Elmer

Open Source Finite Element Software for Multiphysical Problems

ElmerTeam

CSC – IT Center for Science Ltd.

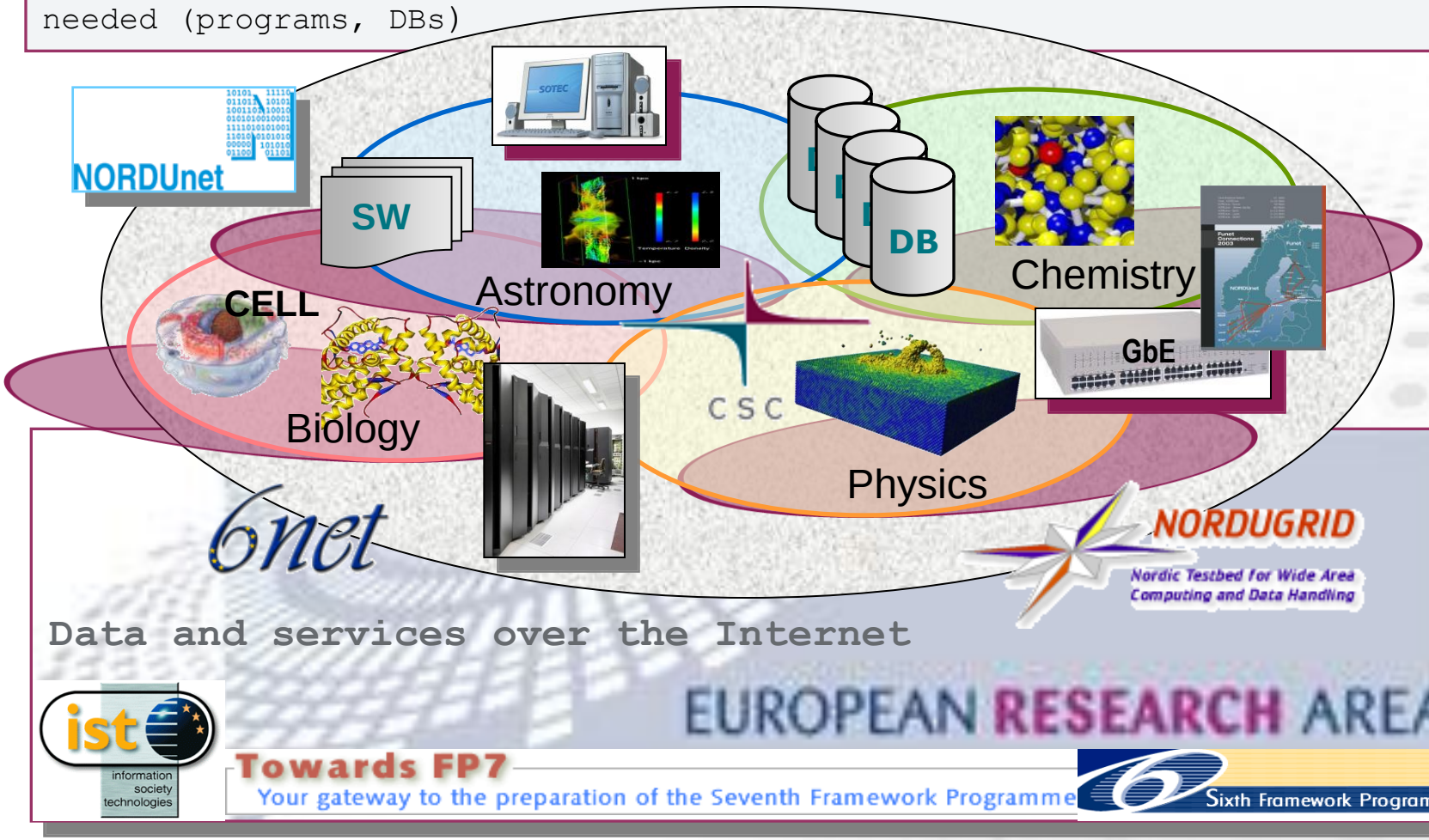
April 2013

What is CSC?

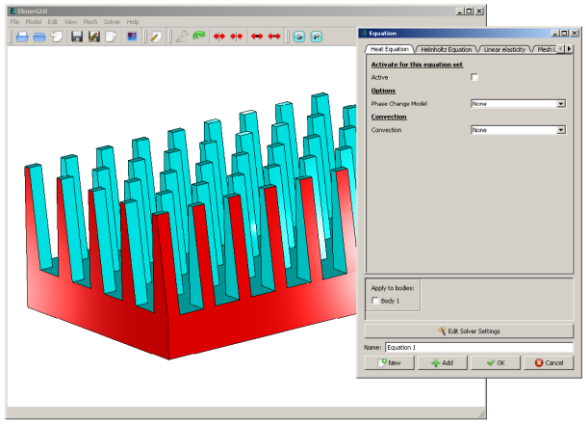
- Founded in 1971 as a technical support unit for Univac 1108
- Connected Finland to the Internet in 1988
- Reorganized as a company, CSC – Scientific Computing Ltd. in 1993
- All shares to the Ministry of Education and Culture of Finland in 1997
- Operates on a **non-profit** principle
- Facilities 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.”**

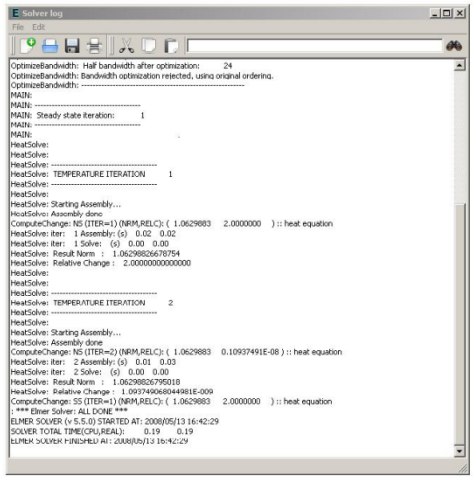
CSC as a Finnish IT Infrastructure for Research

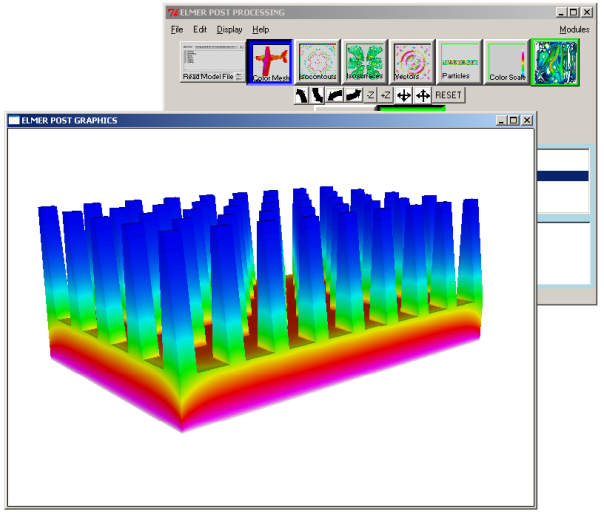
The volume of data is growing exponentially. To exploit the data for, e.g., drug design, a global, constantly updating IT infrastructure is needed (programs, DBs)



