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OF WEST BOHEMIA

Code Agros and Possibilities of its Use for Modeling and Design

Current Features and Outlook to the Future

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July 2, 2015, College Station

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RICE – Regional Innovation Centre for Electrical Engineering

- RICE is a trademark of the Faculty of Electrical Engineering for the R&D area.
- More than 160 researchers.
- New infrastructure enabling the implementation of unique multi-disciplinary research projects
- Whole research chain from basic research up to development of functional samples and their complete testing.
- R&D projects with total budget over 80 mil. EUR.
- https://rice.zcu.cz

Basic characteristic of the application

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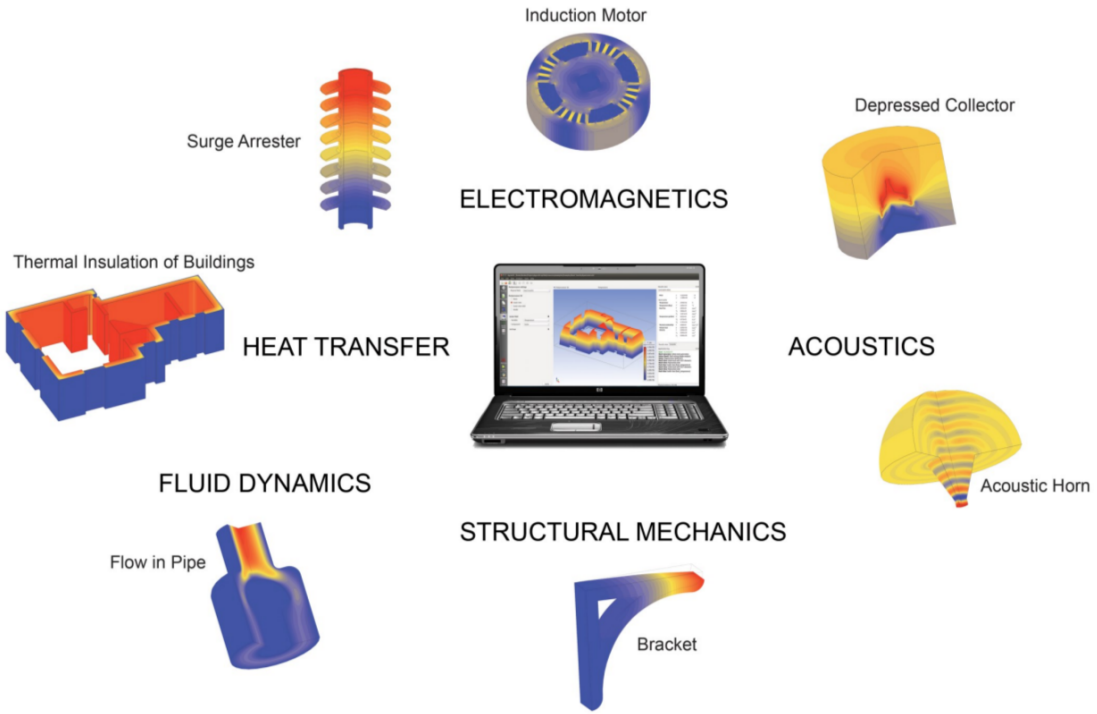
Basic characteristic of the application

Basic characteristic of the application

- Development since 2009
- Open-source project distributed under GNU GPLv2
- Multiplatform application with embedded Python support
- Current state: 180 000 lines of C++ source code
- Collaborations with other universities and industrial partners



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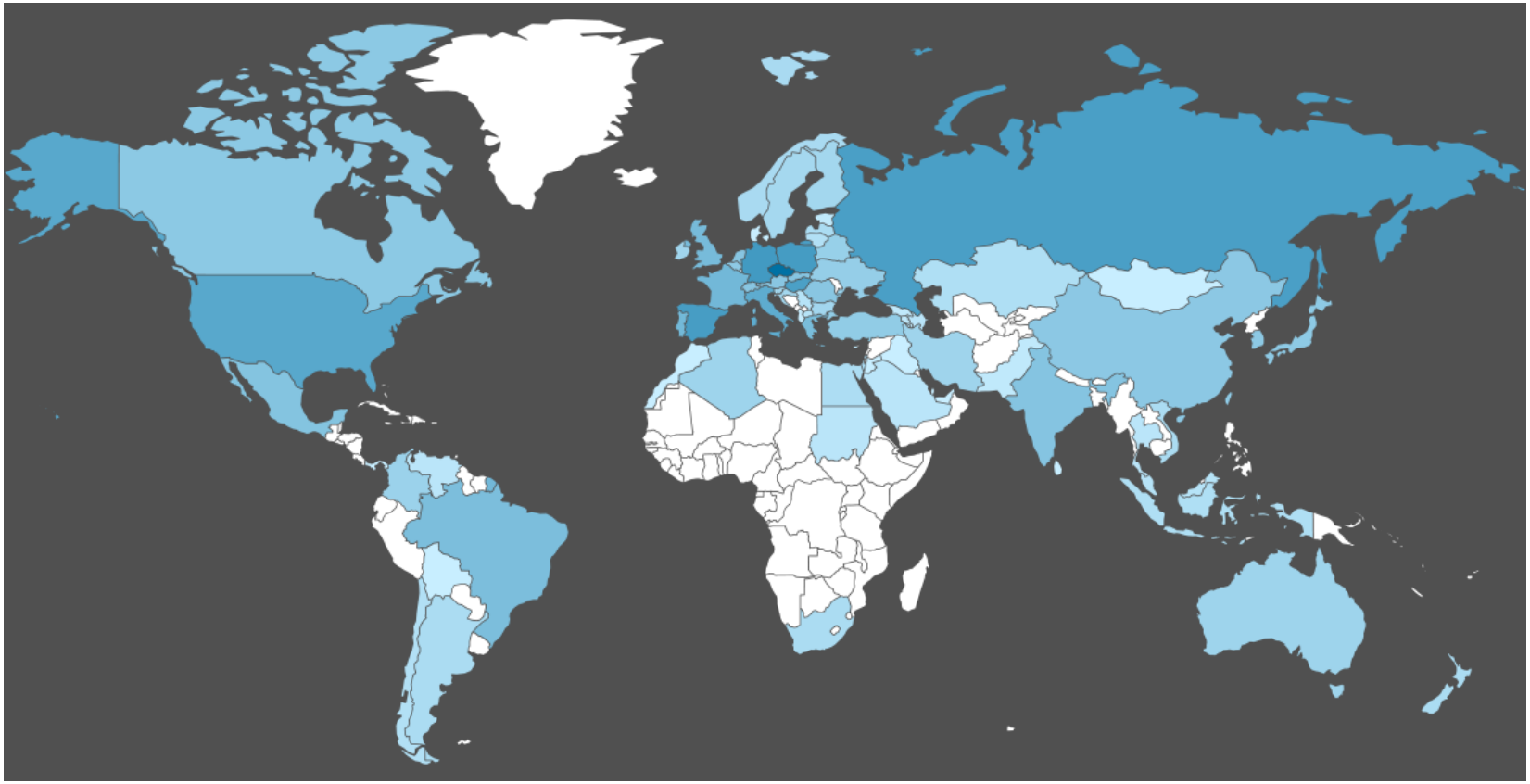

