50. Top500 rating
1993–2020

The Top500 lists http://www.top500.org/ were started in 1993.

100.
150.
200.
250.
300.
350.
400.
450.
500.

Cray T3E
SGI Power Challenge
IBM SP2
SGI Origin 2000
IBM SP Power3
IBM eServer p690
HP Proliant 465c DC
Cray XT4/XT5
Cray XC40
Cray XC30
HP Proliant 465c 6C
HP Proliant SL230s
Atos BullSequana XH2000
Atos BullSequana X400
Cray X-MP
Cray C94
IBM SP1
Digital AlphaServer
Convex C3840

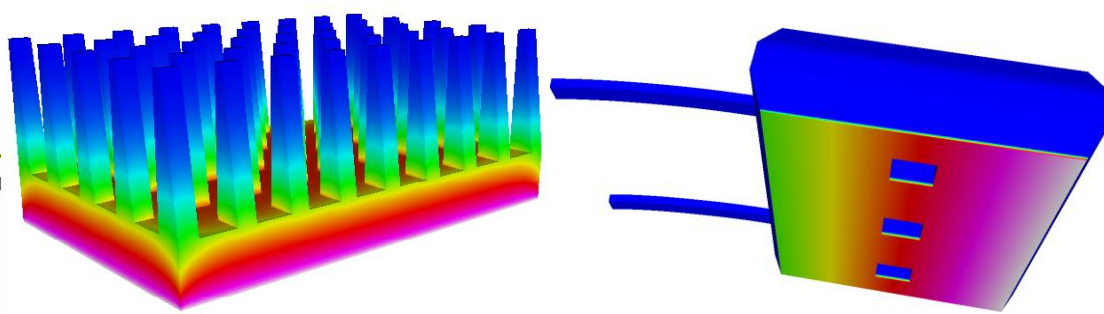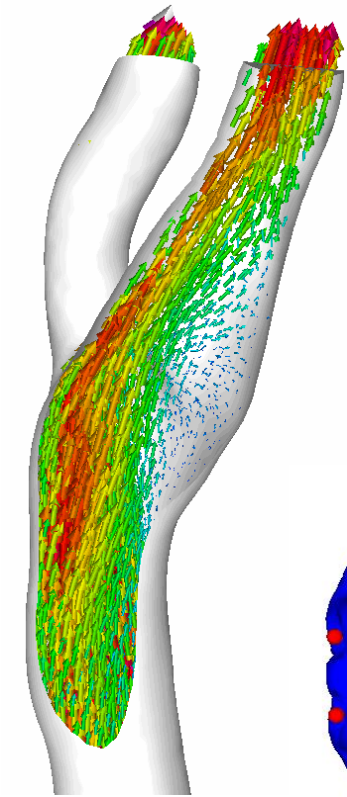# Introduction to Elmer

ElmerTeam

CSC – IT Center for Science, Finland

Elmer FEM webinar

2021

Elmer finite element software for multiphysical problems
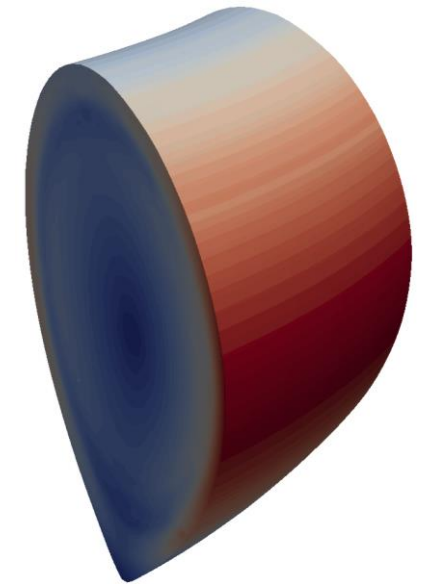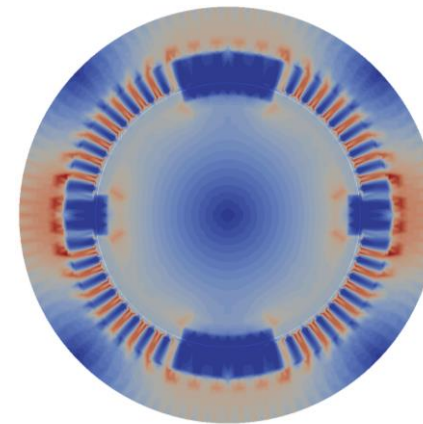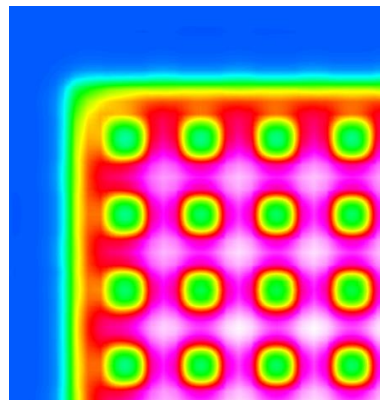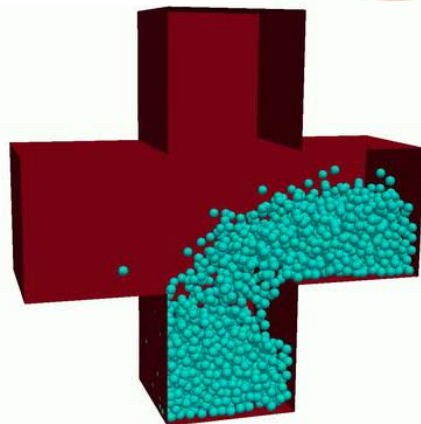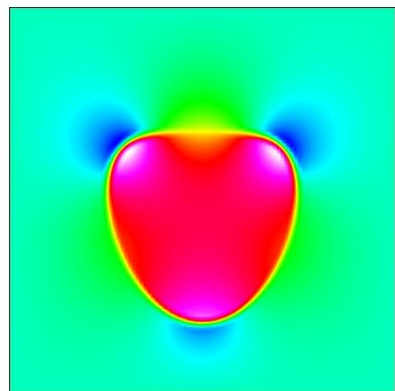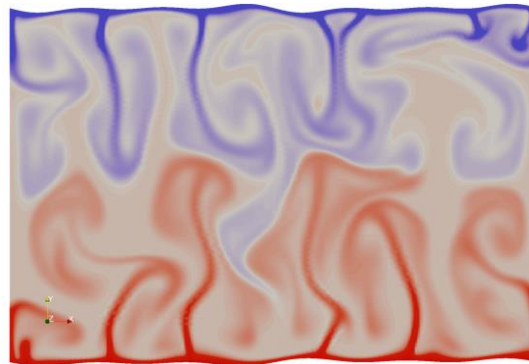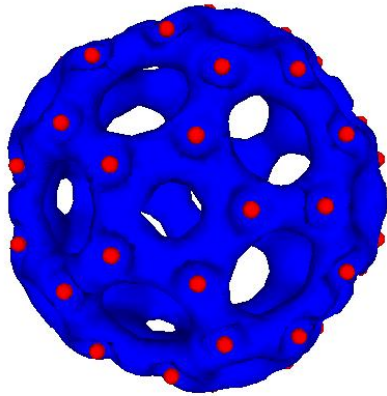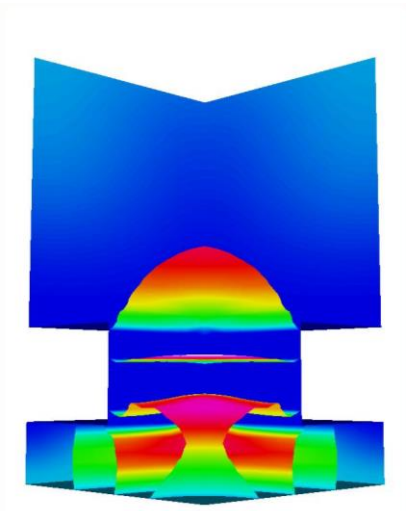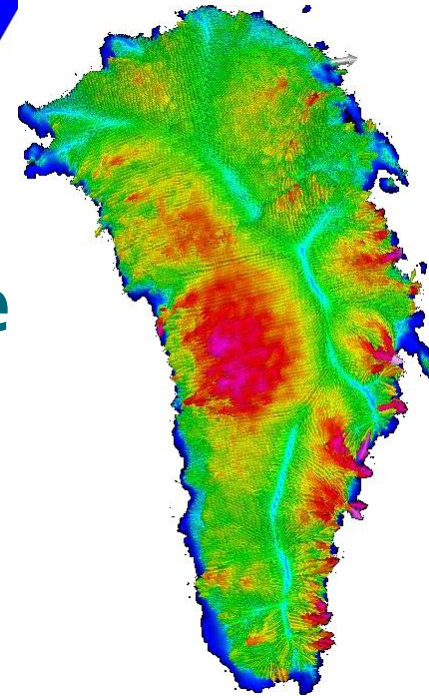
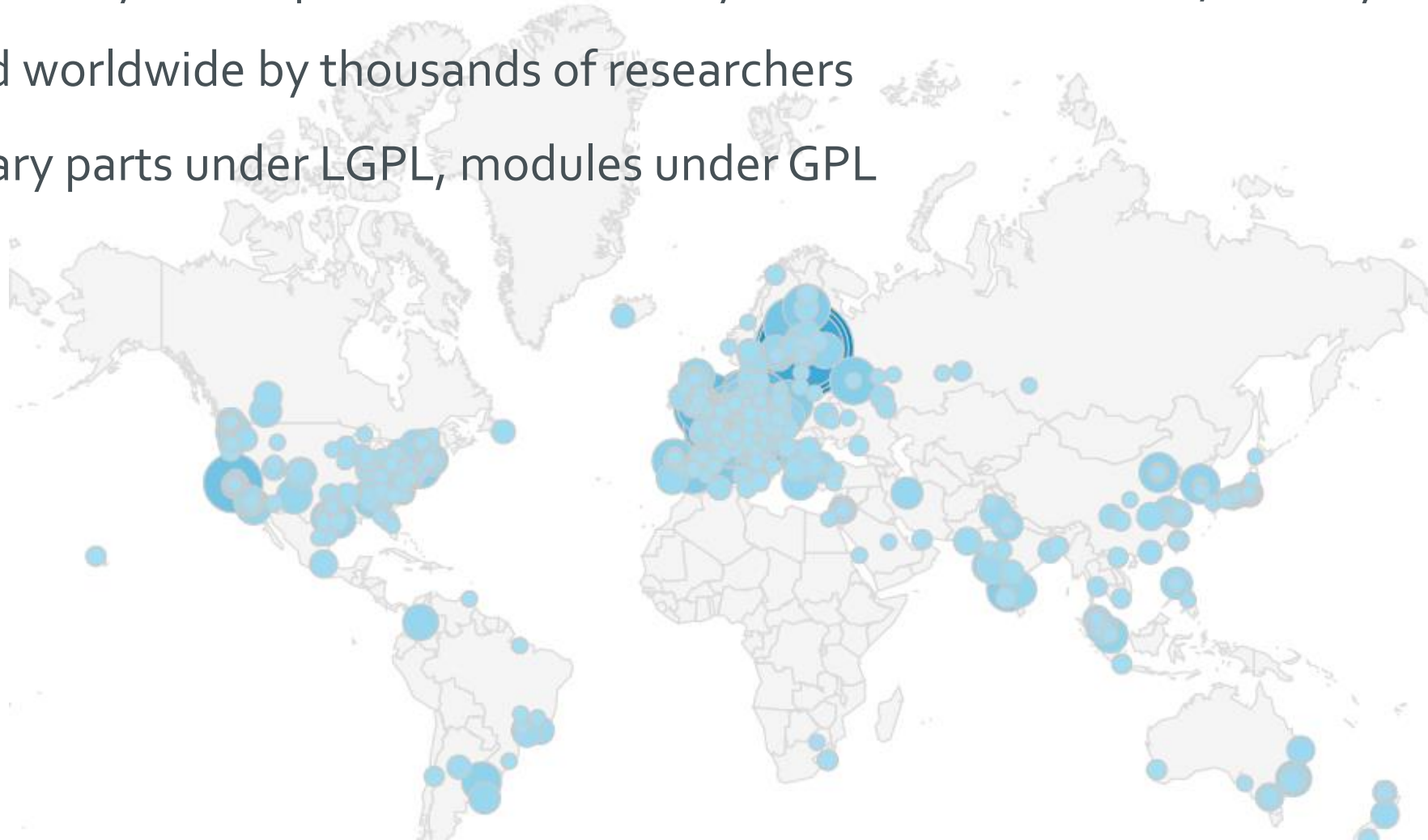Figures by Esko Järvinen, Mikko Lyly, Peter Råback, Timo Veijola (TKK) & Thomas Zwinger