Elmer – A finite element software for multiphysical problems







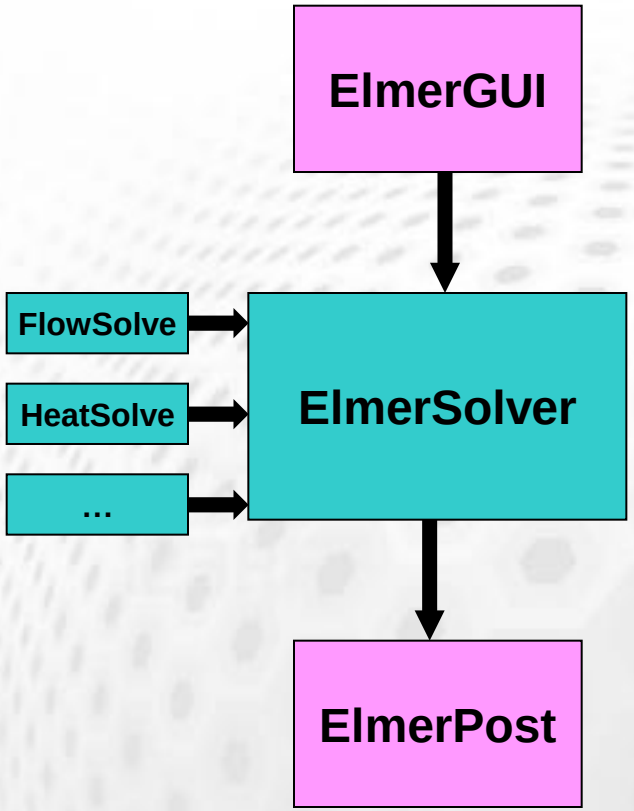
ElmerGUI + ElmerSolver + ElmerPost

ElmerGrid

ElmerFront

Components of Elmer software suite

- Elmer is actually a suite of several programs
- You may use many of the components independently
- ElmerGUI – Pre- and Postprocessing
- ElmerSolver - Solution
- ElmerPost - Postprocessing
- ElmerGrid – structured meshing and mesh import
- Others
  - ElmerFront: the old preprocessor
  - Mesh2D: Delaunay mesher usable through ElmerFront
  - MATC: library for on-the-fly arithmetics
  - ElmerParam: black-box interfacing of ascii-file based simulations



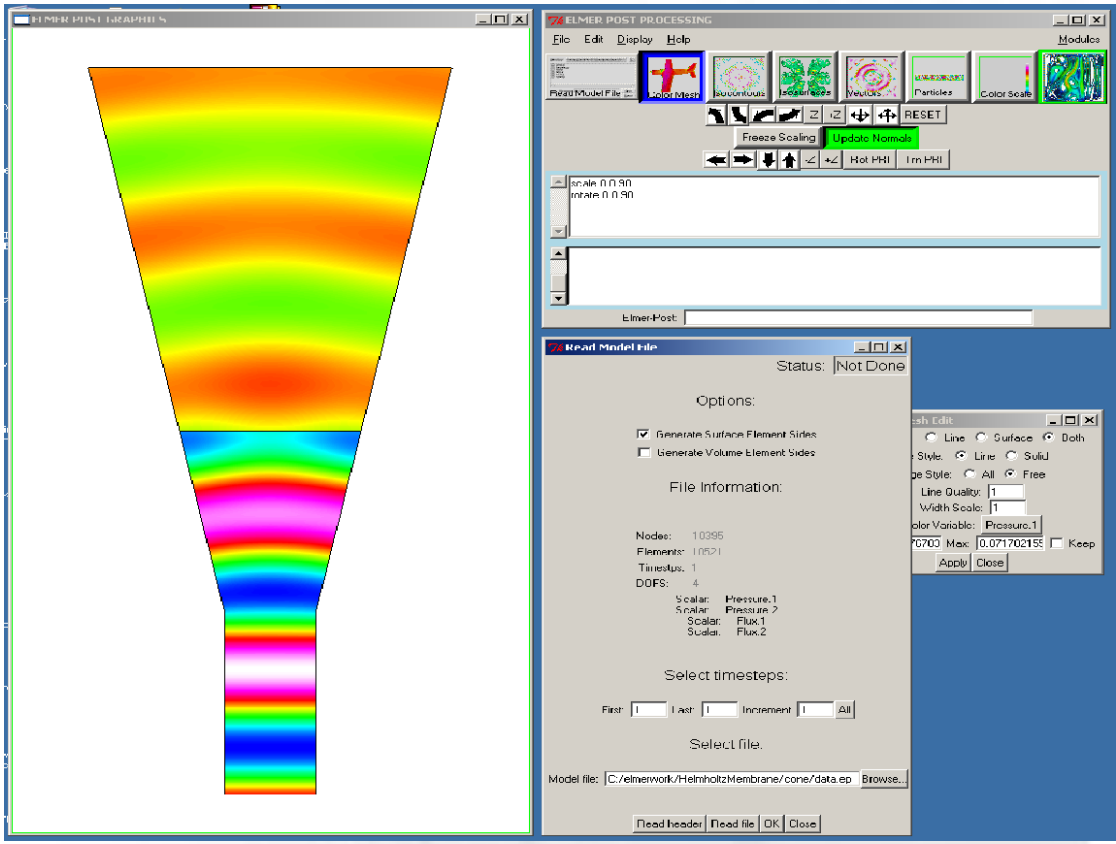
ElmerSolver

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

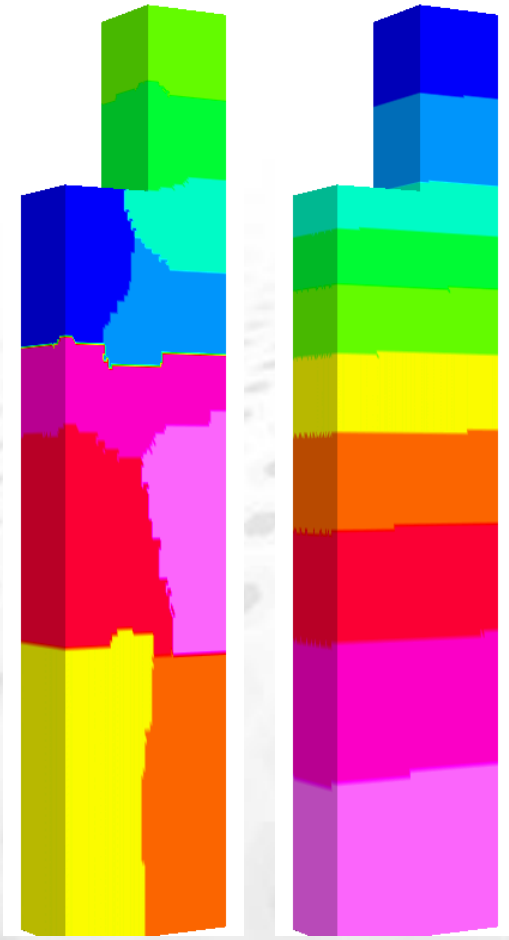
ElmerPost

- 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 algorhitms
- 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,…)