users from 76 different countries - 6025 unique users (26.7.2015)

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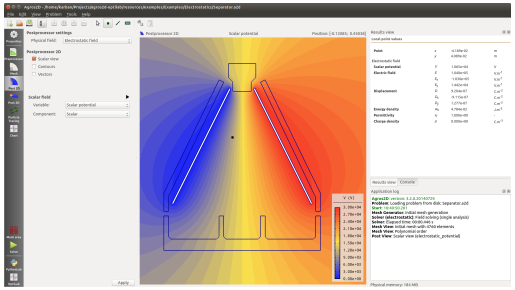
Basic characteristic of the application

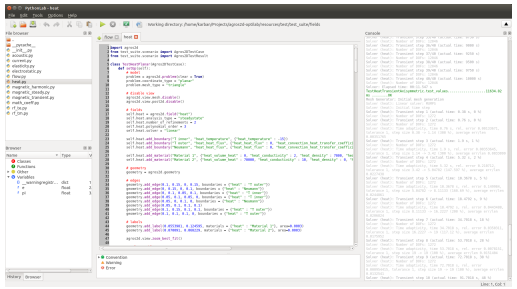
Brief description

Agros2D



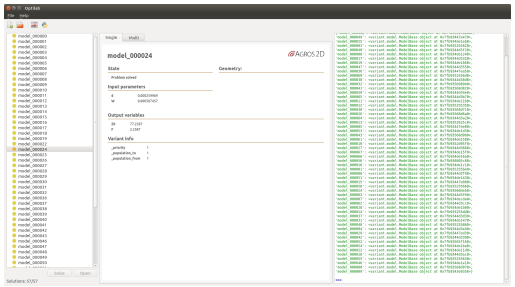
- Interactive geometry creation, CAD support, material library
- Automatic mesh generators
- Advanced higher-order finite elements method with automatic *hp*-adaptivity
- Adaptive nonlinear solvers
- Powerful visualization and postprocessing

PythonLab



- Powerful integrated environment (code completion, objects browser, console)
- Full control of Agros2D based on Python scripting language
- Object-oriented Python module
- Source code debugger and profiler
- Creation of scripts from existing models

OptiLab (in development)



- Integrated environment for data analysis
- Parameter sweep analysis
- Sensitivity analysis
- Single and multi-objective optimization
- Evolution-based and gradient-based algorithms
- Model order reduction

Basic characteristic of the application

Supported physical fields and couplings

Supported physical fields

Physical field	Steady State	Harmonic An.	Transient An.
Electrostatics	x		
Electric Currents	x	x	
Magnetic Fields	x	x	x
Radio Frequency Fields		x	x
Heat Transfer	x		x
Structural Mechanics	x		
Fluid Flow	x		x
Porous Media and Subsurface Flow	x		x
Acoustics		x	x
General Coefficient Form PDEs	x	x	x

Coupled problems

- Magnetic fields (Joule losses) + Heat transfer
- Electric currents (Joule losses) + Heat transfer
- Heat transfer (temperature) + Structural Mechanics
- Magnetic fields (internal forces) + Fluid Flow
- Magnetohydrodynamics (in development)