Short history of Elmer

- Project initiated as a national project 1995
  - FreeFEM++ 87, OpenFOAM 89, Code Aster 90, Netgen 94, Gmsh 97, Fenics 03,…
  - CFD toolbox: Emphasis on crystal growth and pulp manufacturing
  - Strategic choice: MPI + Fortran90

- Initially Elmer included all pieces
  - Now obsolite: Original pre- and postprocessors (ElmerFront & ElmerPost)

- Initial project followed by large number of application projects
  - Strengths and weaknesses of the software reflects these projects

- First international colloboration on computational glaciology in 2001
  - Resulted eventually to a large Elmer/Ice community

- Release under open source on sf.net in 2008
  - More international project portfolio
  - Included in many EU projects over the years

Current status of Elmer

- Still mainly developed at CSC but many external contributors, thank you!

- Used worldwide by thousands of researchers

- Library parts under LGPL, modules under GPL

Elmer is hosted at GitHub and accepts contributions

Elmer in numbers

Software

- ~440,000 lines of active code
  - ~3/4 in Fortran, 1/4 in C/C++

- ~700 consistency tests

- ~800 pages of documentation

- ~1000 code commits yearly

Community

- ~20,000 downloads for Windows binary yearly
  - Linux users untracked

- ~2000 forum postings yearly

- ~100 people participate on Elmer courses yearly

- Several Elmer related scientific visits to CSC yearly

Not This Year!

Elmer finite element software

- **Elmer** is actually a suite of several programs
  - Components may also be used independently

- **ElmerGUI** – Preprocessing

- **ElmerSolver** – FEM Solution
  - Each physical equation is a **dynamically loaded** library to the main program

- **ElmerGrid** - structured meshing, mesh import & partitioning
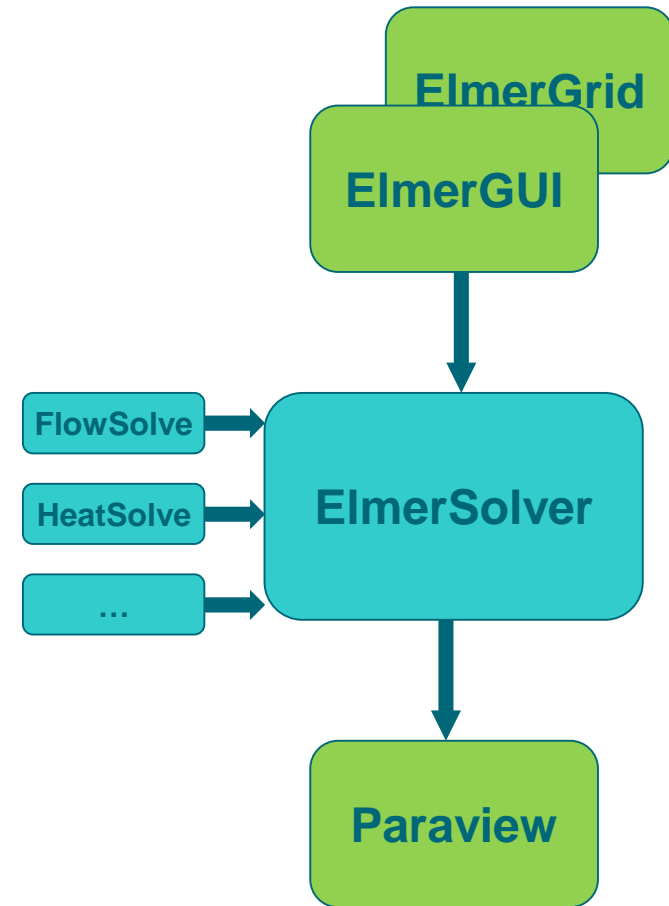
ElmerGUI

- Graphical user interface of Elmer
  - Based on the **Qt** library (GPL)
  - Developed at CSC since 2008
  - Facelift by Saeki Takayuki in 2020!

- 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
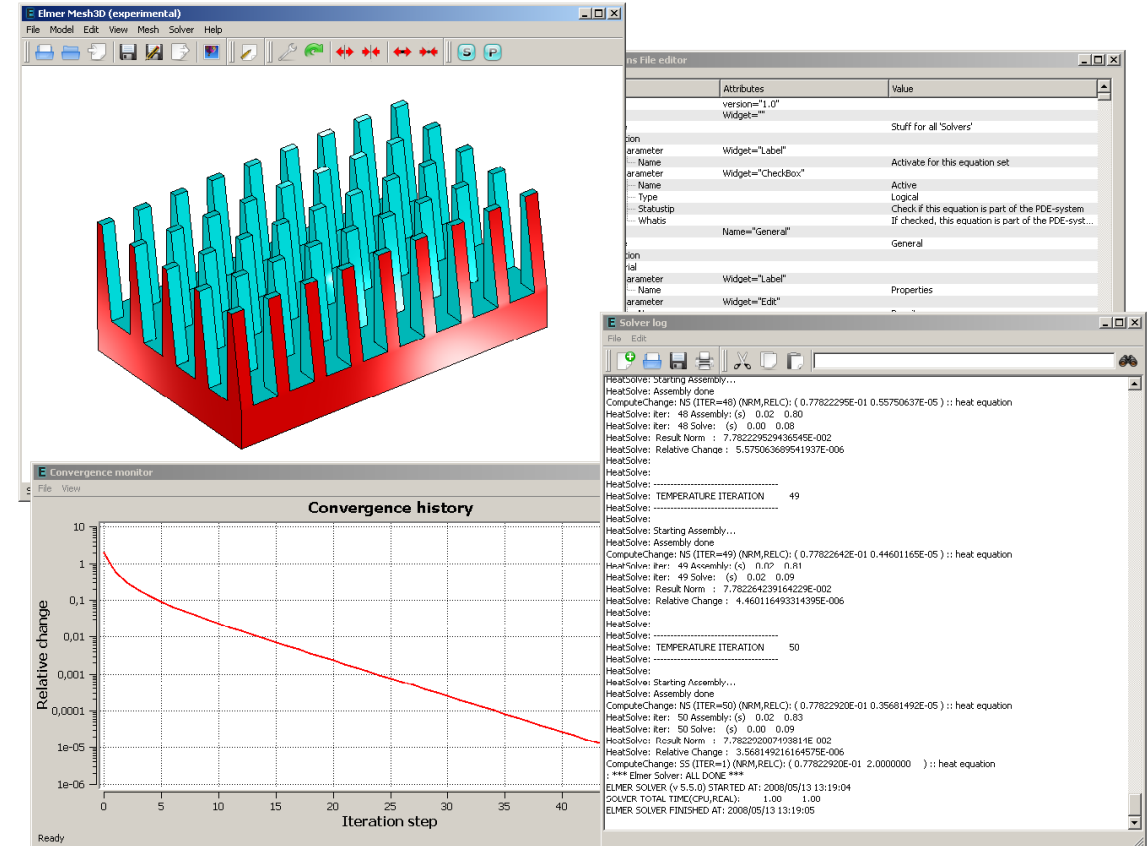
ElmerSolver

- Assembly and solution of the finite element equations and beyond

- Large number of auxiliary routines

- Note: When we talk of Elmer we mainly mean ElmerSolver

- ~95% of development effort

```
ELMER SOLVER (v 8.3) STARTED AT: 2017/06/19 18:35:01
ParCommInit:  Initialize #PEs:           1
MAIN: =========================================================
MAIN: ElmerSolver finite element software, Welcome!
MAIN: This program is free software licensed under (L)GPL
MAIN: Copyright 1st April 1995 - , CSC - IT Center for Science Ltd.
MAIN: Webpage http://www.csc.fi/elmer, Email elmeradm@csc.fi
MAIN: Version: 8.3 (Rev: 8068c86, Compiled: 2017-06-18)
MAIN:  HYPRE library linked in.
MAIN:  MUMPS library linked in.
MAIN: =========================================================
MAIN: Reading Model: flux.sif
LoadMesh: Base mesh name: ./angle
MAIN: --------------------------------------
Loading user function library: [HeatSolve]...[HeatSolver]
HeatSolve: --------------------------------------
HeatSolve:   TEMPERATURE ITERATION         1
HeatSolve: --------------------------------------
HeatSolve: Assembly:
DefUtils::DefaultDirichletBCs: Setting Dirichlet boundary conditions
ComputeChange: NS (ITER=1) (NRM,RELC): ( 0.25941344E-01  2.0000000    ) :: heat equation
CompareToReferenceSolution: Solver 1 PASSED:  Norm = 2.59413436E-02  RefNorm = 2.5941343
CompareToReferenceSolution: Relative Error to reference norm: 1.512027E-09
CompareToReferenceSolution: PASSED all 1 tests!
ElmerSolver: *** Elmer Solver: ALL DONE ***
ElmerSolver: The end
SOLVER TOTAL TIME(CPU,REAL):        0.10       0.15
ELMER SOLVER FINISHED AT: 2017/06/20 01:35:01
```