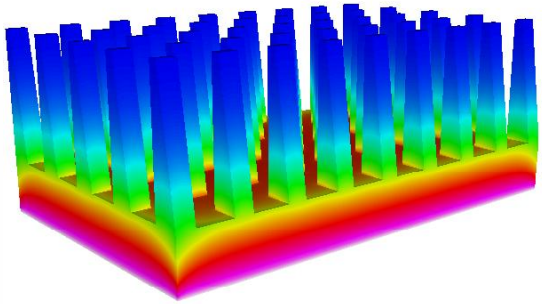
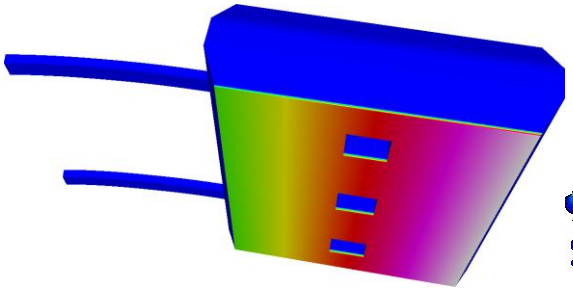
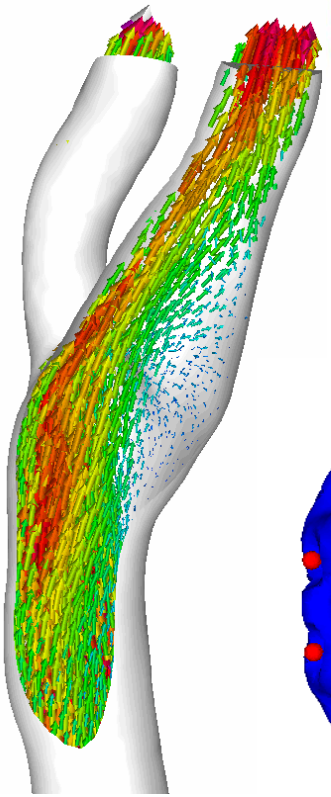
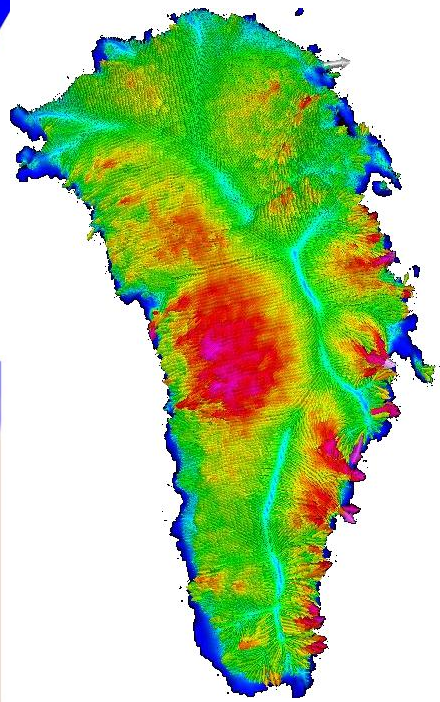


Elmer – Numerical Methods

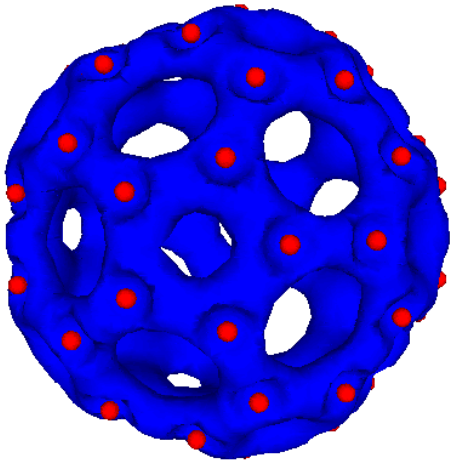
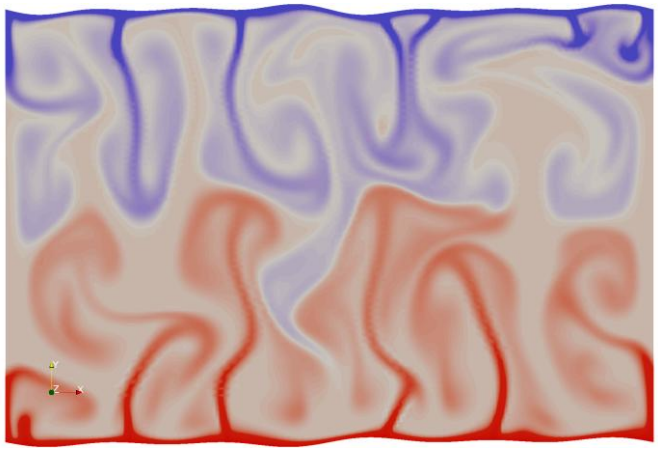
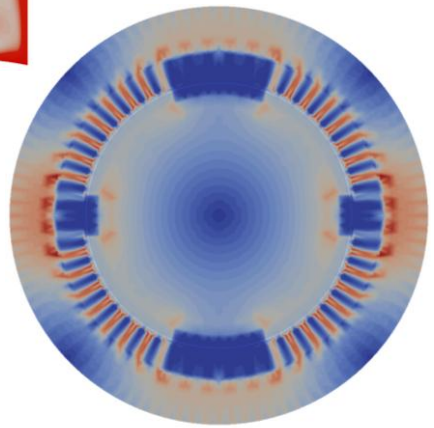
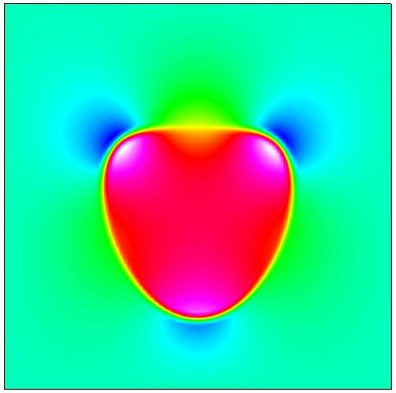
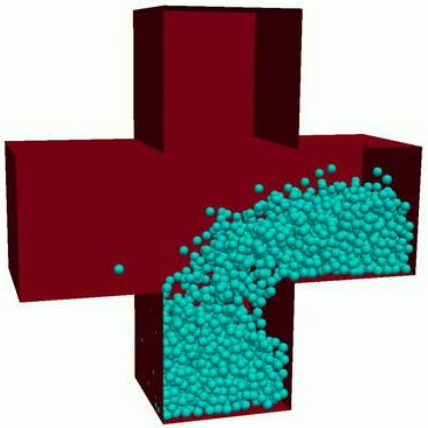
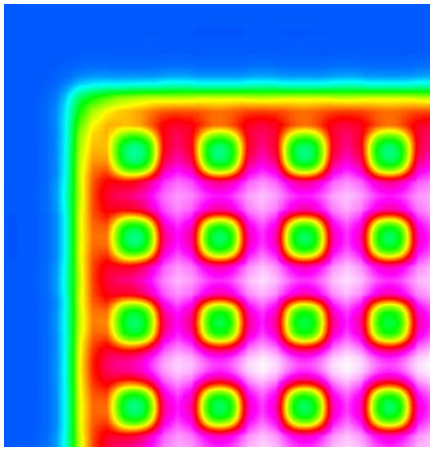
- Time-dependency
  - Static, transient, eigenmode, scanning
- Discretization
  - Element families: nodal, edge, face, and p-elements, DG
  - Formulations: Galerkin, stabilization, bubbles
  - Continuity: Mortar finite elements (under developments)
- Linear system solvers
  - Direct: Lapack, Umfpack, (SuperLU, Mumps, Pardiso)
  - Iterative Krylov space methods (HutIter & Hypre)
  - multigrid solvers (GMG & AMG) for “easy” equations (own & Hypre)
  - Preconditioners: ILU, BILU, Parasails, multigrid, SGS, Jacobi,…
- Parallellism
  - Parallel assembly
  - Solution with selected methods
- Adaptivity
  - For selected equations, works well in 2D