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Agros2D

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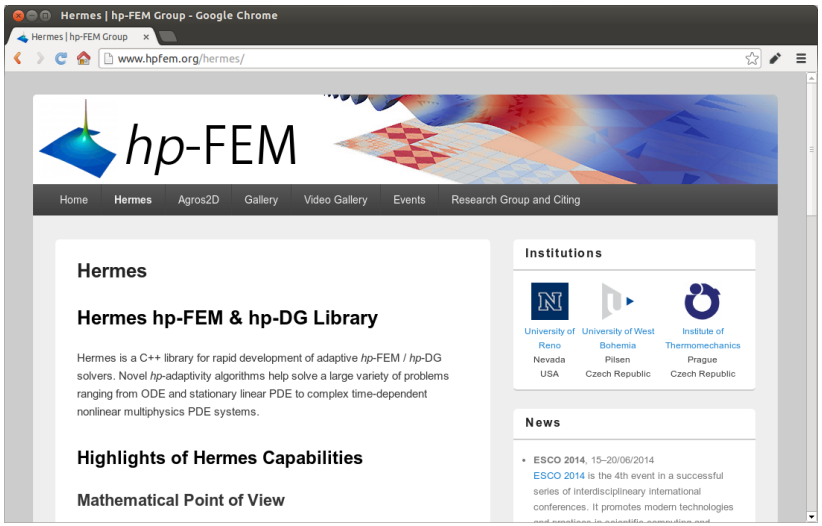
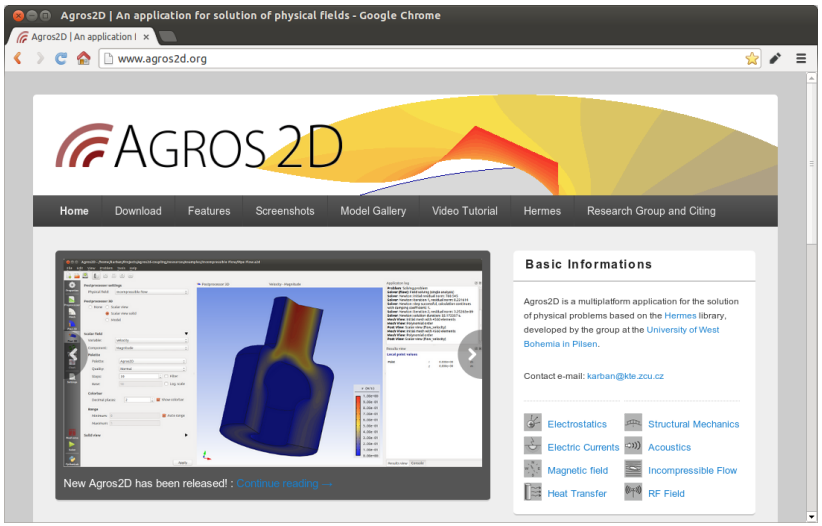
Agros2D - Hermes

Webpage

Stable version can be downloaded from our webpage



http://www.hpfem.org/



http://www.agros2d.org/

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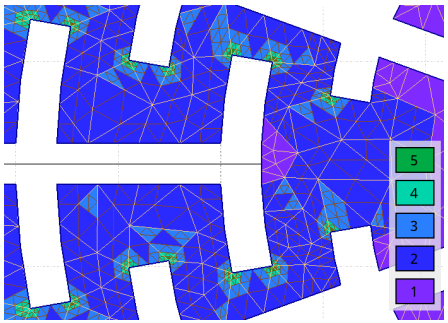
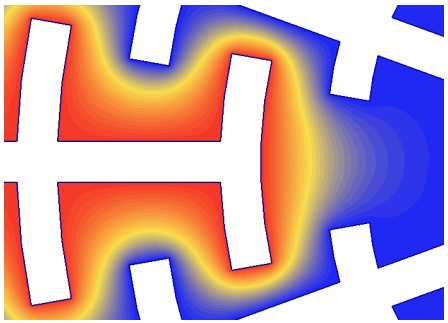
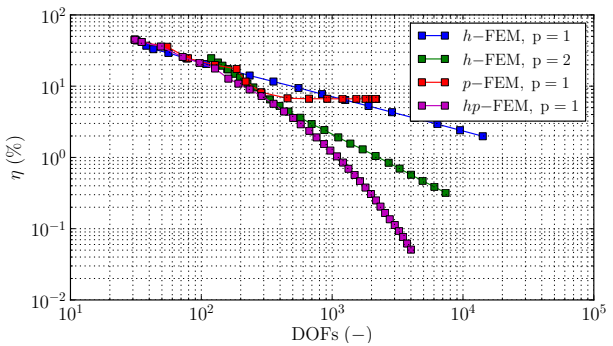
Agros2D - Hermes

Advanced features

- Finite elements of nonuniform higher orders of accuracy (powerful in terms of convergence rates)
- Fully adaptive algorithms (very efficient, but their application still requires more time).
- Multi-mesh technologies (different fields are calculated on different meshes best corresponding to their features),
- Dynamical meshes
- Hanging nodes of any order (leads to significant savings of DOFs without loss of accuracy),
- Combination of various element types (curvilinear elements fit for curved interfaces and boundaries).
- Order reduction (real-time computing with acceptable accuracy of results).







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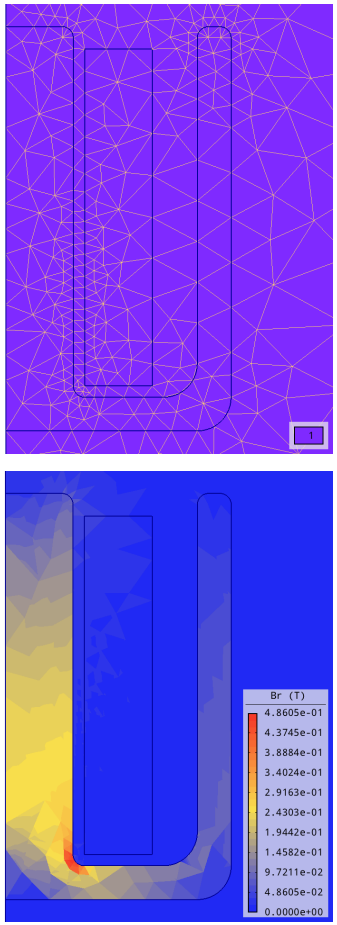