ElmerGrid (standalone + built-in ElmerGUI)

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

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

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

- Partitioning
  - Simple geometric (upper figure)
  - Metis library (lower figure)
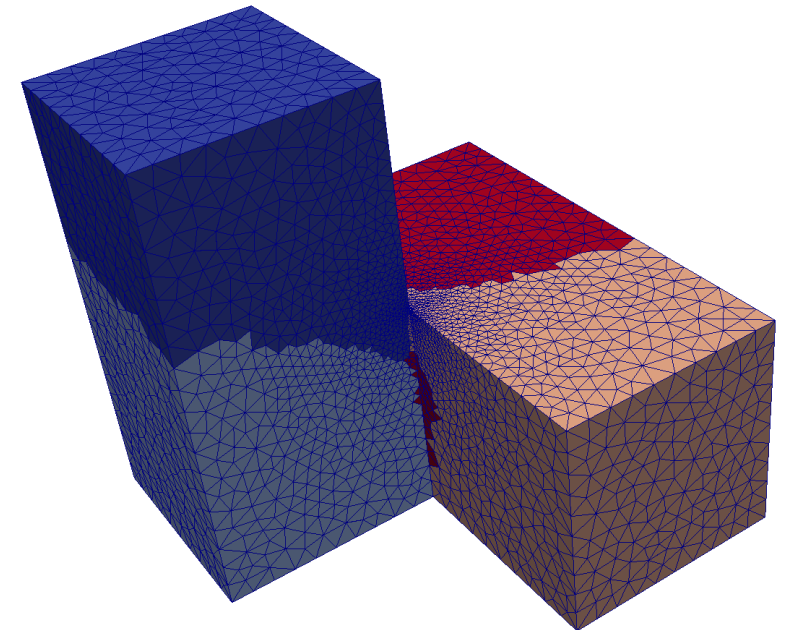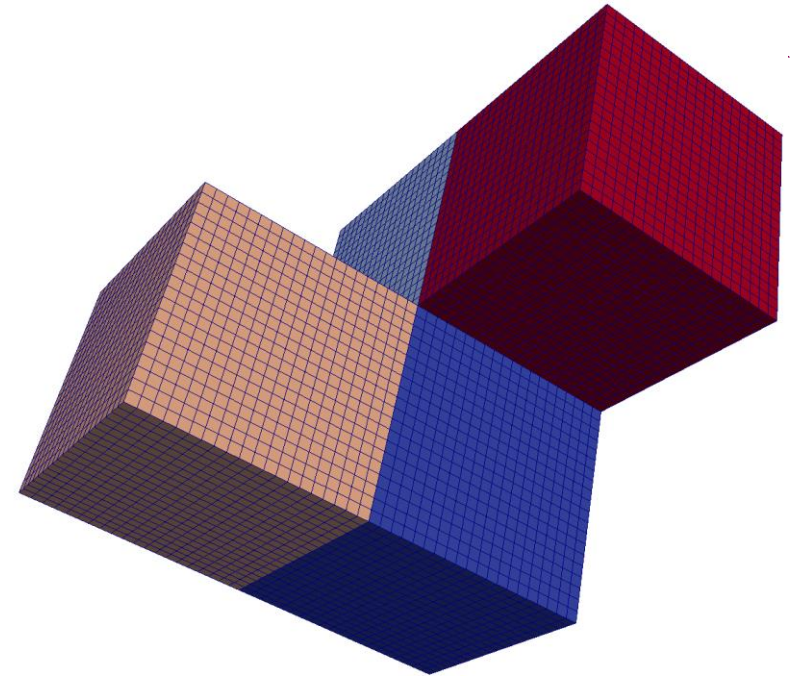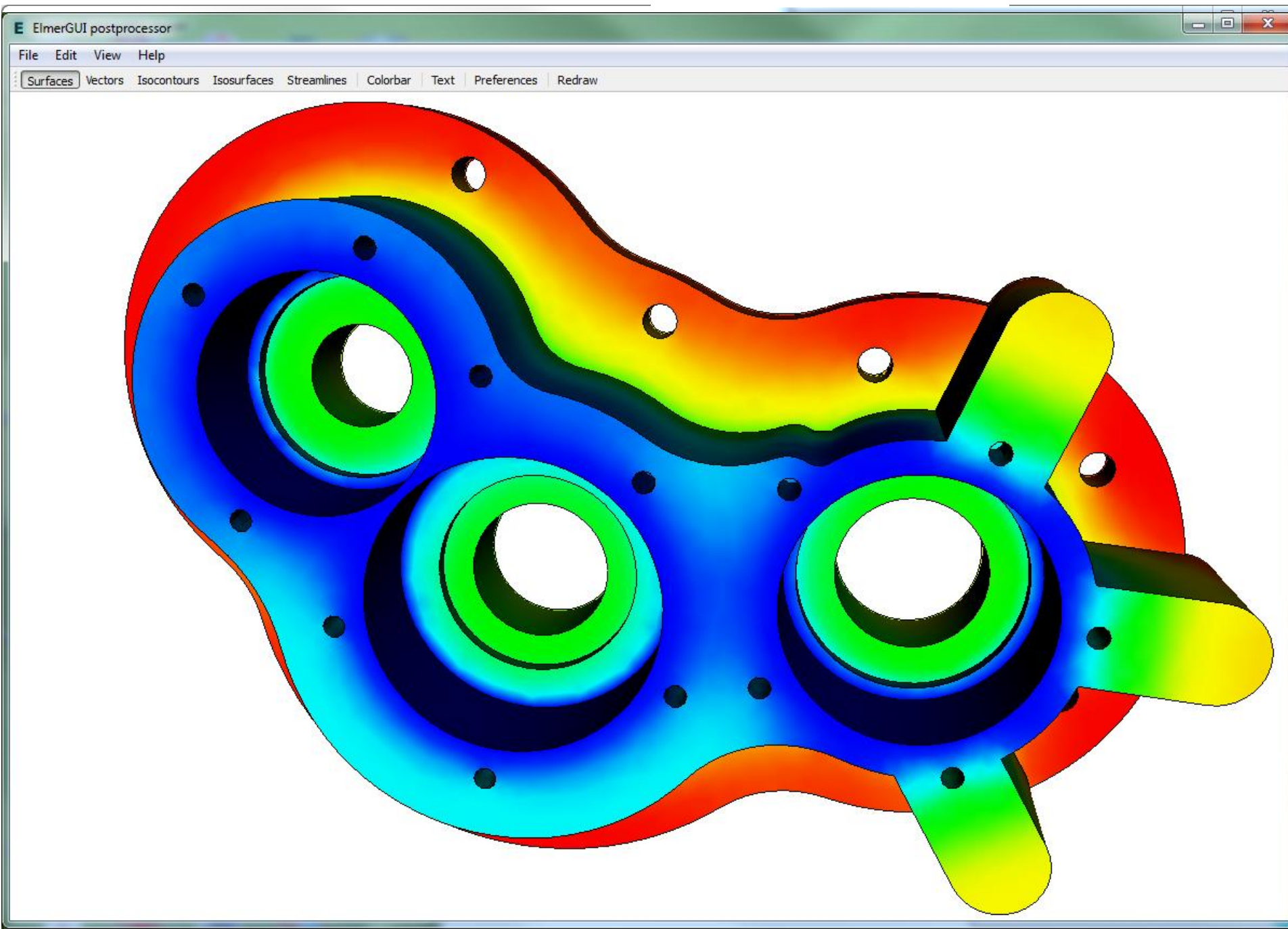
$$\Omega = \bigcup \Omega_e$$

$$-\nabla \cdot \kappa \nabla T = h \ \text{ in } \Omega$$

$$T = T_0 \ \text{ at } \Gamma$$

$$A_{ij} + = \int \kappa \nabla \varphi_i \cdot \nabla \varphi_j \, d\Omega_e$$

$$b_i + = \int h \varphi_i \, d\Omega_e$$

$$x = A^{-1} b$$

Some core features of ElmerSolver

Physical Models

- Fluid mechanics

- Structural mechanics

- Electromagnetics

- Acoustics

- Heat transfer

- Species transport

- Free surface problems

- Particle tracking & transport

- …

= ~50 physical models as DLLs

Numerical Methods

- Time dependency: steady, transient, harmonic, eigenmode

- Large selection of element types (nodal, Hcurl, Hdiv, p-elements)

- Several stabilization methods

- Large selection of direct, iterative and multigrid linear solvers

- Mortar finite elements for nonconforming meshes

- Extensive support of parallel algorithms

- ---

Quadrilateral

Triangle
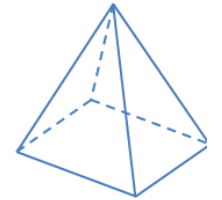
Pyramid
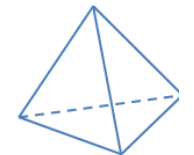
Tetrahedron
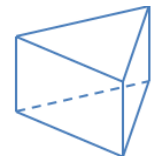
Prism with triangular base
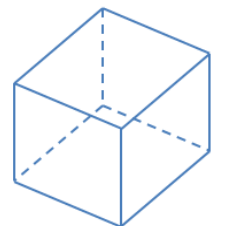
Hexahedron

Elmer is part of the open source ecosystem
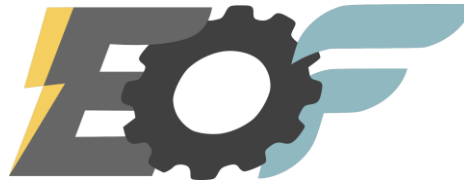
- Elmer utilizes many libraries and software and vice versa
- Developers **of EOF library** and **pyelmer** will present their work in the Webinar series!

Poll on application fields (status 2/2021)

What are your main application fields of Elmer?