Elmer - Physical Models

- Heat transfer
  - Heat equation
  - Radiation with view factors
  - convection and phase change
- Fluid mechanics
  - Navier-Stokes (2D & 3D)
  - RANS: *SST* k-Ω, k-ε, v^2-f
  - LES: VMS
  - Thin films: Reynolds (1D & 2D)
- Structural mechanics
  - General Elasticity (unisotropic, lin & nonlin)
  - Plate, Shell
- Acoustics
  - Helmholtz
  - Linearized time-harmonic N-S
  - Monolithic thermal N-S
- Species transport
  - Generic convection-diffusion equation
- Electromagnetics
  - Emphasis on steady-state and harmonic analysis
  - New Whitney element formulation for magnetic fields
- Mesh movement (Lagrangian)
  - Extending displacements in free surface problems
  - ALE formulation
- Level set method (Eulerian)
  - Free surface defined by a function
- Electrokinetics
  - Poisson-Boltzmann
- Thermoelectricity
- Quantum mechanics
  - DFT (Kohn Scham)
- Particle Tracker
- ….

Elmer Simulations

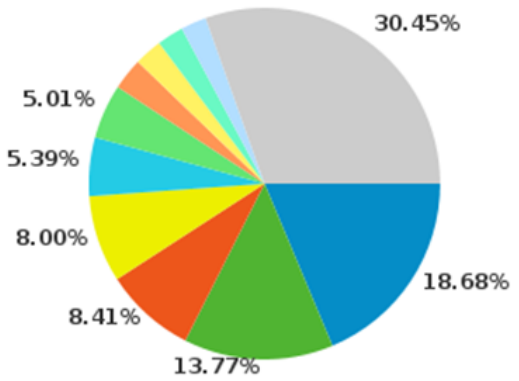
Figures by Esko Järvinen, Mikko Lyly, Peter Råback, Timo Veijola (TKK) & Thomas Zwinger

elmerfem.org statistics for 2011: countries

Visits	Pages/Visit	Avg. Time on Site	% New Visits	Bounce Rate
68,784	**4.47**	**00:04:57**	**46.89%**	**51.80%**
% of Site Total: **100.00%**	Site Avg: **4.47 (0.00%)**	Site Avg: **00:04:57 (0.00%)**	Site Avg: **46.73% (0.34%)**	Site Avg: **51.80% (0.00%)**

	Detail Level: Country/Territory	Visits	Visits
1.	United States	**12,847**	18.68%
2.	Germany	**9,473**	13.77%
3.	Finland	**5,787**	8.41%
4.	France	**5,503**	8.00%
5.	United Kingdom	**3,706**	5.39%
6.	Italy	**3,443**	5.01%
7.	Canada	**2,014**	2.93%
8.	India	**1,767**	2.57%
9.	Japan	**1,676**	2.44%
10.	Spain	**1,619**	2.35%
11.	Russia	**1,391**	2.02%
12.	Netherlands	**1,376**	2.00%
13.	Switzerland	**1,321**	1.92%
14.	Poland	**1,216**	1.77%
15.	China	**1,187**	1.73%
16.	Belgium	**958**	1.39%
17.	Sweden	**882**	1.28%
18.	Australia	**775**	1.13%
19.	Czech Republic	**761**	1.11%
20.	Argentina	**664**	0.97%

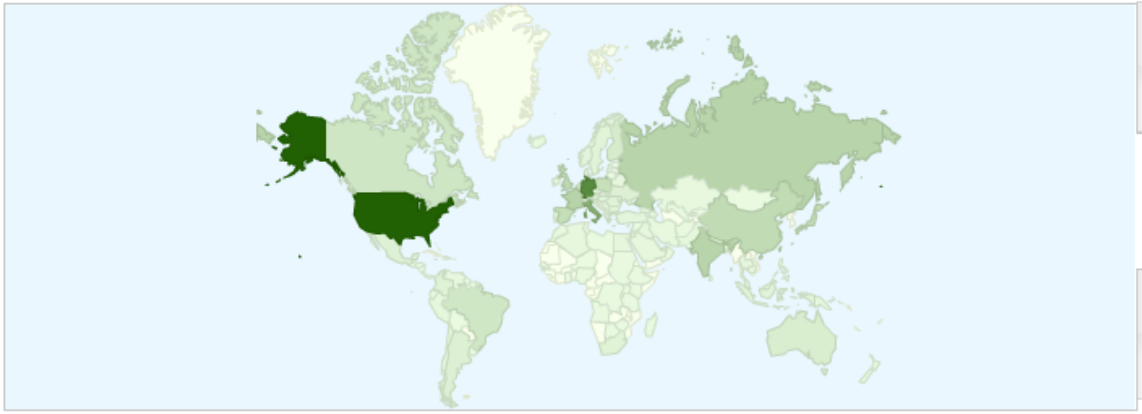
Country/Territory contribution to total: Visits



~20k Windows downloads at sf.net in a year

Home / WindowsBinaries (Change File)

Date Range: 2012-04-01 to 2013-03-31



DOWNLOADS
19 185
In the selected date range

TOP COUNTRY
United States
16% of downloaders

TOP OS
Windows
93% of downloaders

OS downloads as: Percent

	Country	Android	BSD	Linux	Macintosh	Unknown	Windows	Total
1.	United States	0%	0%	3%	3%	1%	80%	3,182
2.	Germany	0%	0%	4%	1%	0%	80%	2,313
3.	Italy	0%	0%	3%	1%	0%	80%	1,537
4.	France	0%	0%	4%	1%	1%	79%	798
5.	India	0%	0%	6%	1%	4%	78%	782
6.	Russia	0%	0%	4%	0%	0%	77%	772
7.	United Kingdom	0%	0%	3%	2%	0%	81%	642
8.	China	0%	0%	3%	1%	1%	78%	637
9.	Japan	0%	0%	2%	2%	0%	77%	599
10.	Spain	0%	0%	6%	0%	20%	63%	561
11.	Poland	0%	0%	2%	0%	0%	87%	532
12.	Canada	1%	0%	2%	2%	0%	85%	410
13.	Brazil	0%	0%	4%	1%	0%	88%	391
14.	Finland	0%	0%	2%	1%	0%	78%	300

Poll on application fields (status 3/2013)

What are your main application fields of Elmer?