Magnetic sensor

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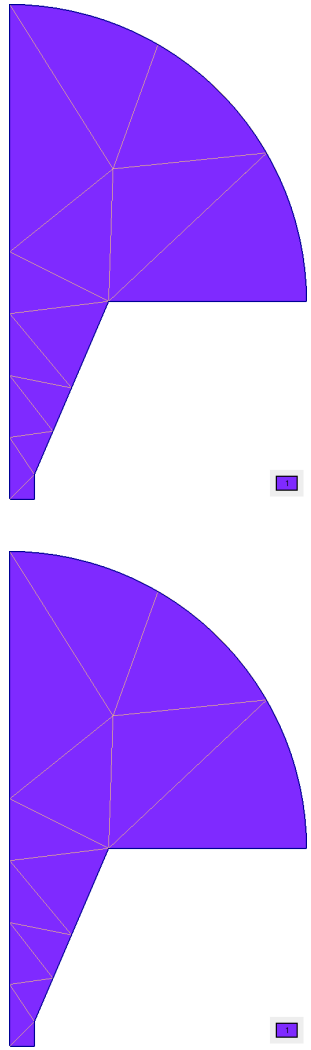

Mesh (real and imaginary part)

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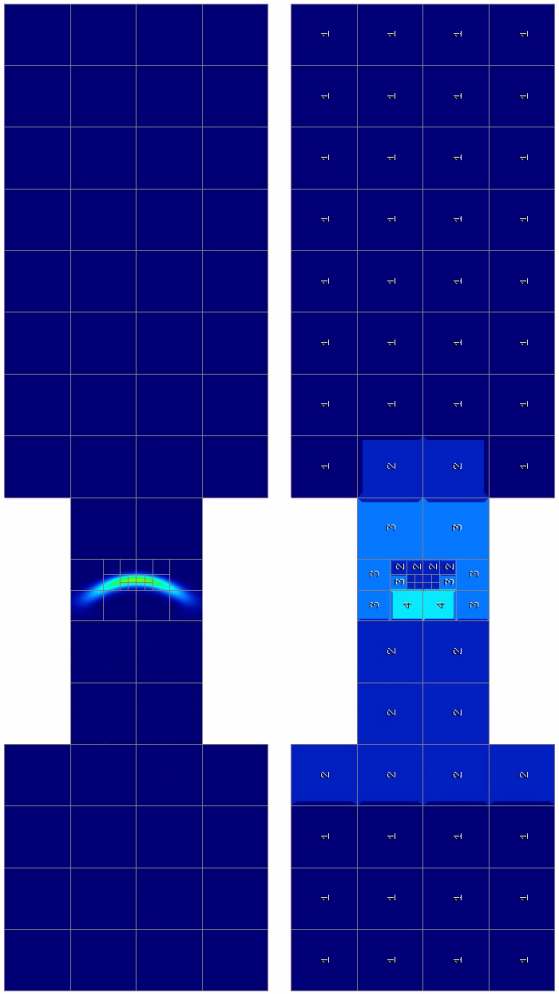

Flame propagation

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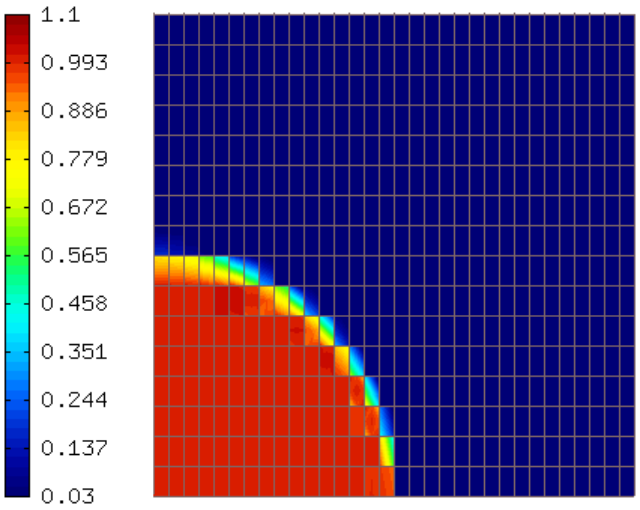

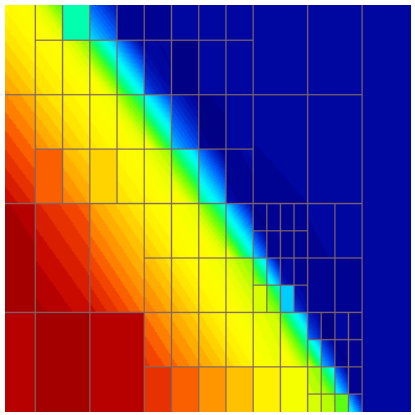

Hanging nodes of arbitrary level

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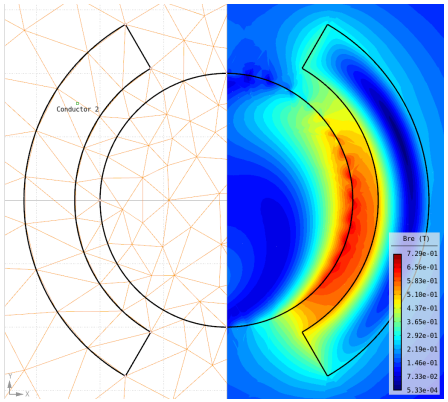
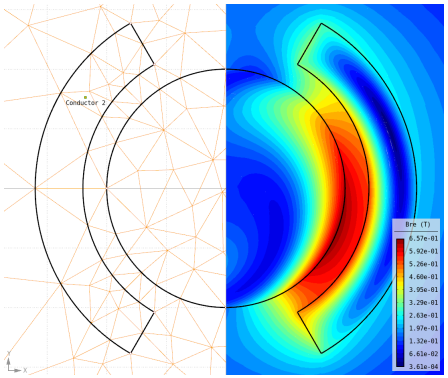


triangle elements: 3305 DOFs
(arc divided into straight lines)



curvilinear elements: 2849 DOFs
(approximated by arcs)