Field	Votes	Percent
Heat transfer	78	28%
Fluid mechanics	72	26%
Solid mechanics	57	20%
Electromagnetics	53	19%
Quantum mechanics	5	2%
Something else (please specify)	16	6%
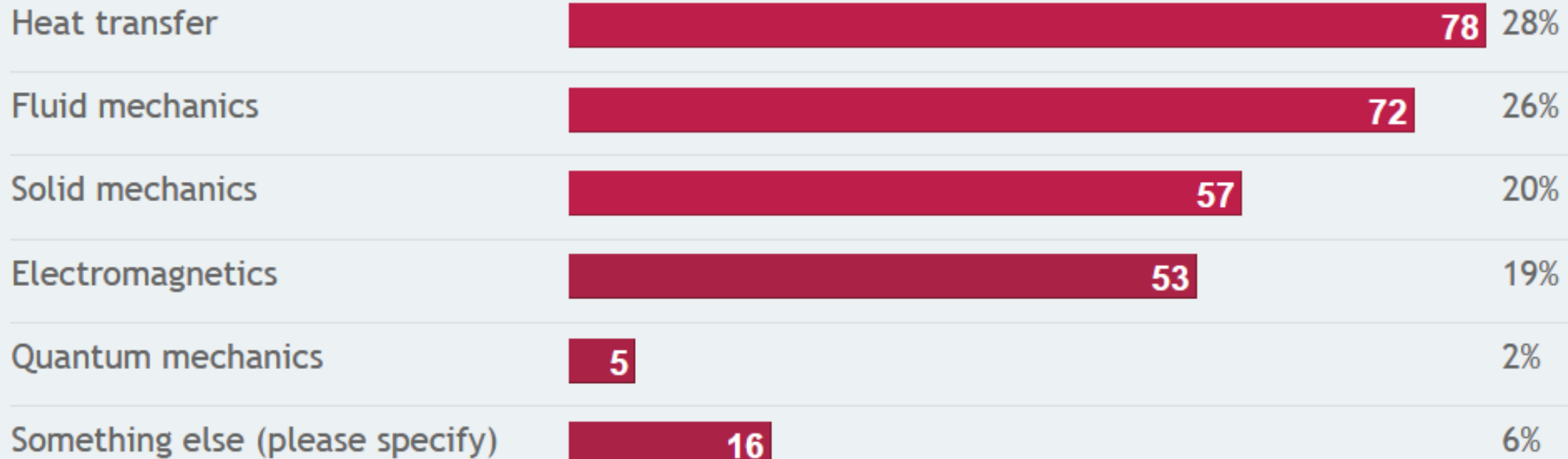
Total votes: 281

Elmer for Crystal Growth

- The main application when Elmer development was started

- Focused on the Czhockralski (CZ) growt of silicon crystals

- Multiphysics problem: Heat transfer, radiation, fluid flow, transport phenomena,…
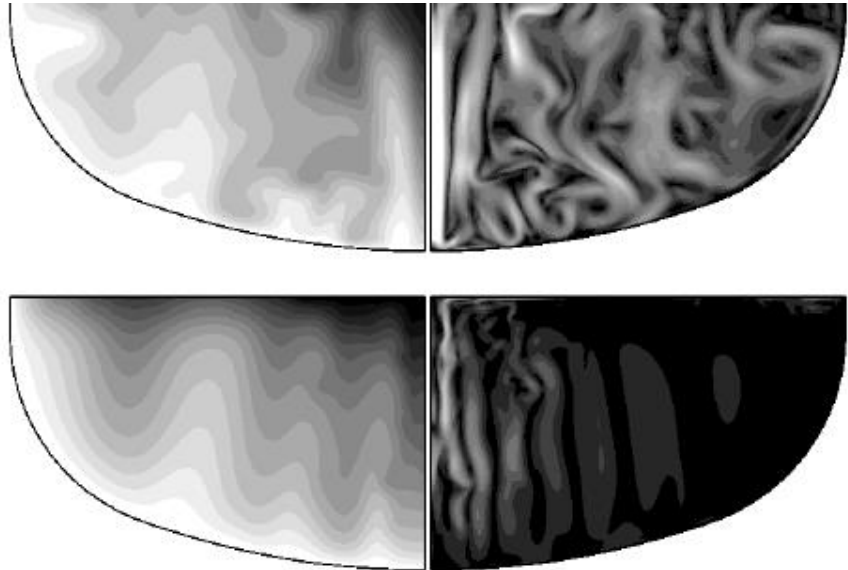
V. Savolainen et al., *Simulation of large-scale silicon melt flow in magnetic Czochralski growth,* **J. Crystal Growth 243 (2002), 243-260.**

Seed

Single Silicon Crystal

Quartz Crucible

Water Cooled Chamber

Heat Shield

Carbon Heater

Graphite Crucible

Crucible Support

Spill Tray

Electrode

Figure by Jari Järvinen
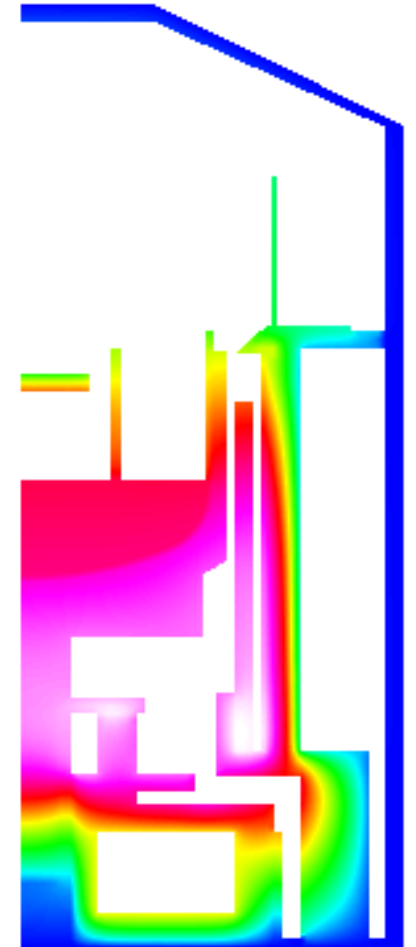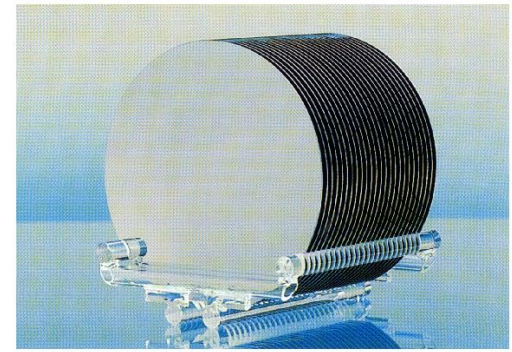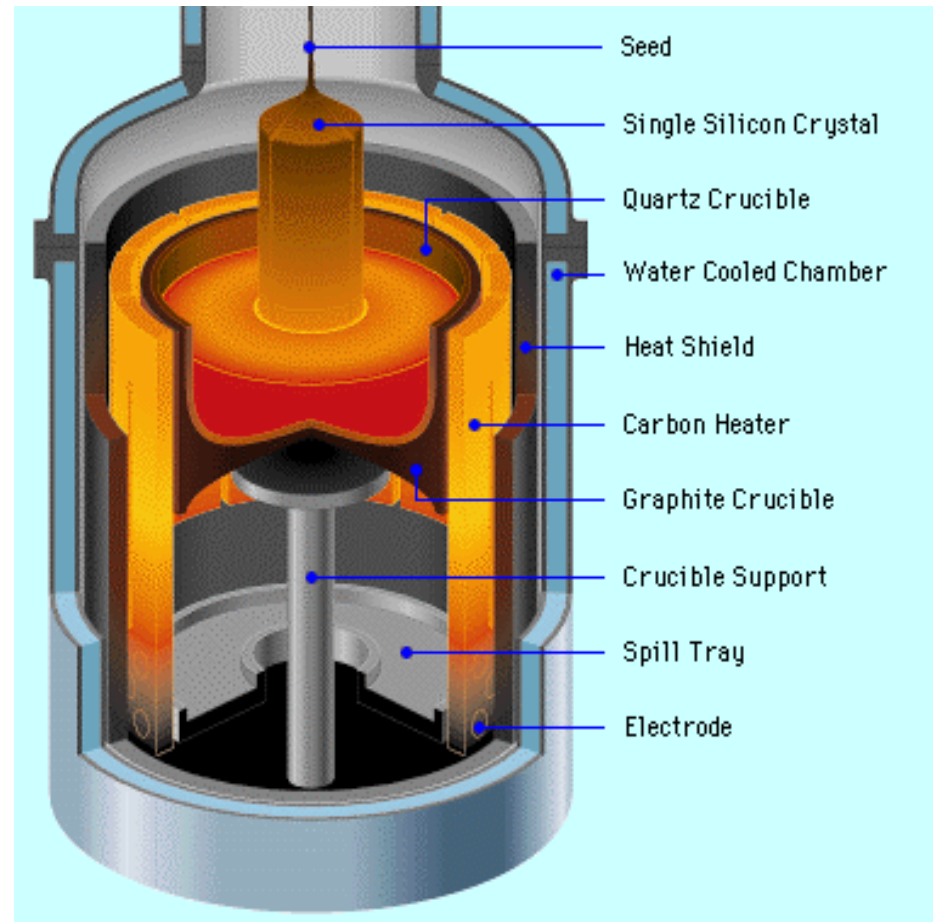
Elmer for Micro-electro-mechanical systems, MEMS

