HiFlow^3 - A Finite Element Software

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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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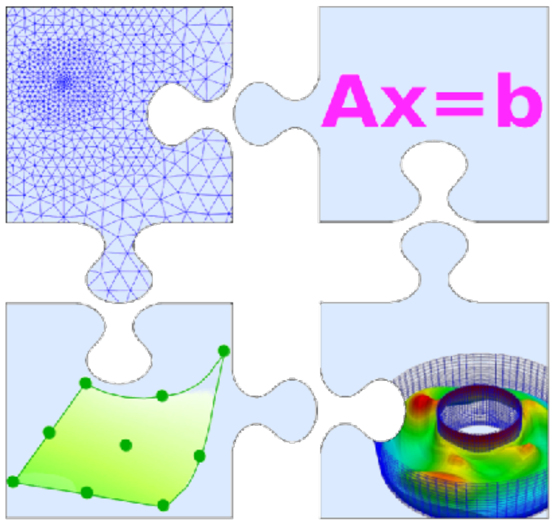
A modular approach

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

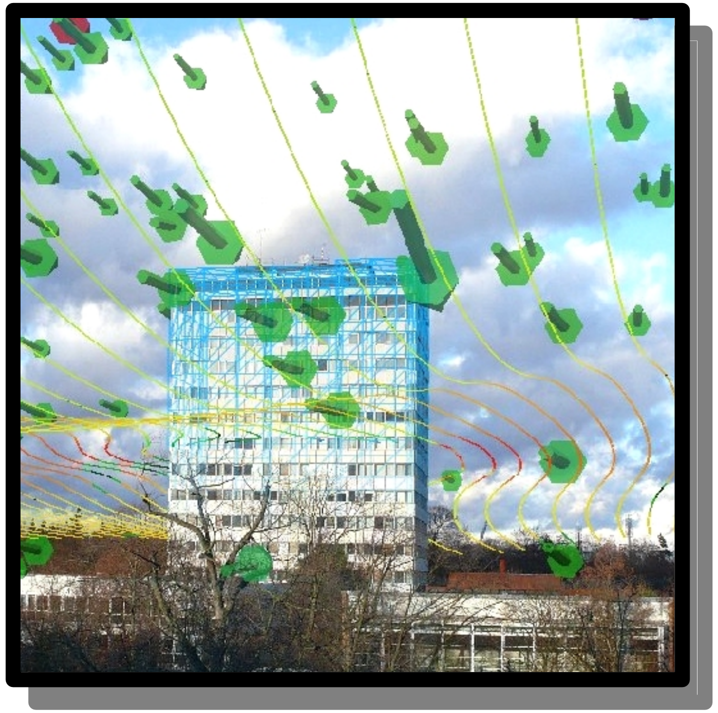
Linear Algebra toolbox
- matrix and vector structures
- linear and nonlinear solvers
- preconditioners