You may select up to **5** options

Heat transfer	57	28%
Fluid mechanics	54	27%
Solid mechanics	44	22%
Electromagnetics	33	16%
Quantum mechanics	3	1%
Something else (please specify)	12	6%

Total votes : 203

Submit vote

Short history of Elmer

- 1995 Elmer development was started as part of a national CFD program
  - Collaboration with TKK, VTT, JyU, and Okmetic Ltd.
- 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
  - Roughly 400 000 lines of code
- 2010 Used wordwide by thousands (?) of researchers
  - About 1500 downloads of the Windows binary each month
  - ~50000 visits to community forum from ~120 countries during last year
- Readily available in major Linux systems
- Application projects are nowadays mainly international
  - Used in a number of EU-projects
  - Central tool in computational glaciology
- May 2012 ElmerSolver library to be published under LGPL

Elmer - Developers

- Current main developers at CSC
  - CSC: Mika Malinen, Juha Ruokolainen, Peter Råback, Sampo Sillanpää, Thomas Zwinger, Mikko Byckling, Sami Ilvonen
- Other/past developers & contributors
  - CSC: Mikko Lyly, Erik Edelmann, Jussi Heikonen, Esko Järvinen, Jari Järvinen, Antti Pursula, Ville Savolainen, Sami Ilvonen, …
  - VTT: Martti Verho
  - TKK: Jouni Malinen, Harri Hakula, Mika Juntunen
  - Trueflaw: Iikka Virkkunen
  - Open Innovation: Adam Powell
  - LGGE: Olivier Gagliardini, Fabien Gillet-Chaulet,…
  - University of Uppsala: Jonas Thies
  - etc… (if your name is missing, please ask it to be added)

Alternative mesh generators for Elmer

Open source

- ElmerMesh2D
  - 2D Delaunay
  - Usable via the old ElmerFront
- ElmerGrid
  - Simple structured mesh generation
  - Usable via ElmerGUI
- Tetgen, Netgen
  - Tetrahedral mesh generation
  - Usable via ElmerGUI as a plug-in
- Gmsh
  - Includes geometry definition tools
  - ElmerGUI/ElmerGrid can read the format
- Salome
  - The OS alternative with best CAD support
  - Save in .unv format, read by ElmerGUI/ElmerGrid

Commercial

- GiD
  - Inexpensive
  - With an add-on module can directly write Elmer format
- Gambit
  - Preprocessor of Fluent suite
  - ElmerGUI/ElmerGrid can read .FDNEUT format
- Comsol multiphysics
  - ElmerGUI/ElmerGrid can read .mphtxt format
- Ask for your format:
  - Writing a parser from ascii-mesh file usually not big a deal

Poll on Mesh generators (status 3/2013)

What mesh generation software do you use with Elmer?

You may select up to **10** options

Total votes : 75

Submit vote

Alternative postprocessors for Elmer

Open source

- ElmerPost
  - Postprocessor of Elmer suite
- ParaView, Visit
  - Use ResultOutputSolve to write .vtu or .vtk
  - Visualization of parallel data
- OpenDX
  - Supports some basic elementtypes
- Gmsh
  - Use ResultOutputSolve to write dat
- Gnuplot, R, Octave, …
  - Use SaveData to save results in ascii matrix format
  - Line plotting

Commercial

- Matlab, Excel, …
  - Use SaveData to save results in ascii matrix format
  - Line plotting

Poll on visualization tools (status 3/2013)

What visualization software do you use?

You may select up to **10** options

Total votes : 53

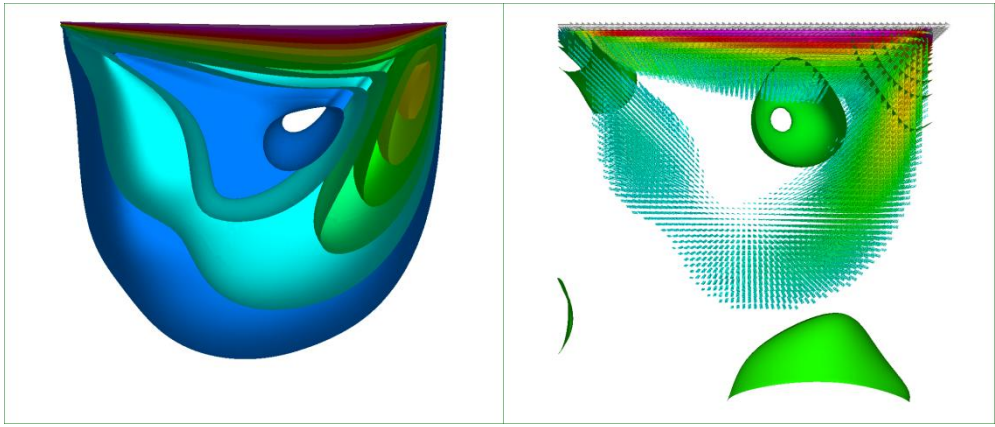
Submit vote

Elmer and Parallelization

- Parallelization with MPI
  - Assembly parallelizes almost trivially
  - Solution by iterative methods (GMG, Krylov methods, Hypre)
  - Many preconditioners (ILUn) not the same in parallel - convergence
- Mesh partitioning (serial)
  - Partitioning by Metis
  - Simple geometric division
- Parallel meshing
  - Partitioned mesh multiplication and mesh exstrusion supported
- Some work on multithreading
  - OpenMP pragmas
  - Hybrid methods under development
  - Elmer ported on Intel Phi
- Recent developments towards improved scalability
  - FETI: Effficient scaling of Navier's equation
  - Block preconditioning: Particularly suitable for the Stokes' equation
  - Trilinos library taken into use