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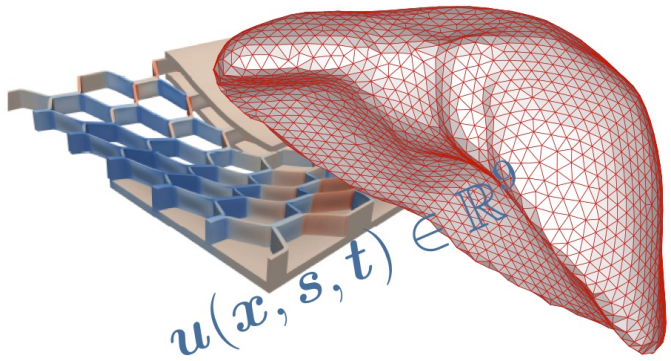

Proper Generalized Decomposition (PGD)

1

[1] Chady Ghnatios, Françoise Masson, Adrien Leygue, Elias Cueto, Francisco Chinesta: Proper Generalized Decomposition Based Dynamic Data-Driven Control of Material Forming Processes, AIP Conference Proceedings 04-2011

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Agros2D

Agros2D

New features

Our main goals

- our main interest is to bring new computational methods to engineering
- create powerful application for solving physical fields and coupled problems in 2D and 3D
- universal application for solving PDEs on personal computers with shared memory and clusters with distributed memory

Current problems

- very small group $\rightarrow$ lack of manpower for development
- impossible to maintain
  - core library for PDE (Hermes)
  - modules for physical fields (Agros)
  - advanced physical solver for coupled problems (Agros)
  - powerful and simple GUI for end-users without programming knowledge (Agros)

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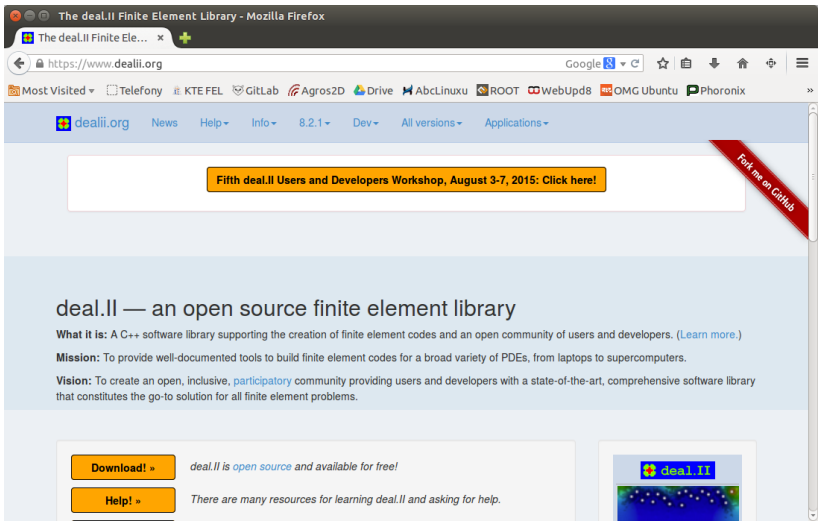
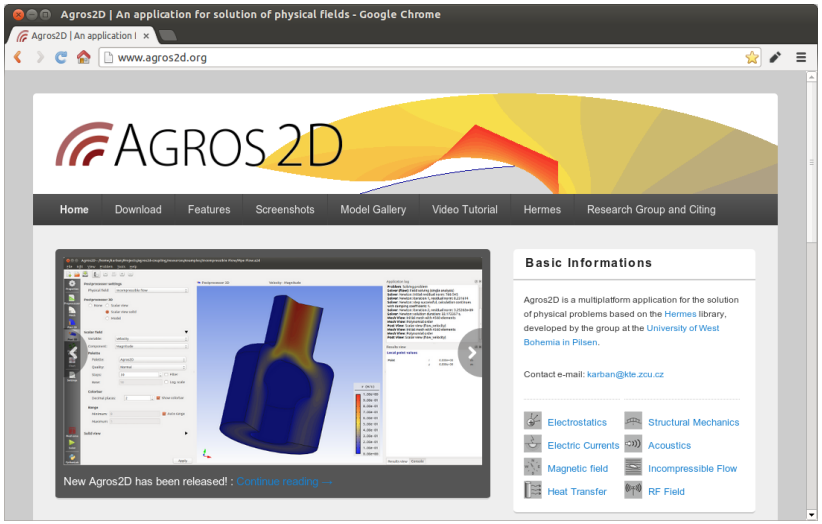
Agros2D

New features

Development version can be downloaded from our private git repository
in near future we are going to move back to GitHub
(version 4.0 – https://edison.fel.zcu.cz:444/)



http://www.dealii.org/



http://www.agros2d.org/

deal.II

Main features

Advantages

- 1D, 2D and 3D dimensions with unified interface
- Very good documentation and tutorials
- Support for a variety of finite elements: Lagrange elements, continuous and discontinuous; Nedelec and Raviart-Thomas elements
- Parallelization on single machine (Thread Building Blocks) and distributing computations using MPI
- Very low-level access to structures $\rightarrow$ we are able to simply realize our methods with the library. We can fully concentrate on method development and implementation
- A complete stand-alone linear algebra library including sparse matrices, vectors, Krylov subspace solvers, support for blocked systems, and interface to other packages such as Trilinos, PETSc and METIS
- Support for several output formats, including many common formats for visualization of scientific data

deal.II

PDE Solvers Comparison

	Hermes	**deal.II**
dimensions	1D, 2D (full), 3D (limited)	1D, 2D, 3D
elements	triangle, quad. (2D), hex. (3D)	quad. (2D), hex. (3D)
curvilinear elements	NURBS	limited but sufficient
h, p, hp adaptivity	full support	full support
hanging nodes	arbitrary order	first order
multimesh	full support	limited (?) support
dynamic meshes	full support	full support
number of active developers	2	≈ 15
operations with matrices	very limited support	full support
low level assembling	very limited (only in the library)	full support
shared memory	OpenMP (GCC, MSVC)	TBB (GCC, Clang, MSVC)
distributed memory	n/a	MPI (via Trilinos or PETSc)