- MEMS provides an ideal field for multi-physical simulation software

- Electrostatics, elasticity and fluid flow are often inherently coupled

- Accelerometers and microphone studied
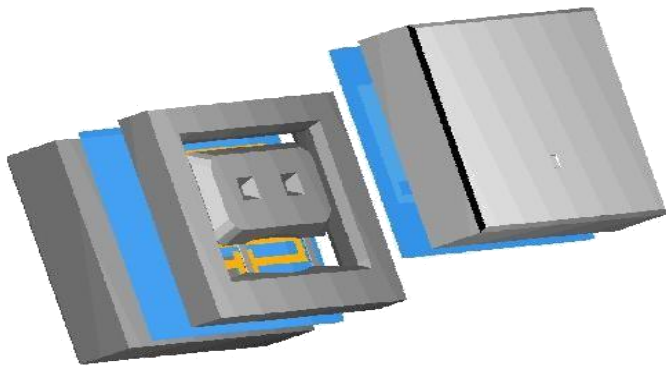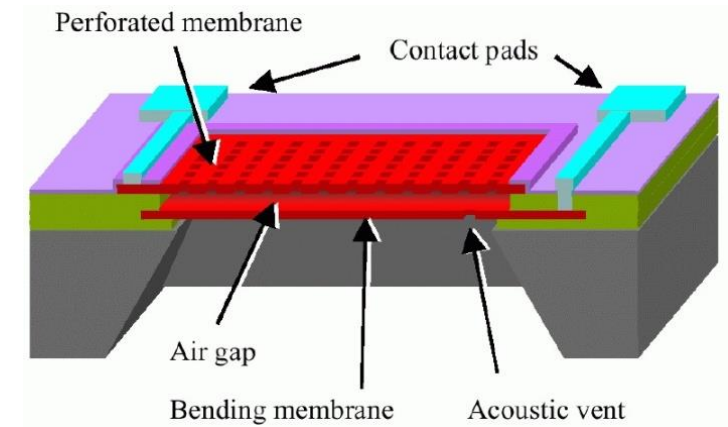
Figure by VTI Technologies
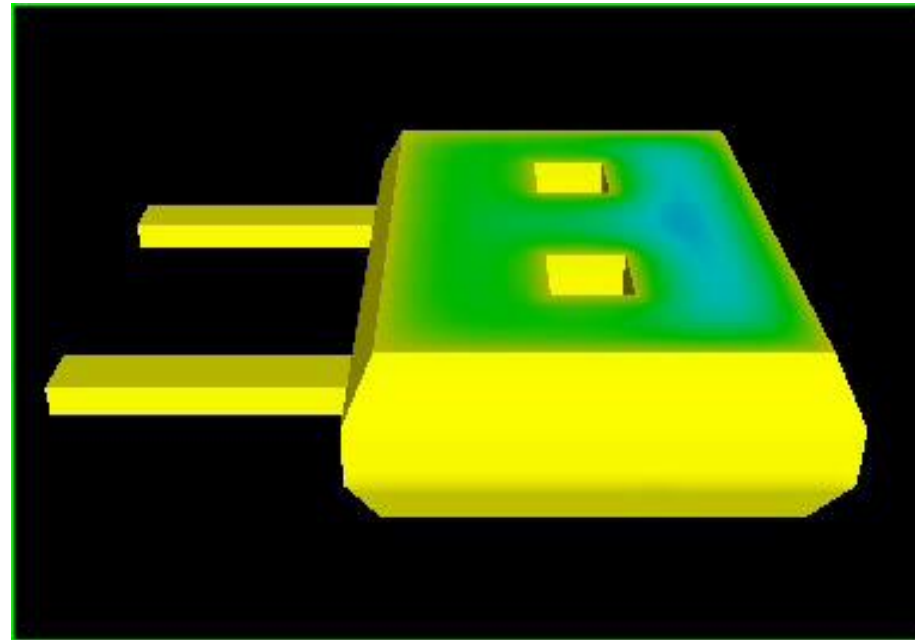
SImulations by Peter Råback
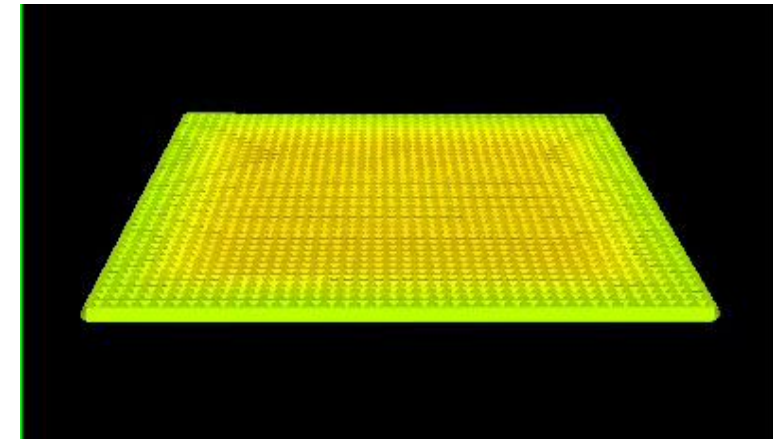
Elmer in Acoustics

- Elmer used in the research and design of mobile phones for Nokia

- Several new models saw the daylight
  - Helmholtz equation
  - linearized time-harmonic Navier-Stokes
  - Large amplitude thermal Navier-Stokes
  - Vibroacoustics
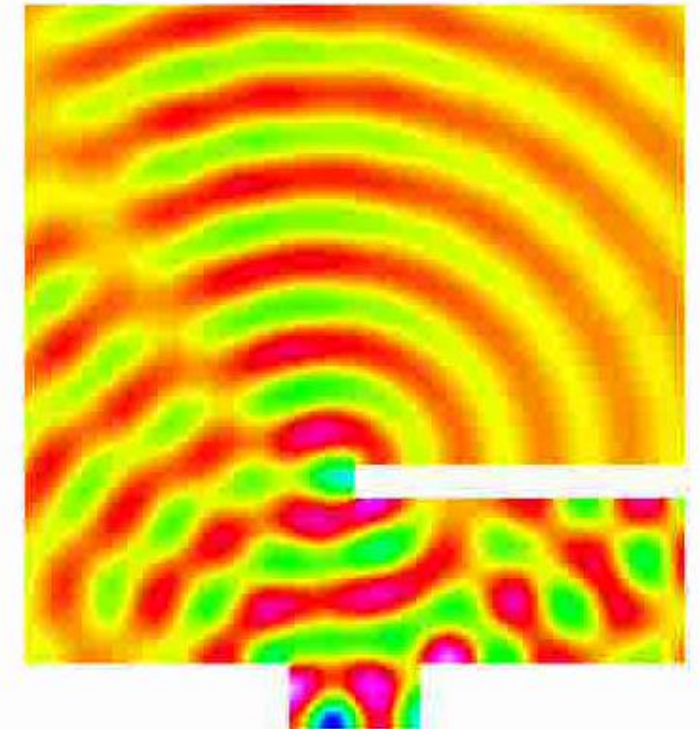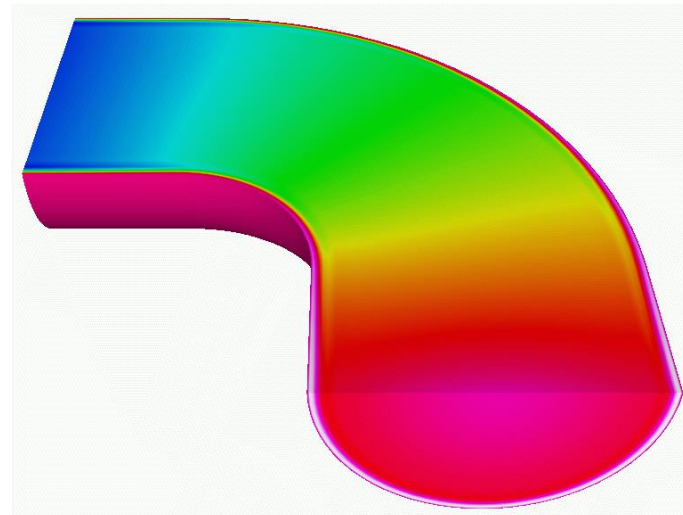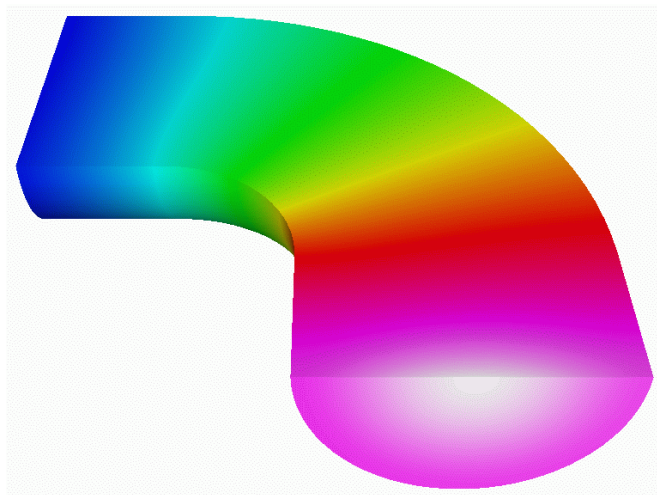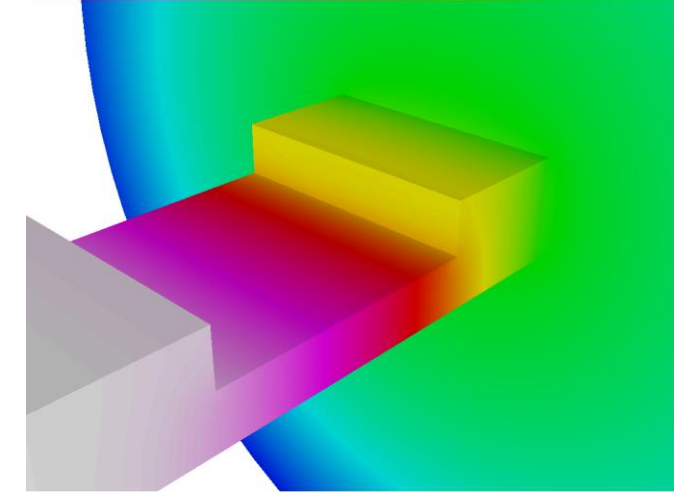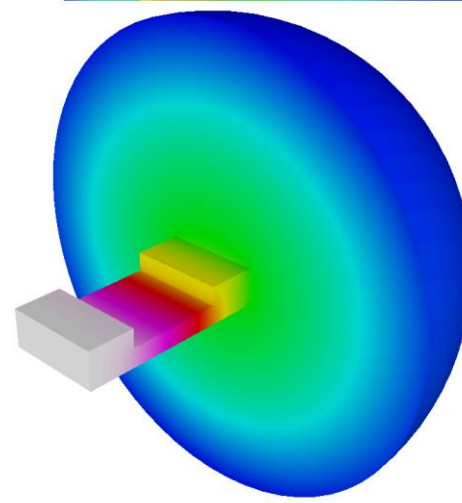
Elmer for glaciology: Elmer/ICE

- **Elmer/Ice** is a leading software used in 3D computational glaciology

- Full 3D Stokes equation to model the flow

- Large number of tailored models to deal with the special problems

- Motivated by climate change and sea level rise

- Currently ~100 peer-reviewed publications in the area

- Dedicated community portal `elmerice.elmerfem.org`

F. Gillet-Chaulet et al., 2012. Greenland ice sheet contribution to sea-level rise from a new-generation ice-sheet model, The Cryosphere, 6, 1561-1576.