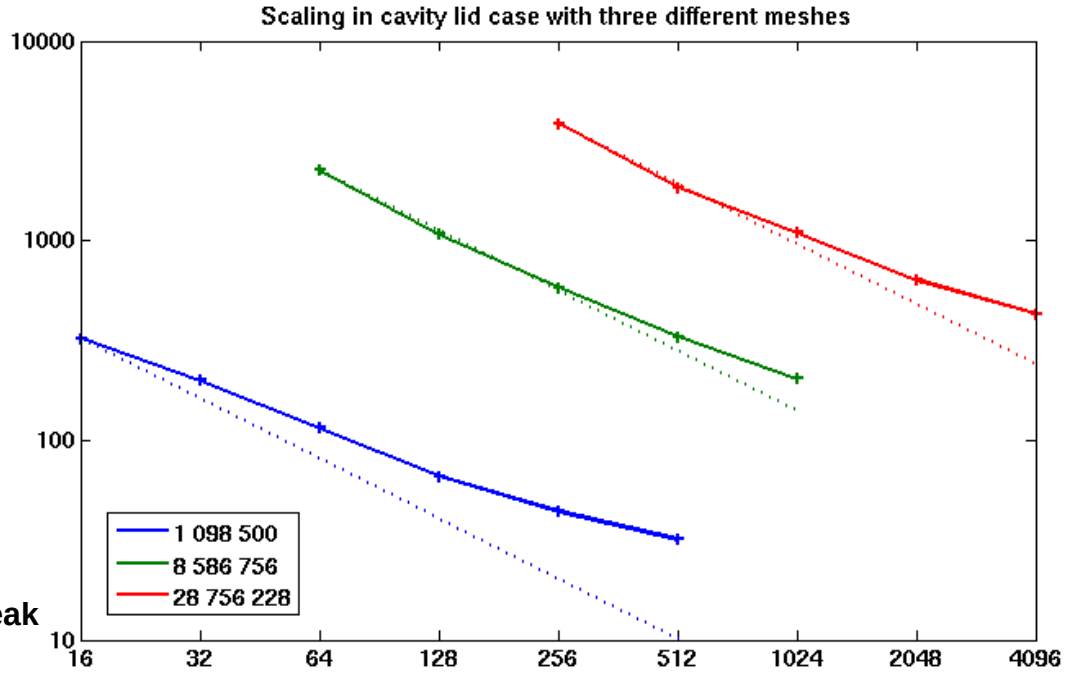
Parallel performance

- Partitioning by Metis or simple geometric division
- Parallel assembly and solution by GMG or Krylov subspace methods.
- Parallel performance may scale up to thousands of cores
- Simulation with over one billion unknowns has been performed

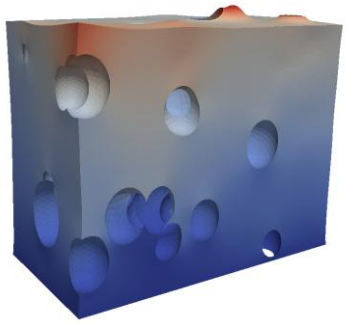


Scaling of wall clock time with dofs in the cavity lid case using GMRES+ILU0. Simulation Juha Ruokolainen, CSC, visualization Matti Gröhn, CSC .

Louhi: Cray XT4/XT5 with 2.3 GHz 4-core AMD Opteron. All-in-all 9424 cores and Peak power of 86.7 Tflops.



Example, Swiss Cheese: Block Preconditioner (serial)



- Strong scaling between best of Krylov methods and block preconditioned (BP) version was compared
- At smallest system performance about the same
- Increasing size with 8^3=512 gives the block solver a huge edge

	BiCGstab(4)+ILU1		GCR+BP(CMG+SGS)	
#dofs	T(s)	#iters	T(s)	#iters
7,662	1.12	36	1.19	34
40,890	11.77	76	6.90	45
300,129	168.72	215	70.68	82
2,303,472	>21,244*	>5000*	756.45	116

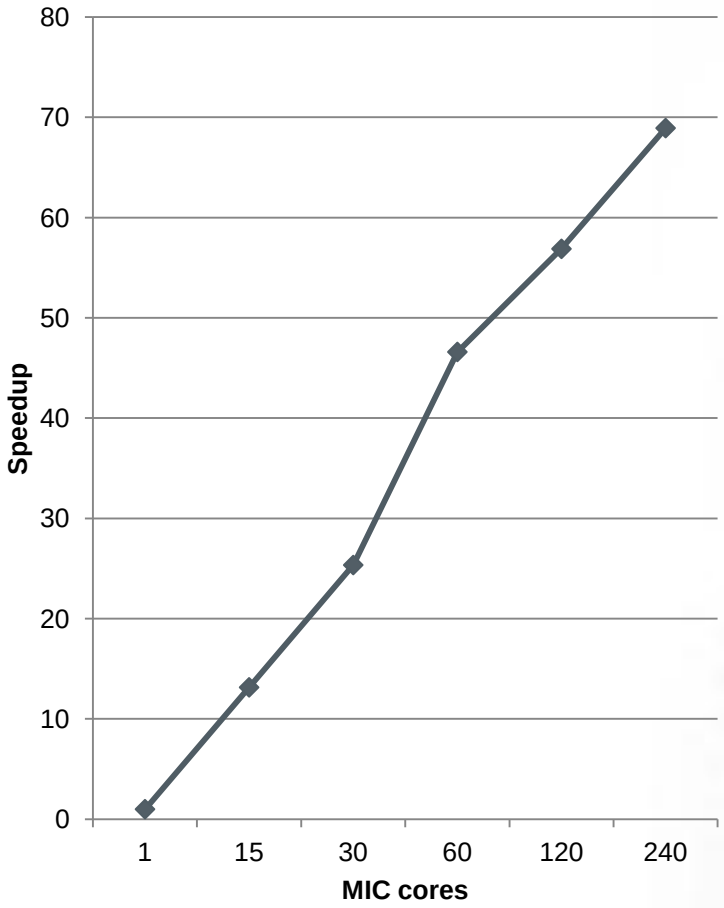
* No convergence was obtained

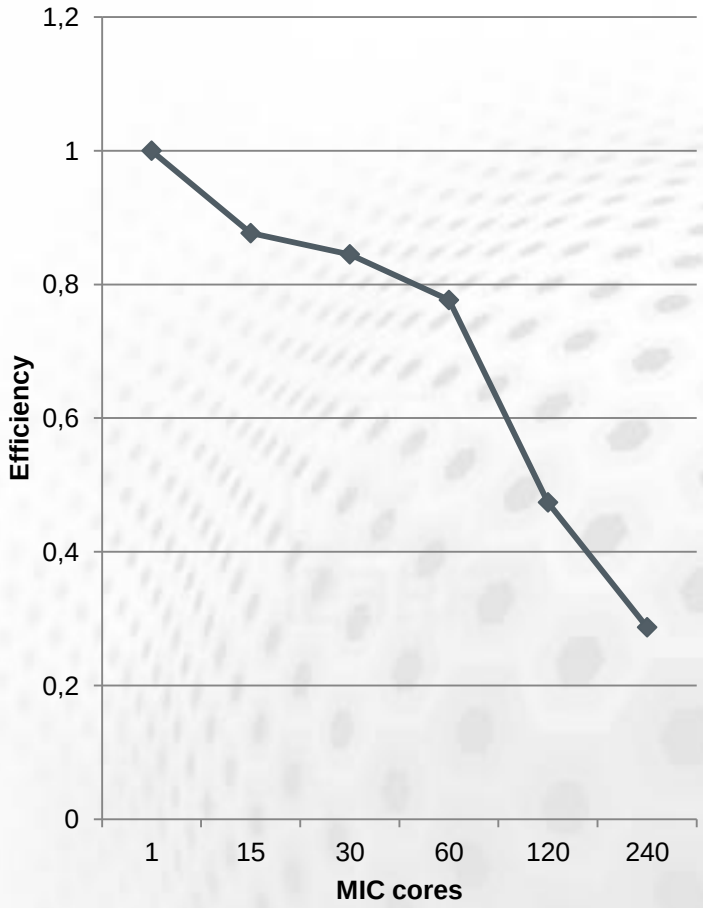
Elmer and MICs

- MIC = Many Integrated Core
  - x86 –architecture
  - Up to 60 cores with 4-way HT
  - Single MIC core not as powerful as a Xeon core
  - Parallelism necessary for performance, e.g. OpenMP
- Elmer porting on MIC started on 2Q/2012
  - Sparse matrix vector products vectorized
  - Support for MKL Pardiso and SpDGEMV added
  - Some solvers modified to support OpenMP
  - All tests passed