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

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

Interfaces and Backends



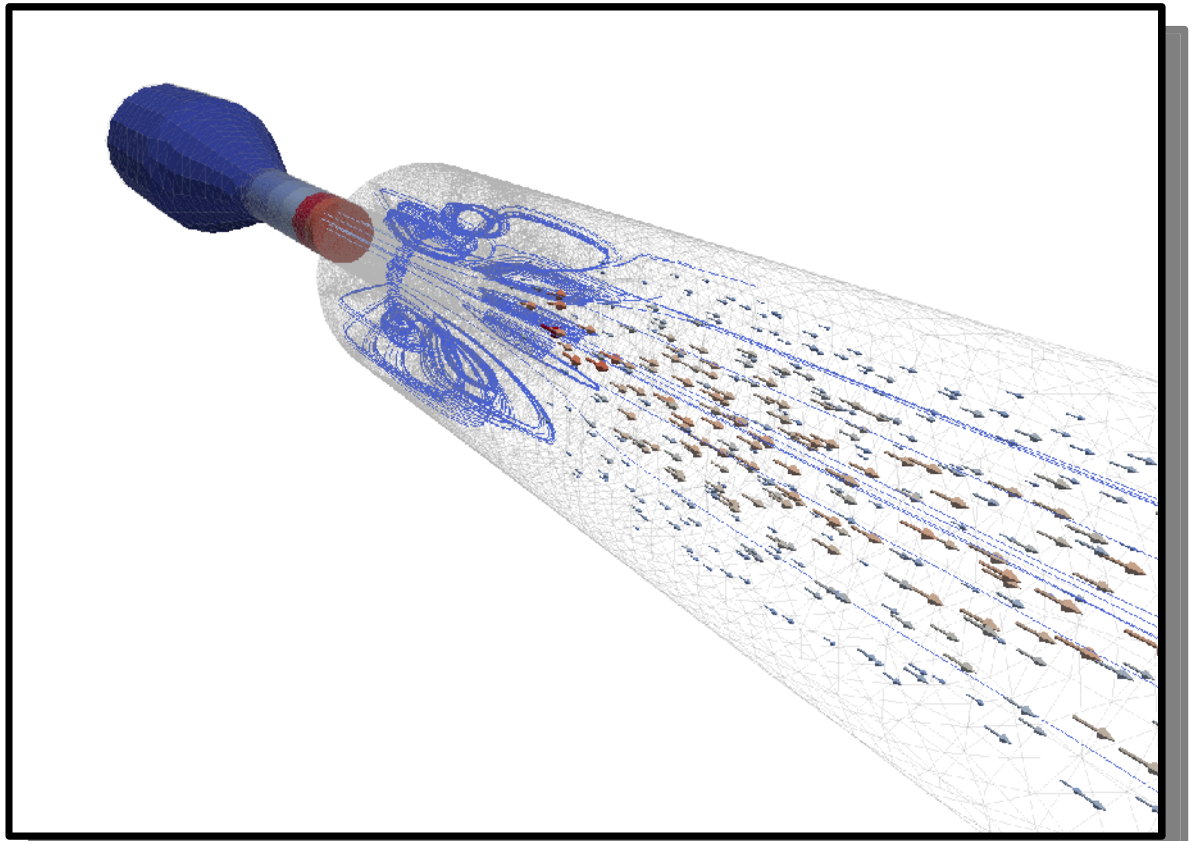
– **interfaces** to various toolkits:
METIS, MUMPS, ATLAS, MKL BLAS, HDF5, CLAPLACK, MKL LAPACK, CUDA, OpenCL, GaussQ, ILU++, OpenMP, UMFPACK