Elmer for fluid-stucture interaction, FSI
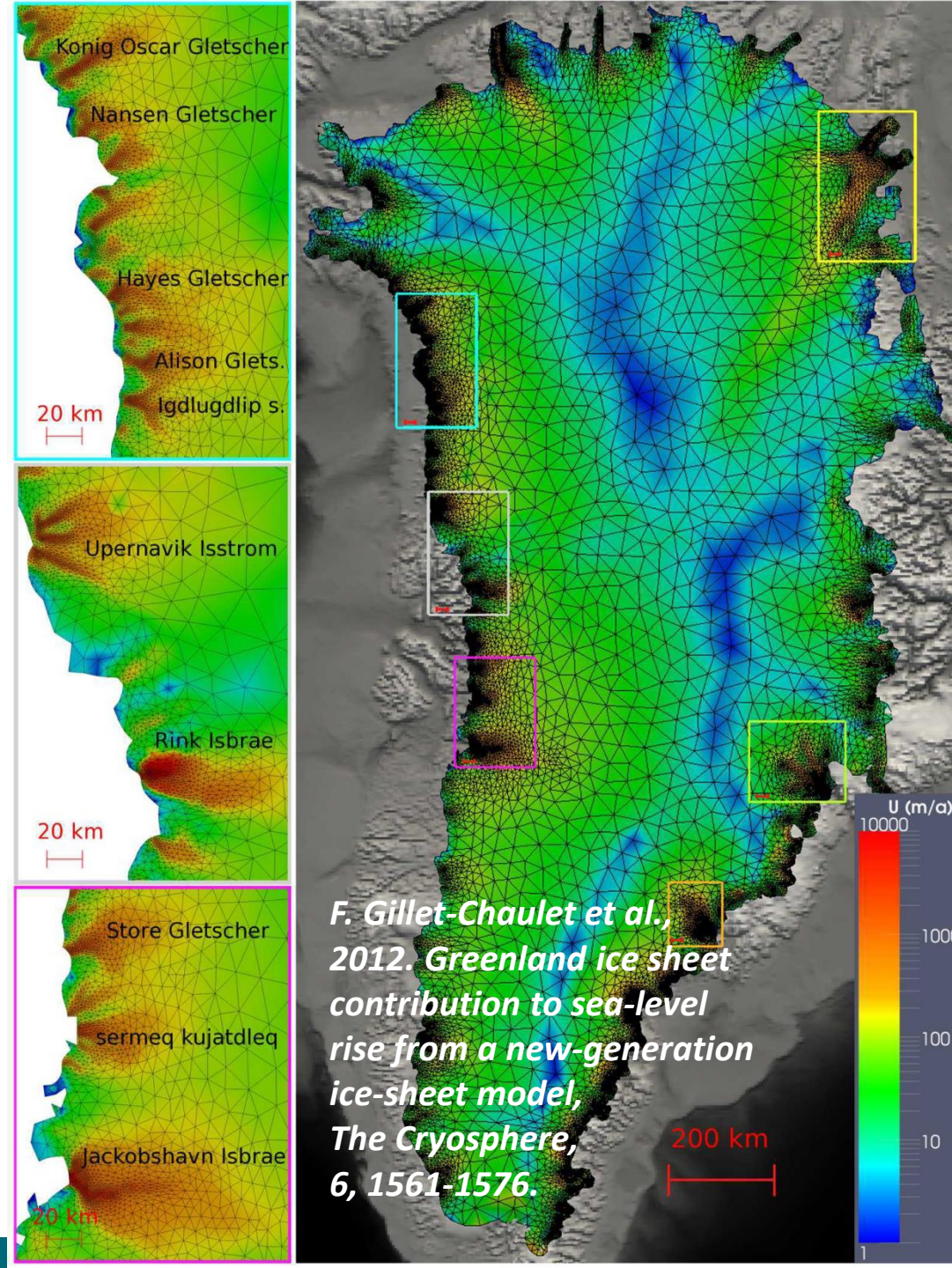
- Modeling of blood flow in elastic arteries poses a challenging case of fluid-structure-interaction

- Geometrically nonlinear elasticity equation & novel coupling procedures implemented
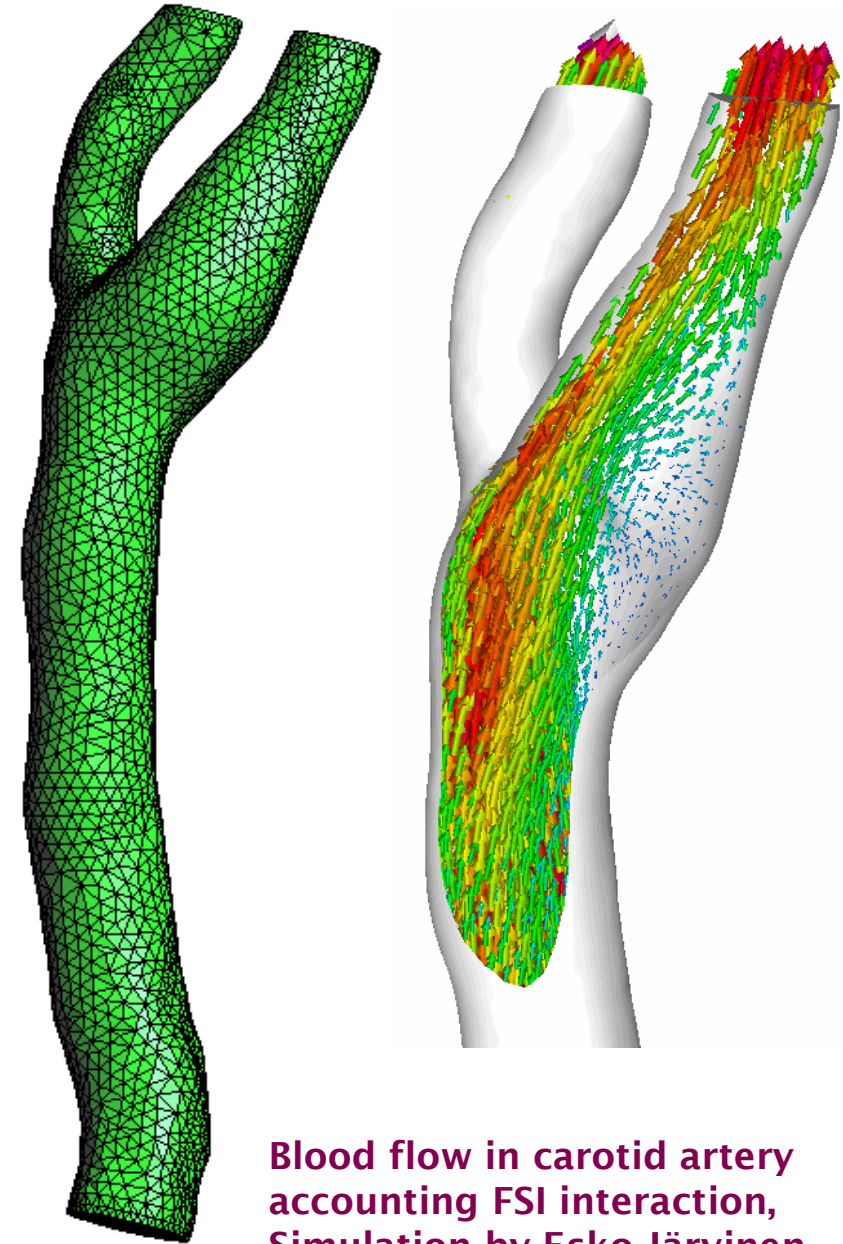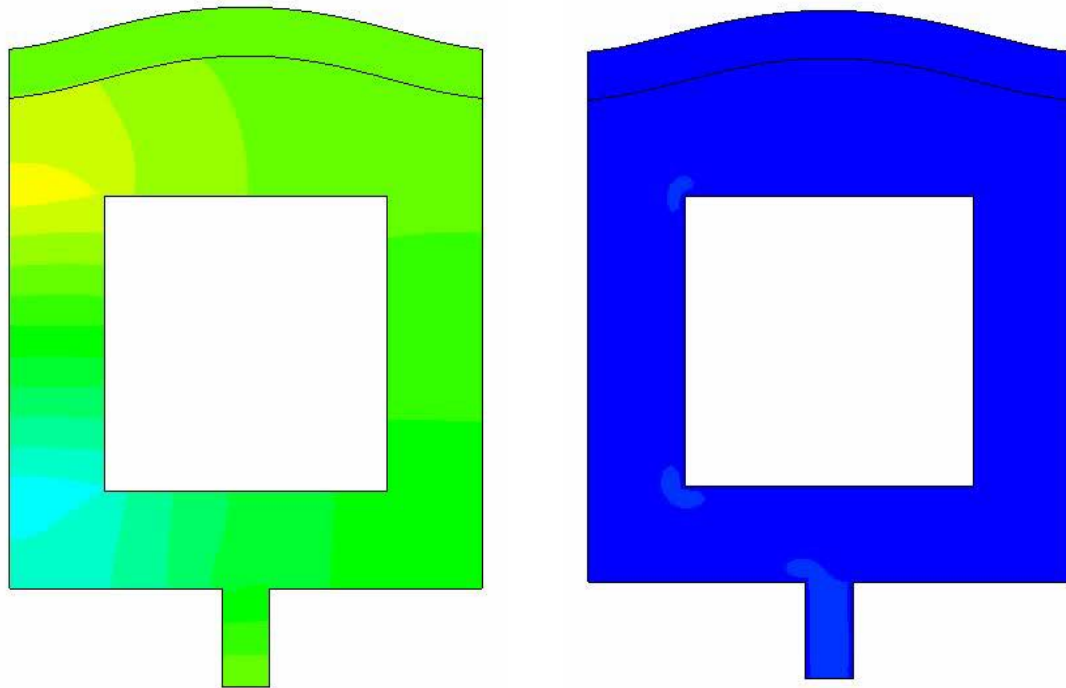
Blood flow in carotid artery accounting FSI interaction, Simulation by Esko Järvinen

Elmer for electromechanics

- Latest major development focus of Elmer
  - SEMTEC project: Project with 7 companies and 5 research institutions

- Work buildnig on Hcurl conforming elements
  - Utilizes so called AV formulation of Maxwell's equations