Finite element assembly

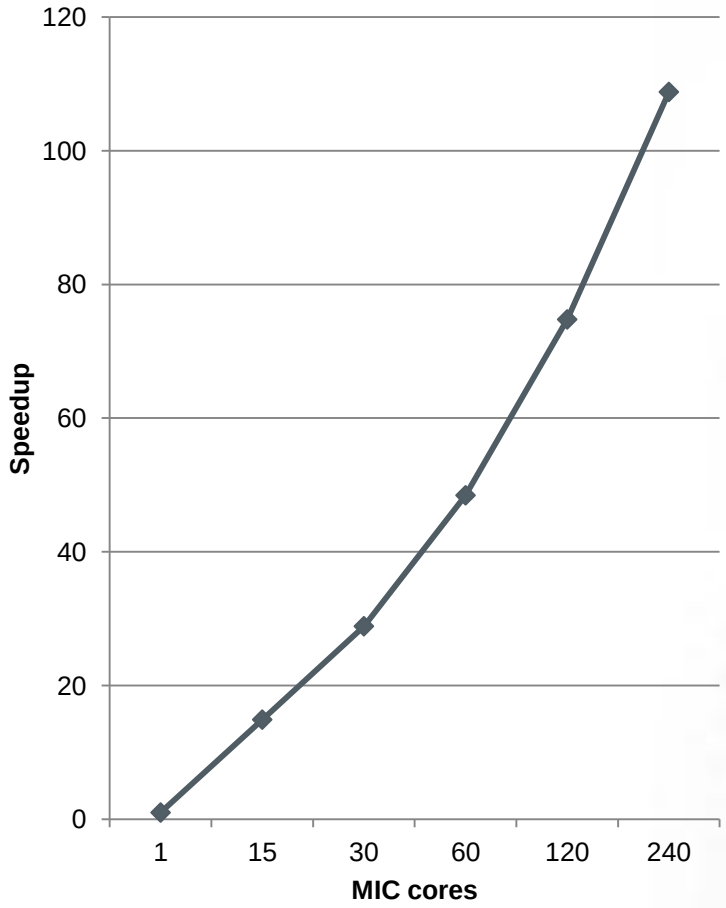
Xeon Phi, parallel scaling and efficiency