– **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**

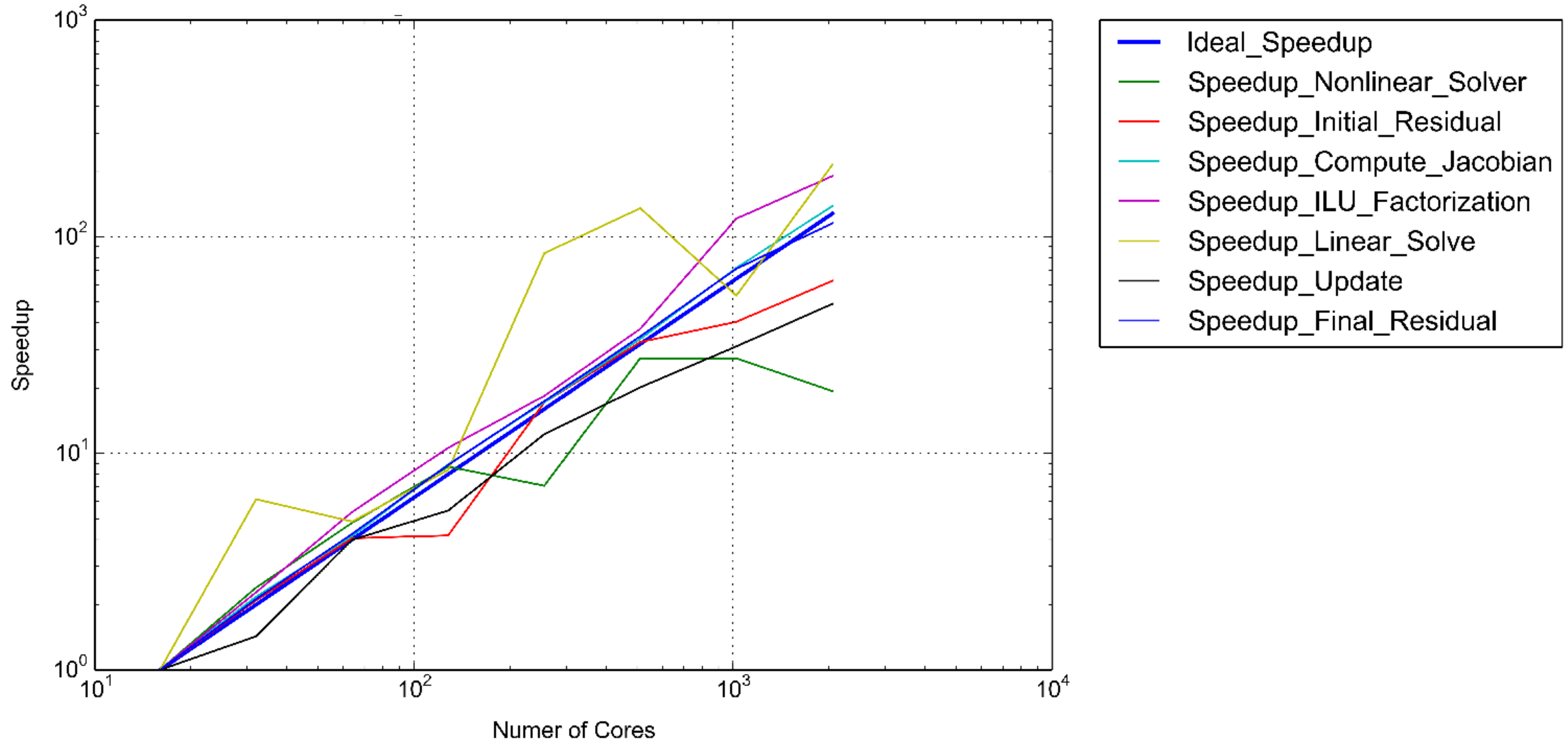
Performance and Scalability

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



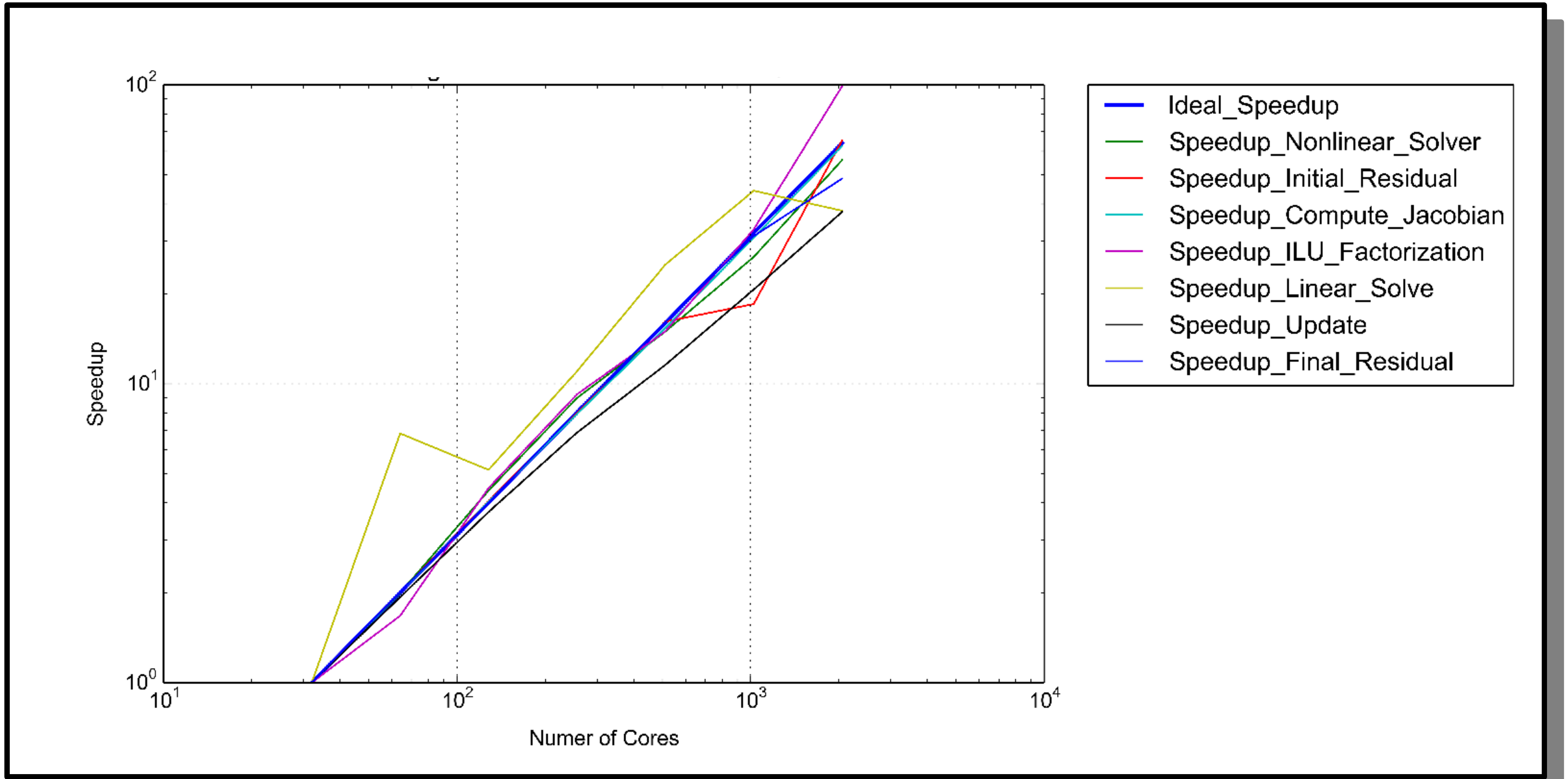
Performance and Scalability