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Agros2D - deal.II

Current state according to stable version

DONE

- all physical fields implemented (generated from XML description)
- weak coupling
- adaptive transient analysis (BDF methods)
- nonlinear solvers (Newton and Picard)
- h, p, hp adaptivity (Kelly estimator, p-reference estimator)
- linear algebraic solvers (UMFPACK, PARALUTION with OpenCL and CUDA support)

TODO

- hard coupling (low priority)
- adaptive dynamic meshes in transient analysis (partially works)
- nonlinearities in transient analysis (not started)
- linear algebraic solvers (native MUMPS support)
- stable Windows version (almost done)

Agros2D - deal.II

Future

Optimistic time schedule

	Date
2D beta version with similar features according to stable version	15.06.2015
2D release version with similar features according to stable version	31.08.2015
3D beta version with limited support (GUI is not yet prepared)	31.12.2015

Future and ideas

- rewrite visualization to Qt3D (low level access, future part of Qt framework)
- utilization of OpenCASCADE for preprocessor
- powerfull optimization toolbox (OptiLab – in progress – Frantisek Mach)
- DG and BEM solver
- PDE + general ODE support (electric circuits, dynamics, . . .)
- better Windows support (80 % of real users)

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Engineering Examples

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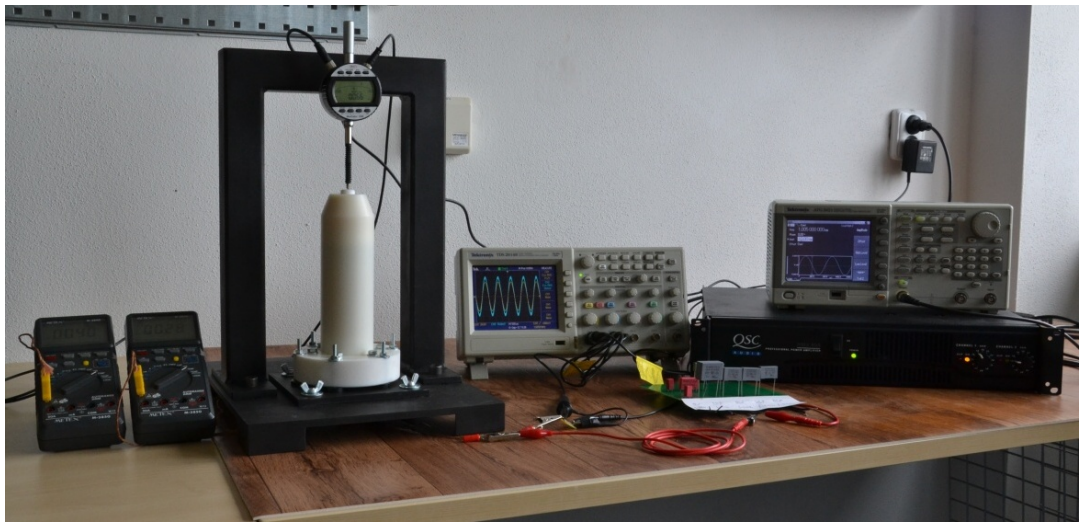
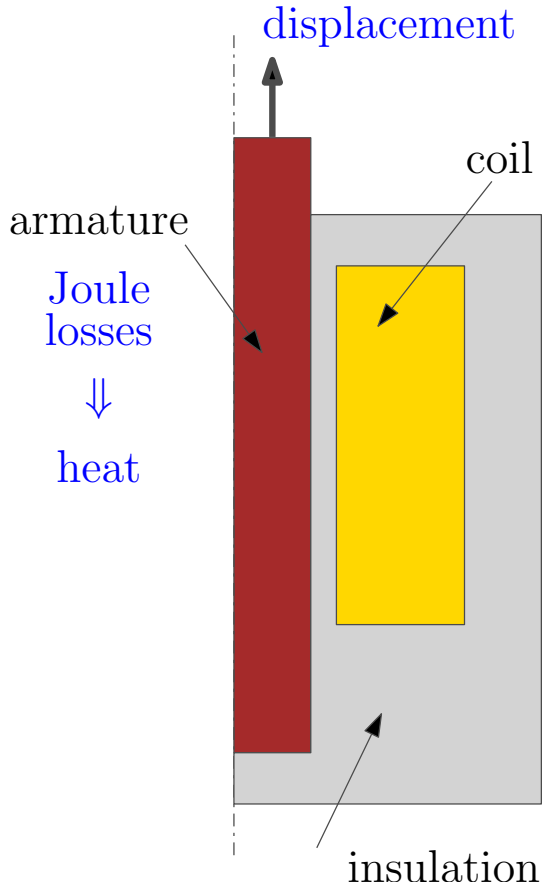
Engineering Examples

Coupled problems – Thermoelastic actuator

- Device used for precise positioning of various technical components
- Coupling of
  - harmonic magnetic field (Joule losses)
  - heat transfer (temperature difference)
  - structural mechanics (mechanical displacements)





Engineering Examples

Coupled problems – Thermoelastic actuator

Harmonic magnetic field is described by equation

$$\mathrm{curl}\ \left(\frac{1}{\mu}\ \mathrm{curl}\ \underline{\boldsymbol{A}}\right) + \mathrm{j}\omega\gamma\underline{\boldsymbol{A}} = \underline{\boldsymbol{J}}_{\mathrm{ext}},$$

where $\underline{\boldsymbol{A}}$ is phasor of vector magnetic potential, γ is electrical conductivity and $\underline{\boldsymbol{J}}_{\mathrm{ext}}$ is external current density.