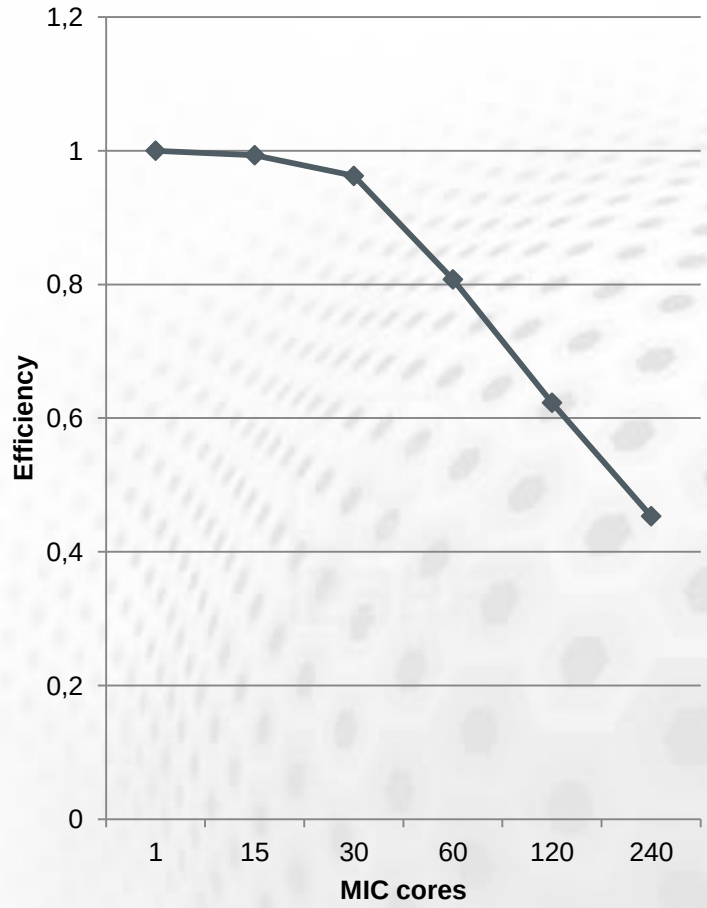




SpDEGEMv

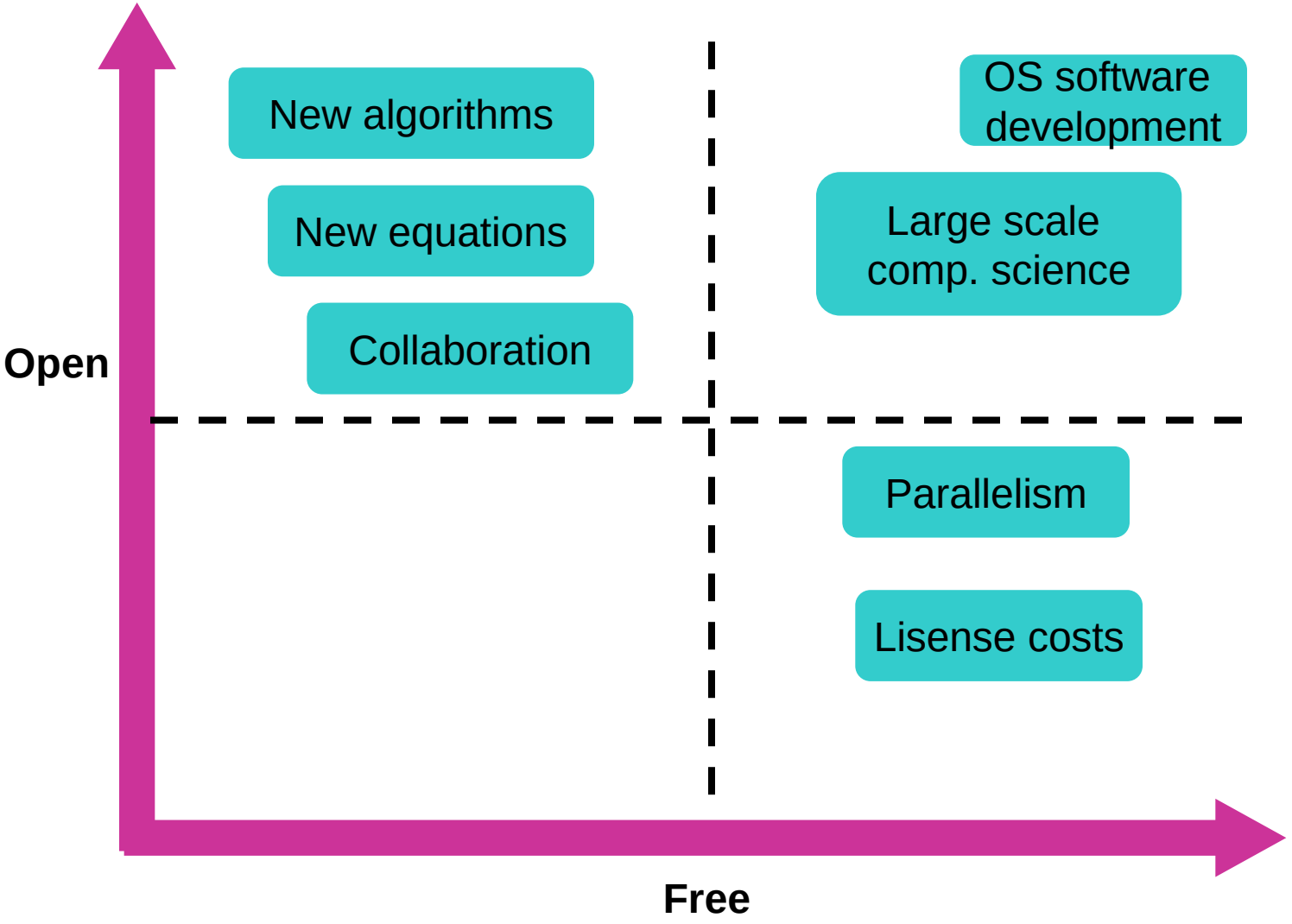
Xeon Phi, parallel scaling and efficiency



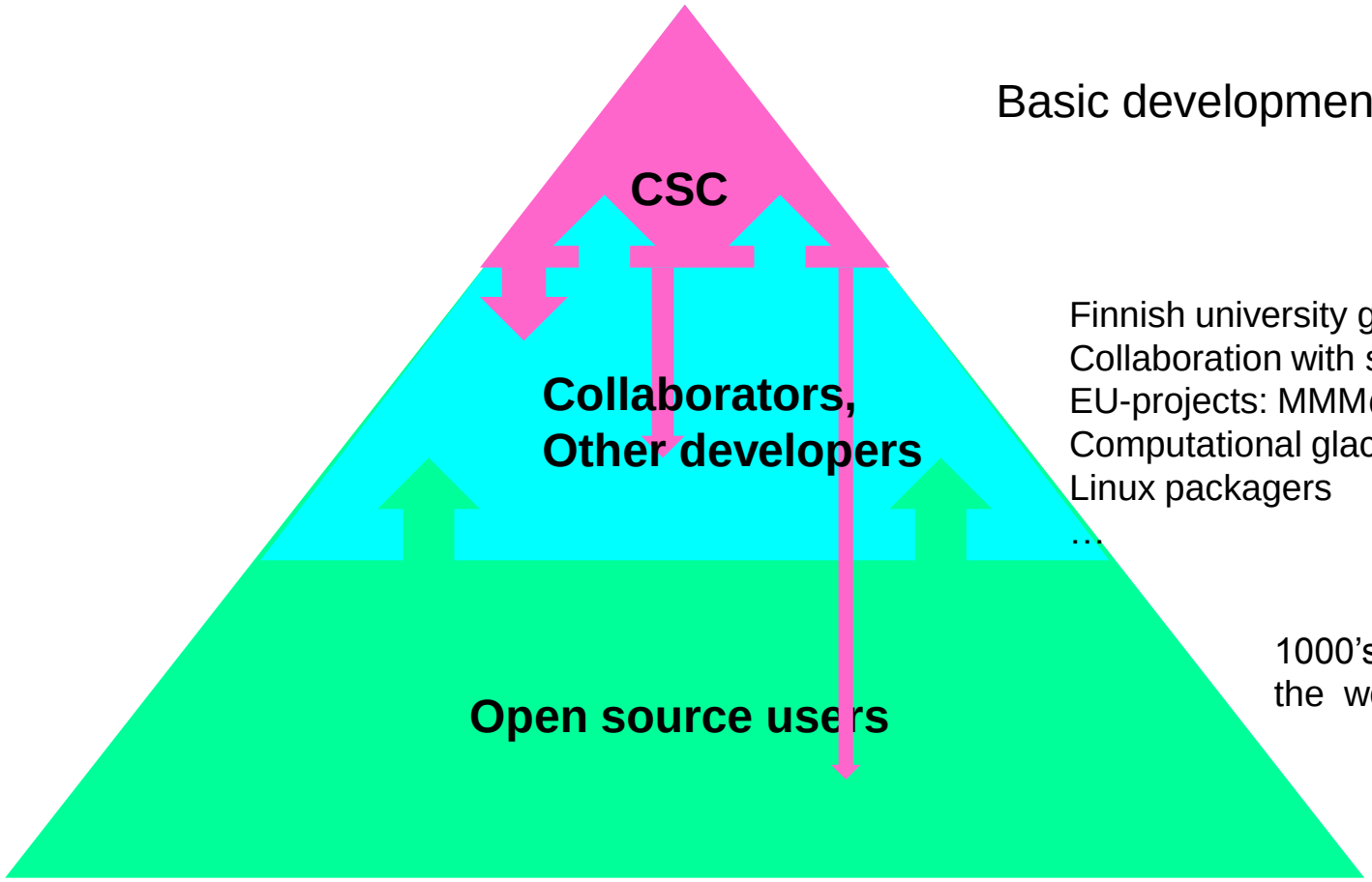


Reasons to use open source software

free as in ”beer” vs. free as in ”speech”



Ecosystem of Elmer



Basic development of Elmer

Finnish university groups
Collaboration with selected companies
EU-projects: MMM@HPC, PRACE,…
Computational glaciology,
Linux packagers
…

1000's of users around
the world (basic & advanced)

Elmer – Infrastructure for Open Innovation

University D

Institute C

Company B

User / Developer / Customer

Elmer As Infrastructure

Elmer Courses

Elmer Support

GPL modules

propriety modules

Elmer Library

HPC

Most important Elmer resources

- http://www.csc.fi/elmer
  - Official Homepage of Elmer
  - Overview, examples, compilation, …
  - pointers to other sources of information
- http://sourceforge.net/projects/elmerfem/
  - Version control system: svn
  - Binaries
- www.elmerfem.org
  - Discussion forum, wiki & doxygen
- Further information: Peter.Raback@csc.fi

- Thank you for your attention!