Scaling of Nozzle benchmark on JUROPA, FZ Jülich



Performance and Scalability

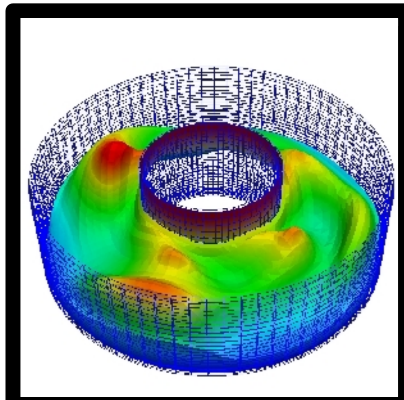
Scaling of Nozzle benchmark on JUQUEEN, FZ Jülich



Fields of Application

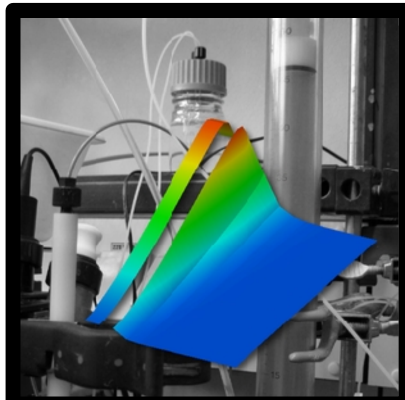
amongst others:

Environmental Sciences
Baroclinic Wavetank

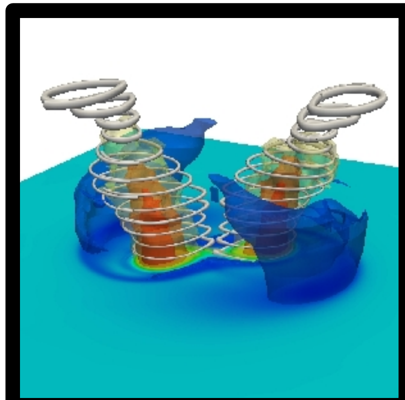


Medical Engineering
Aortic Blood Flow

Biochemistry
Chromatographic System



Environmental Sciences
Tropical Cyclones



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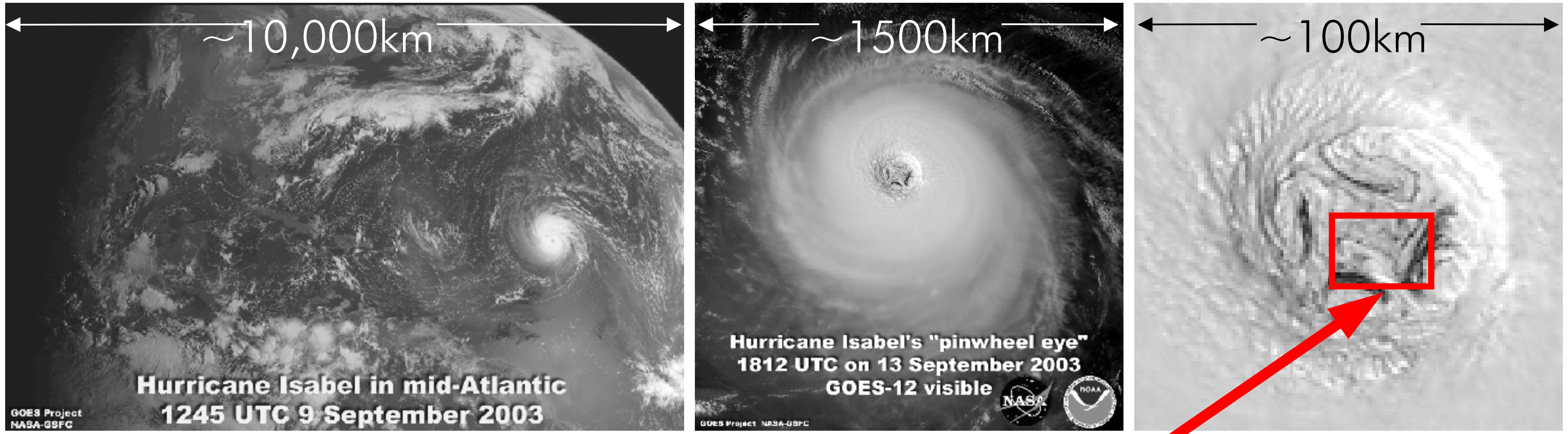
Goal Oriented Adaptivity

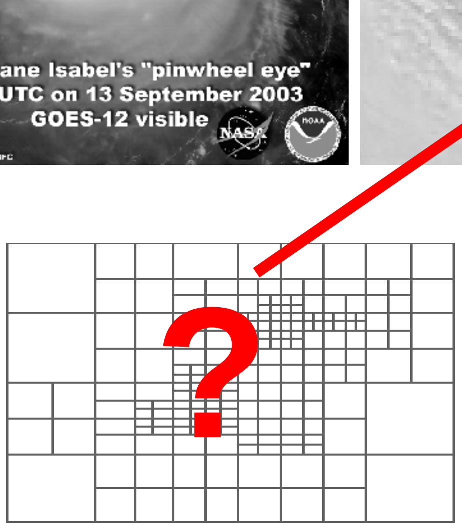
For Tropical Cyclones

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

Reference: Baumann, M., *Numerical Simulation of Tropical Cyclones using Goal-Oriented Adaptivity,* Phd-Thesis, Karlsruhe Institute of Technology, 2011