Induced transform current density can be expressed as

$$\underline{\boldsymbol{J}}_{\mathrm{eddy}} = \mathrm{j}\omega\gamma\underline{\boldsymbol{A}}.$$

and specific Joule power losses

$$w_{\mathrm{J}} = \frac{\|\underline{\boldsymbol{J}}_{\mathrm{eddy}}\|^2}{\gamma}.$$

Engineering Examples

Coupled problems – Thermoelastic actuator

Nonstationary temperature field is described by equation

$$\mathrm{div}\ \lambda\ \mathrm{grad}\ T - \rho c_\mathrm{p} \frac{\partial T}{\partial t} = -w_\mathrm{J},$$

where T je temperature, ρ je mass density, c_p specific heat and λ is temperature conductivity of the material. Joule power losses is obtained from magnetic field computation.

On the outer boundary we consider convection in the form

$$-\lambda \frac{\partial T}{\partial n} = \alpha (T - T_\mathrm{ext}).$$

where α is generalized convective coefficient and T_ext is ambient temperature. The generalized coefficient also includes the influence of radiation.

Engineering Examples

Coupled problems – Thermoelastic actuator

Structural analysis is described by Lamé's equation in the form

$$(\lambda + \mu)\ \mathrm{grad}\ \mathrm{div}\ \boldsymbol{u} + \mu \triangle \boldsymbol{u} = -\boldsymbol{f} + (3\lambda + 2\mu)\ \alpha_{\mathrm{T}}\ \mathrm{grad}\ T,$$

where $\boldsymbol{u}$ is displacement vector, $\boldsymbol{f}$ is vector of internal forces and λ and μ are Lamé's coefficients which can be expressed as

$$\lambda = \frac{\nu E}{(1+\nu)(1-2\nu)}, \quad \mu = \frac{E}{2(1+\nu)},$$

α_{T} is a coefficient of thermal expansion, E is Young's module, ν is Poisson's number and $\mathrm{grad}\ T$ is temperature gradient obtained from heat transfer computation.

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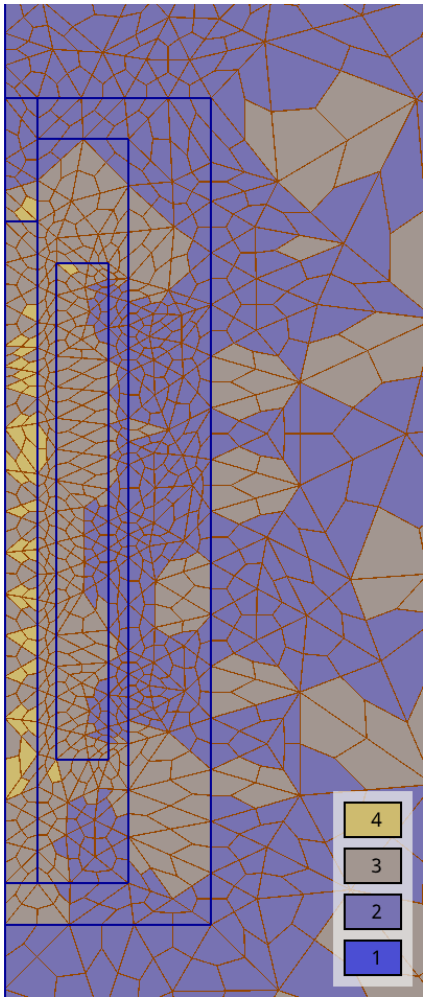
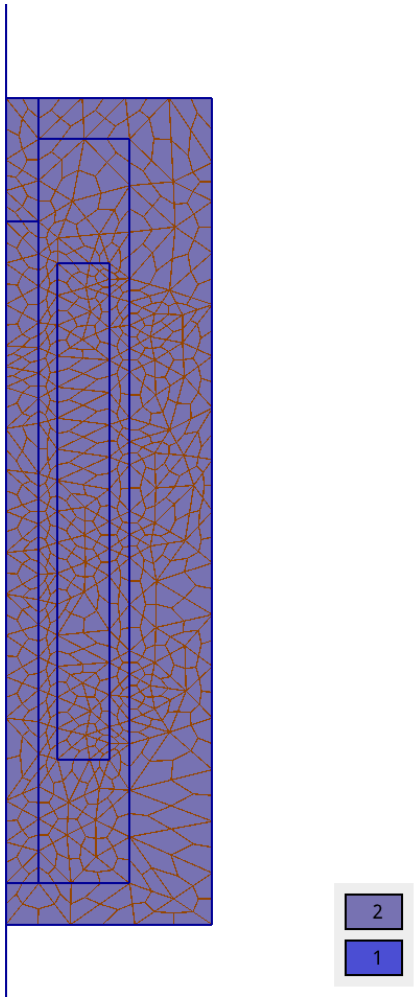
Engineering Examples