- Rotating boundaries & Electrical circuits add to the complexity
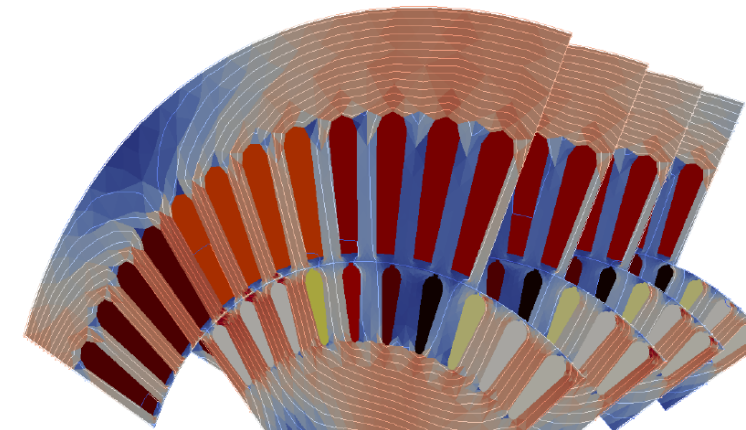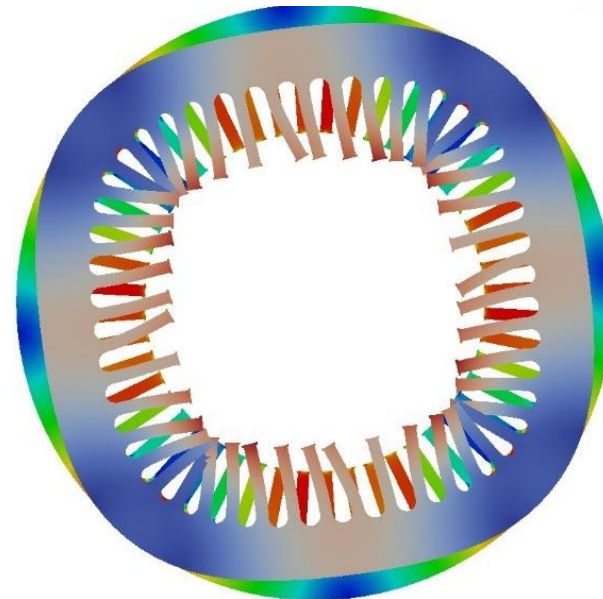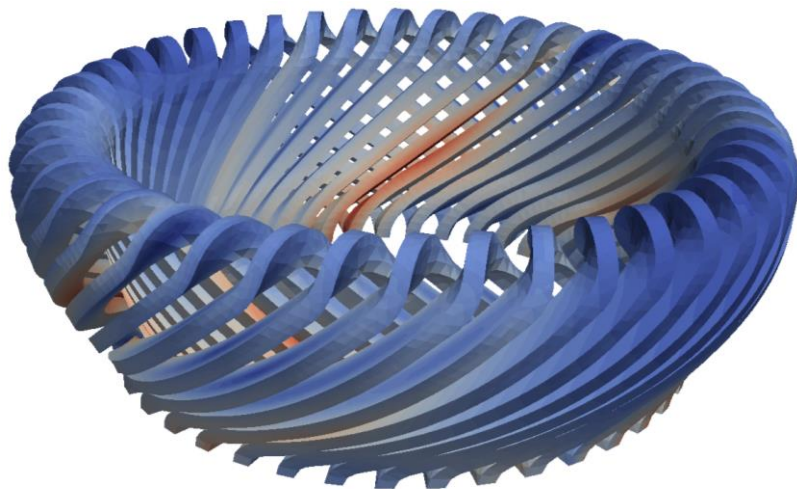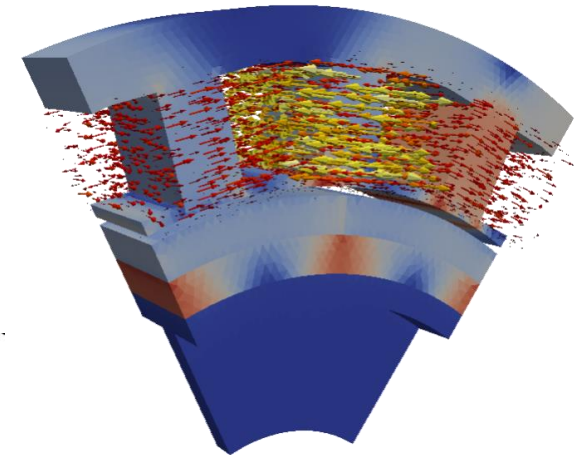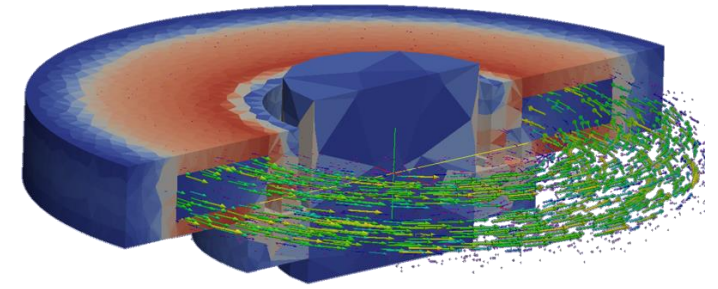
Some remarks about Elmer

- Genuine Multiphysics code by design from early on
  - Favour modularity and generality

- Developed mainly via tens of collaborative projects with academia and industry
  - Missing features where no active projects

- Focus on developments where open source approach is natural
  - Science: Compatibe with the scientific method
  - Novel developments: agility of open source software

- Little emphasis on the GUI & systematic user support
  - Serious users mainly use Elmer in scripted workflows
  - Often complementary rather than competing to commercial codes

- Value stability and backward compability – consistency tests

- Comes from HPC center - Parallellism a high priority

Elmer – Infrastructure for Open Research
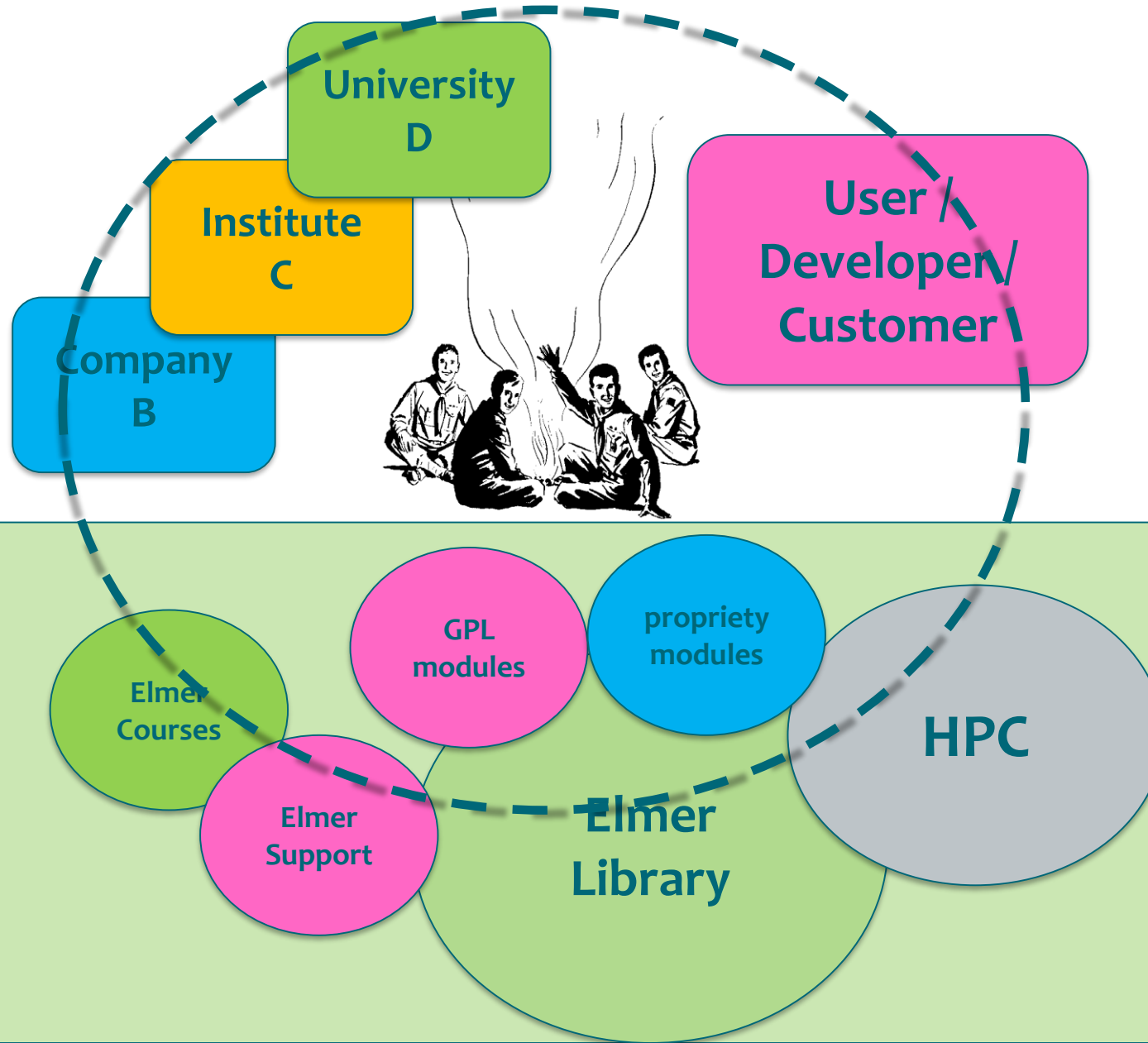
Running Elmer
different paths to your FEM simulations

ElmerTeam

CSC – IT Center for Science, Finland

Elmer FEM webinar

2021

5 ways to run Elmer

1. Compile from **source code**

2. Install ready pre-compiled **package** (Linux, Windows)

3. Run virtual appliance in **virtual machine**

4. Run inside a pre-defined **container** (Docker)

5. Run **remotely** on system with Elmer installation

Compile Elmer from source

- Elmer source code is on GitHub
  - Direct address:
    https://github.com/ElmerCSC/elmerfem
  - Clone with git from command line:
    ```
    git clone https://github.com/ElmerCSC/elmerfem.git
    ```
- For simple instructions see
  https://www.csc.fi/web/elmer/sources-and-compilation

Compile Elmer from source

https://www.csc.fi/web/elmer/sources-and-compilation

- Minimum requirement:
    1. C, C^{++} and Fortran 90 (2008 standard) compiler
    2. Cmake
    3. Patience (it takes a while to compile)
- Strongly recommended additional libraries:
    1. BLAS (optimized for platform, e.g. MKL)
    2. MPI
- Lots of more options (Hypre, MUMPS, …)

Install Elmer from package Windows

- Installer as well as ZIP-archives are under
  https://www.nic.funet.fi/pub/sci/physics/elmer/bin/windows/

  o Different flavours available

  o Might be in need of some system adjustment (path, …)

- Before you start, please check the Readme file

Install Elmer from package

- Don't use the outdated Debian package!

- Use launchpad instead:

$ sudo apt-add-repository ppa:elmer-csc-ubuntu/elmer-csc-ppa
$ sudo apt-get update
$ sudo apt-get install elmerfem-csc

Virtual appliance

- Virtual machines are by software emulated computers
  - Elmer-team provides (mainly for their courses) a pre-configured virtual appliance to be used inside a virtual machine
  - Disclaimer: This appliance comes without any warranty

- The appliance can be downloaded (size 4 GB!!) from https://www.nic.funet.fi/pub/sci/physics/elmer/bin/VirtualMachines/
  - Before you start, please read the Readme1st.txt file
  - Provided OVA-file can be directly imported into VirtualBox

Elmer in a container

- Container are pre-built environments (containing all necessary libraries)

- Docker works on Windows, Linux, Mac

- Find a (makefile-based) way of constructing Docker images under:
  https://github.com/ElmerCSC/elmerfem-docker

- Disclaimer: Dockerfiles come without any warranty

How to teach yourself Elmer

ElmerTeam

CSC – IT Center for Science, Finland

Elmer FEM webinar

2021

How to teach yourself Elmer – Individual routes

- Do you know FEM in advance?