HiFlow³-Finite Element Software

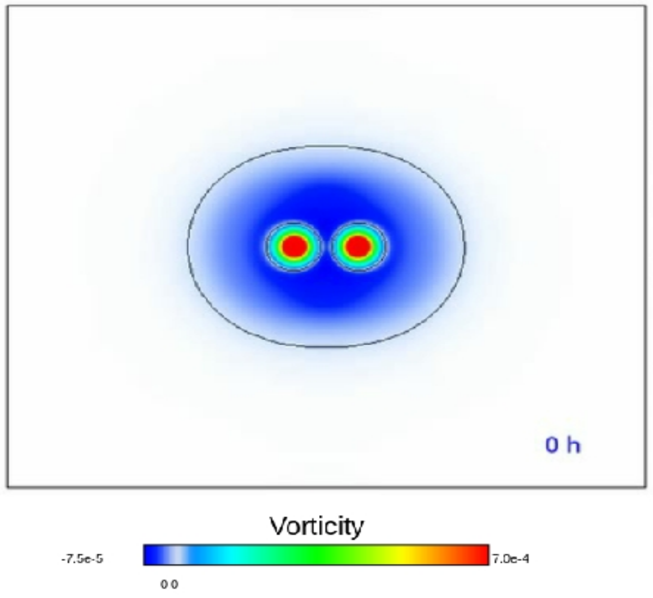
Goal Oriented Adaptivity

For Tropical Cyclones

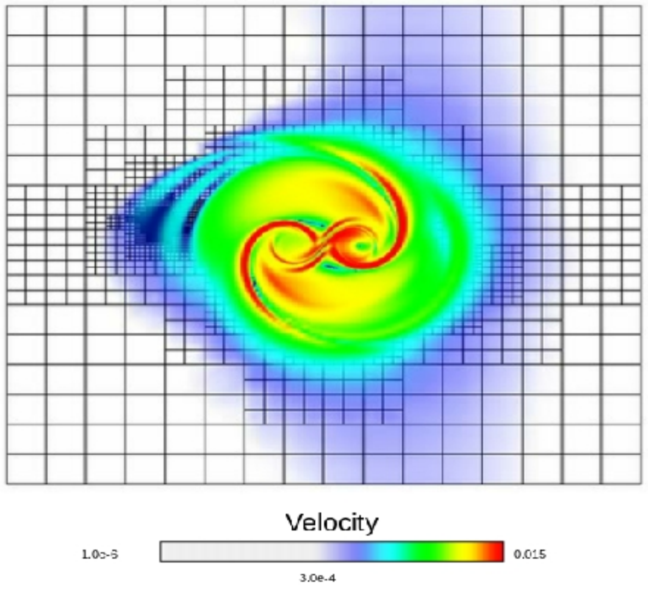
Implementation *highlights* with HiFlow³

- 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. unkowns in 3D

Primal Solution



Dual Solution (Sensitivity)



Reference: Baumann, M., *Numerical Simulation of Tropical Cyclones using Goal-Oriented Adaptivity,* Phd-Thesis, Karlsruhe Institute of Technology, 2011