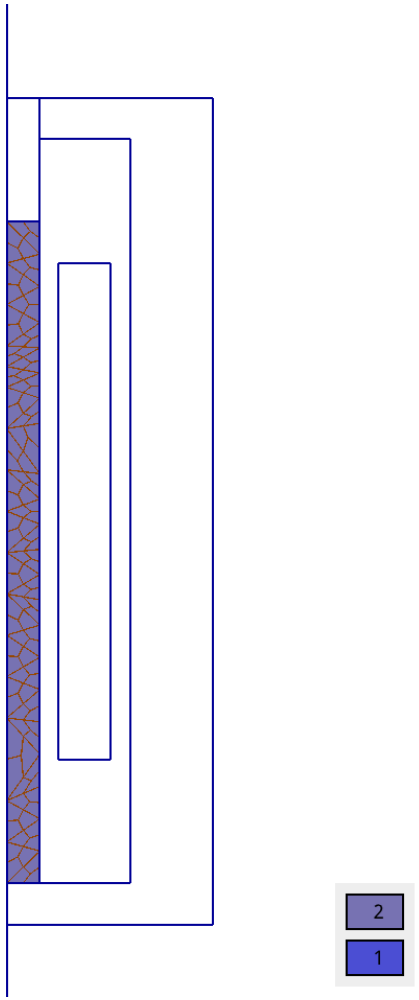
Coupled problems – Thermoelastic actuator



Harmonic magnetics



Heat transfer



Structural mechanics

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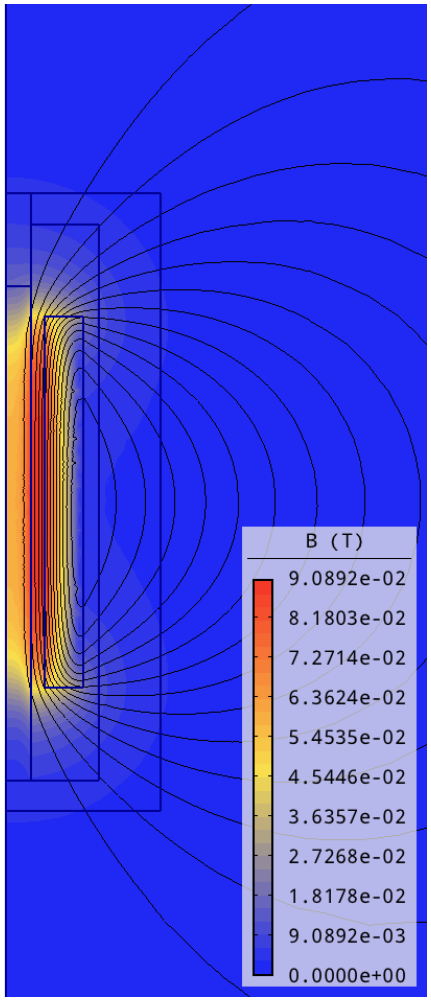
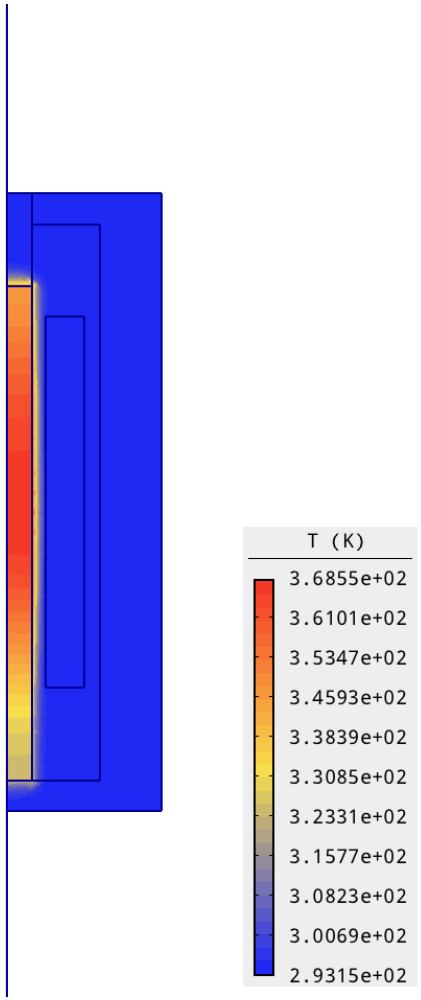
Engineering Examples

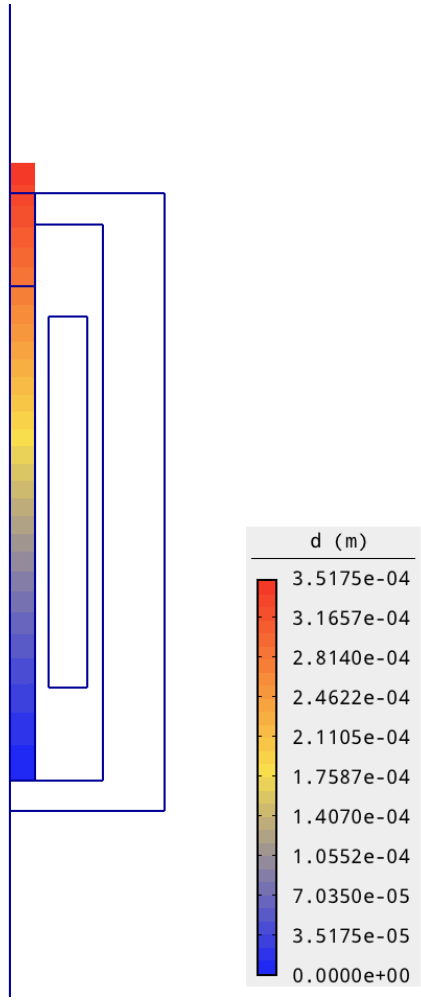
Coupled problems – Thermoelastic actuator



Harmonic magnetics
(flux density)



Heat transfer
(temperature)



Structural mechanics
(displacement)

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Engineering Examples

Coupled problems – Thermoelastic actuator

Thank you for your kind attention

AGROS 2D

http://www.agros2d.org/

We are looking for collaborators for ~~Agros2D~~ Agros project