- Are you command line or GUI person?

- Where do you aim to?
  - Basic school assignment vs. bleeding edge research?

- Do you know programming

- What software do you already use e.g. for meshing

- What is your platform
  - Linux, Windows, Mac

- Two basic approaches: GUI and CL

- Documentation: http://www.nic.funet.fi/pub/sci/physics/elmer/doc

Using Elmer via ElmerGUI

- You should install Elmer with ElmerGUI

- Start going through ElmerGUI tutorials
  - Currently 27 tutorials
  - Some repetition (2D vs. 3D etc.)
  - Start with your favorite 1-field examples

- ElmerGUI includes only a fraction of capabilities of ElmerSolver!

- ElmerGUI tutorials include only a fraction of capabilities of ElmerGUI!

- Still good way to start for most people

- Tutorials are also available under GitHub and
  - recently updated by Rich Bayless, thank you!
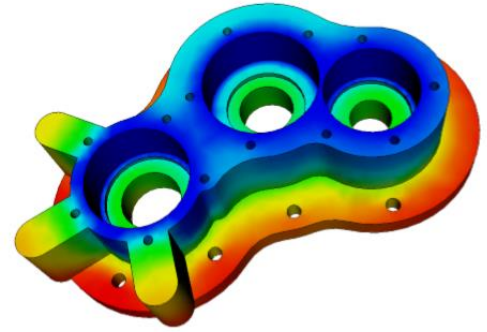
Tutorial 1	Tutorial 2	Tutorial 3	Tutorial 4	Tutorial 5
Tutorial 6	Tutorial 7	Tutorial 8	Tutorial 9	Tutorial 10
Tutorial 11	Tutorial 12	Tutorial 13	Tutorial 14	Tutorial 15
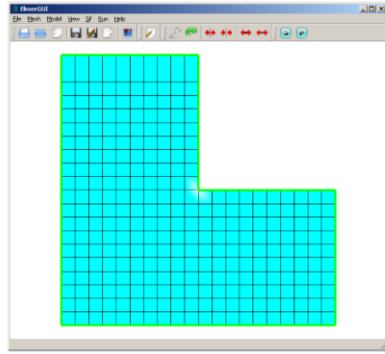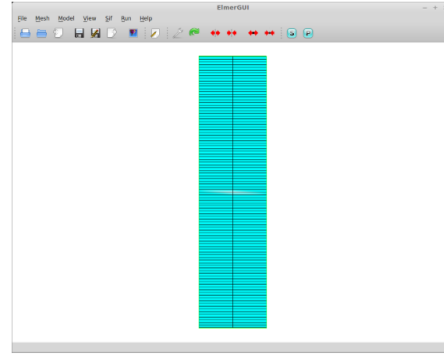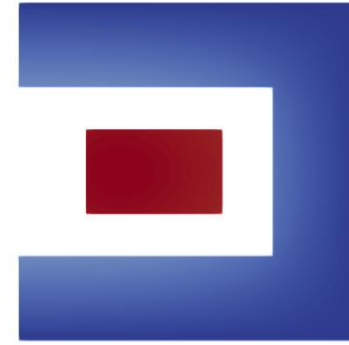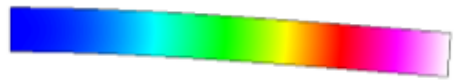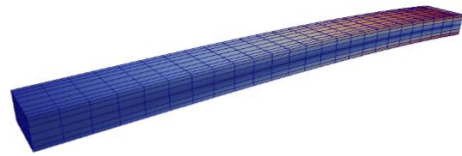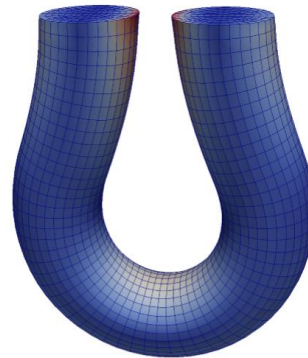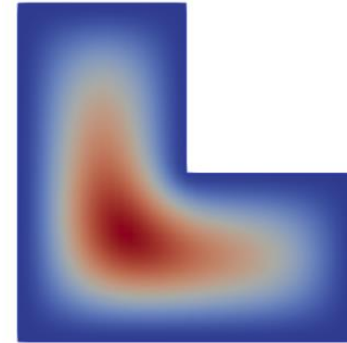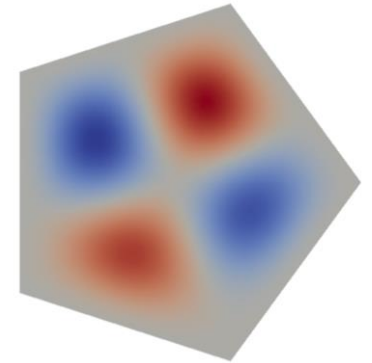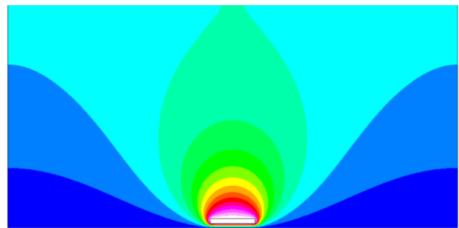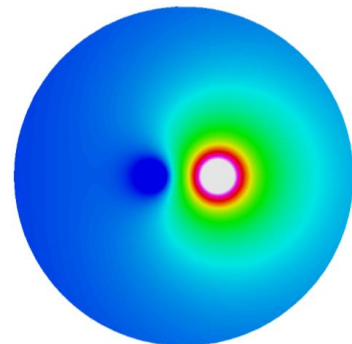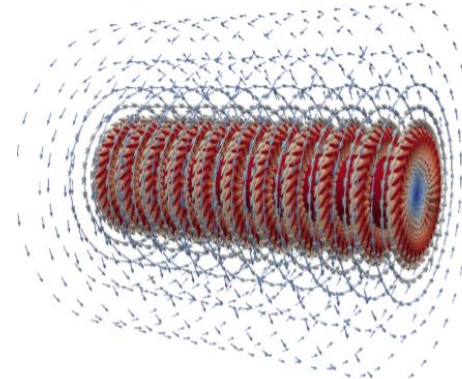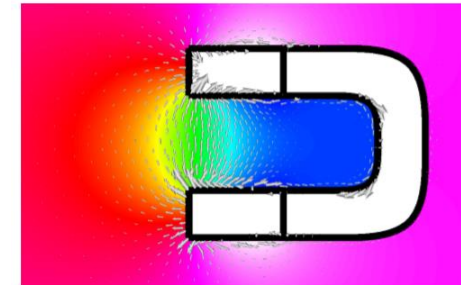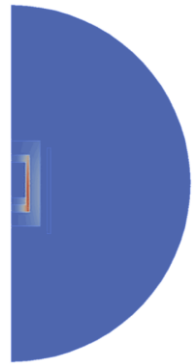
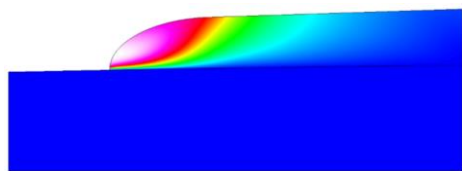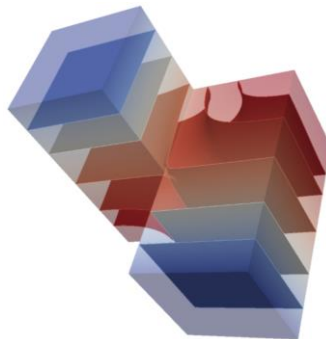| Tutorial 16	Tutorial 17	Tutorial 18	Tutorial 19	Tutorial 20
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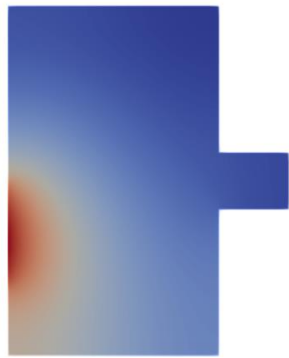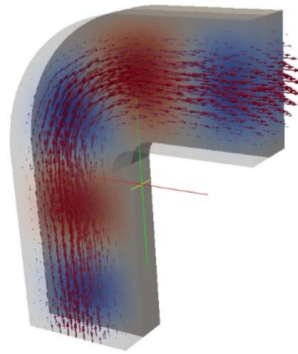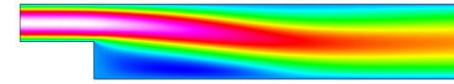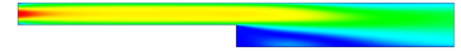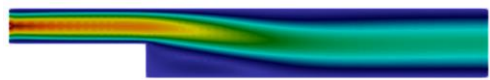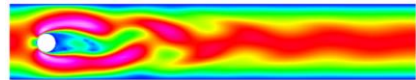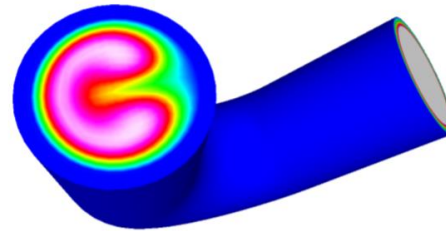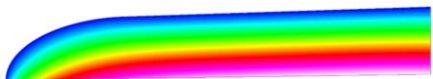
Using Elmer via command line

- Boils down how to write the command file using your favorite editor
  - In the end ElmerGUI is just a nice way to write the .sif file

- There are some non-GUI tutorials
  - Mainly historical ones before the current GUI

- Every test case may be used also as a starting point: 700 test cases!
  - $ELMERSRC/elmerfem/fem/tests
  - Here also many novel features are available
  - Each new feature should have a test for it!

- Elmer manuals gives you ideas what features you need
  - Elmer Models Manuals
  - ElmerSolver Manual

- Then search for the relevant keyword among the sif files
  - "grep" is your friend in Linux

Most important Elmer resources

- **http://www.csc.fi/elmer**
  - Official Homepage of Elmer at CSC

- **http://www.elmerfem.org**
  - Discussion forum, wiki, elmerice community

- **https://github.com/elmercsc/elmerfem**
  - GIT version control

- **http://youtube.com/elmerfem**
  - Youtube channel for Elmer animations

- **http://www.nic.funet.fi/pub/sci/physics/elmer/**
  - Download repository

- Further information: elmeradm@csc.fi

Thank you for your attention!