HiFlow³-Finite Element Software

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**

Outlook

HiFlow^3

Release 1.5

- available from autumn 2014
- **new parallel I/O concept**
  - based on **XDMF** (eXtensible Data Model and Format) and **HDF5** (hierarchival 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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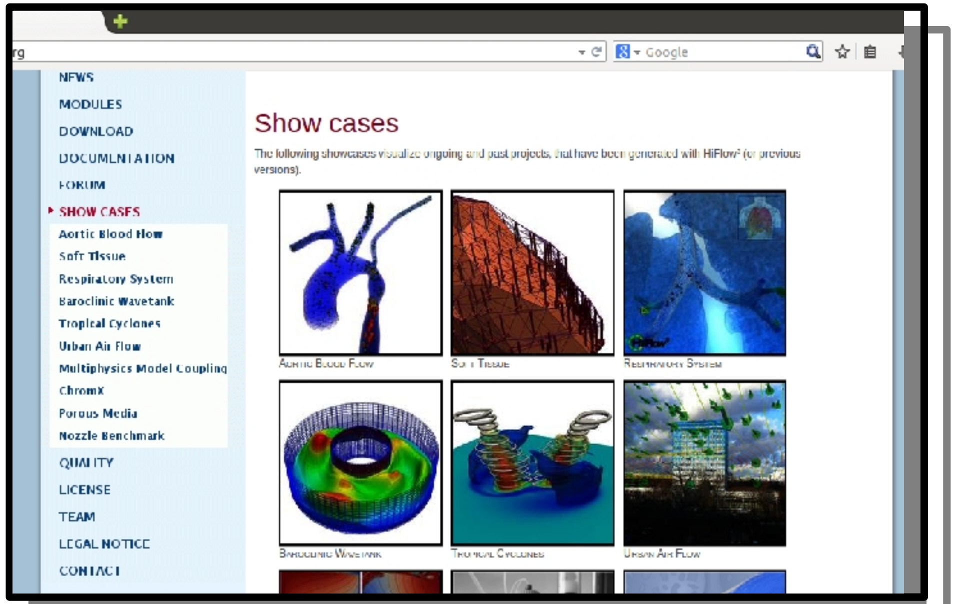
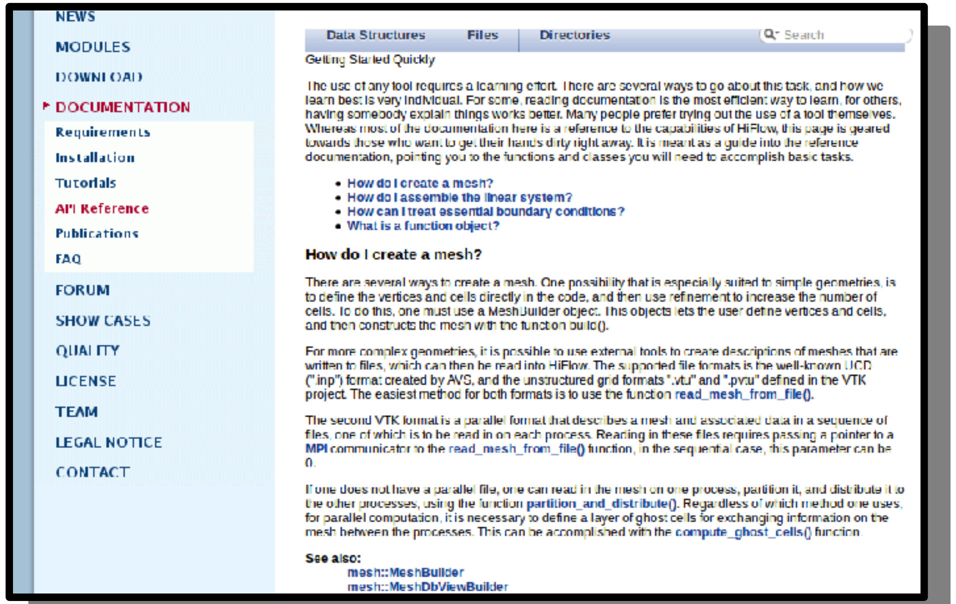
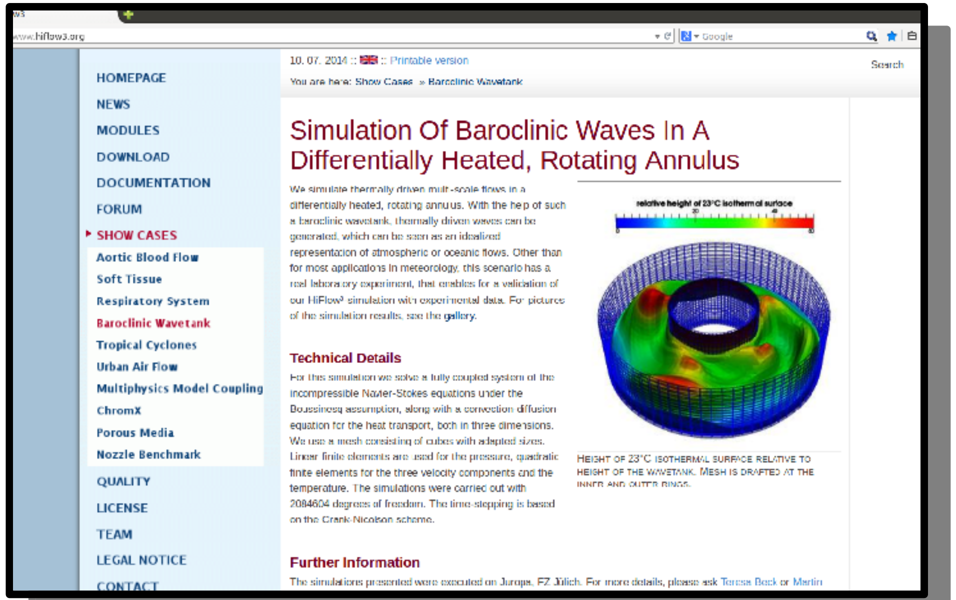
- Documentation
- Show cases
- Tutorials
- Forum
- Download
- ...







Thanks for your attention!