HiFlow³ - A Finite Element Software

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HiFlow³-Finite Element Software

Introduction

– parallel finite element software

– developed by EMCL (Engineering Mathematics and Computing Lab) of Prof. Heuveline, IWR, University of Heidelberg

– 12 years of development and experience

– open source: LGPLv3-License
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A modular approach

Mesh
- 2D: triangles, quads
- 3D: tetrahedrons, hexahedrons
- unstructured meshes
- h-refinement

Finite Element Spaces
- Lagrange Finite Elements
- arbitrary polynomial degree
- p-refinement

Linear Algebra toolbox
- matrix and vector structures
- linear and nonlinear solvers
- preconditioners

User defined application
- PDE
- assembly of matrices and vectors
- postprocessing
- visualization
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Interfaces and Backends

- **interfaces** to various toolkits:
  METIS, MUMPS, ATLAS, MKL BLAS, HDF5, CLAPLACK,
  MKL LAPACK, CUDA, OpenCL, GaussQ, ILU++,
  OpenMP, UMFPACK

- **backends** for matrix and vector node-level
  implementation: CUDA, OpenMP, naive, OpenCL, ...

- **parallelism** introduced on three levels:
  - distributed memory parallelization: MPI
  - shared memory parallelization: OpenMP
  - accelerators: CUDA, OpenCL
Performance and Scalability

Nozzle benchmark:
- Incompressible Navier-Stokes equations
- Reynolds number approx. 500
- Discretization with P2/P1 elements
- about 4 Mio. unknowns
- Block preconditioning with ILU++
- GMRES iterative linear solver
- Newton method
Performance and Scalability
Scaling of Nozzle benchmark on JUROPA, FZ Jülich

![Graph showing the scaling of the Nozzle benchmark on JUROPA, FZ Jülich.](image)
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Performance and Scalability
Scaling of Nozzle benchmark on JUQUEEN, FZ Jülich
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Fields of Application
amongst others:

- Environmental Sciences
  - Baroclinic Wavetank
- Medical Engineering
  - Aortic Blood Flow
- Biochemistry
  - Chromatographic System
- Environmental Sciences
  - Tropical Cyclones
**Goal Oriented Adaptivity**

For Tropical Cyclones

**DFG MetStröm**

**Goal**
- prediction of storm tracks and intensity

**Challenges for the modeling**
- multi-scale problem
- Which regions and which processes are relevant?

**Approach:** goal-oriented adaptivity in space and time

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Goal Oriented Adaptivity
For Tropical Cyclones

Implementation highlights with HiFlow³:
- finite element discretizations in space/time (Q2-Q1/cGP(1))
- h-/Δt-adaptivity in space/time
- adaptivity guided by goal-oriented error estimators
  - computation of dual solution
  - higher-order interpolation
  - mesh adaptation strategy
- preconditioning with ILU++
- simulations with up to 10 Mio. unknowns in 3D

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Release 1.4

– available from 11/07/2014
– maintenance release – streamlined and standardized version
– new features
  – generic interfaces for Matrices and Vectors
  – additional postprocessing abilities
  – support for geometric search
  – evaluation of solution at arbitrary points
  – extended support for single precision
– two new tutorials
– improved examples
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Outlook

Release 1.5

– available from autumn 2014
– **new parallel I/O concept**
  – based on **XDMF** (eXtensible Data Model and Format) and **HDF5** (hierarchical data format)
  – enables using the same parallel I/O data format for both visualization and checkpointing
– **new module Stochastic FEM**
  – model uncertainties in physical problems
  – support of specialized solvers and preconditioners

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Thanks for your attention!