ExaHyPE – An Exascale Hyperbolic PDE Engine

FET-PROACTIVE – Towards Exascale High Performance Computing

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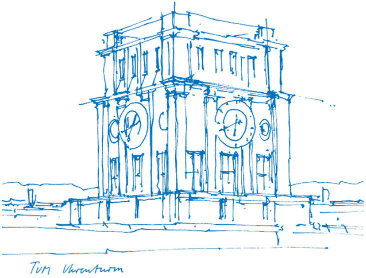
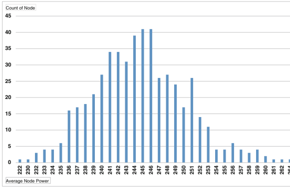
Prague, May 9–10, 2016



Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 671698.

Towards an Exascale Hyperbolic PDE Engine



Results by Wilde et al., ISC'15

Key Assumptions on Exascale Hardware:

Equal work load will no longer lead to balanced computation time.
Moving data is the thriving constraint for performance and energy consumption.

Requirements for Exascale Algorithms:

- dynamic load balancing with lightweight adaptive response
- avoid communication and maximise arithmetic intensity
- **plus:** maximise “science per flop”

$\Rightarrow$ Focus on High Order Discretisation in Space and Time:

- ADER-DG with local time-stepping and novel FV-based limiting

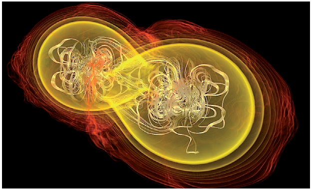
Towards an Exascale Hyperbolic PDE Engine

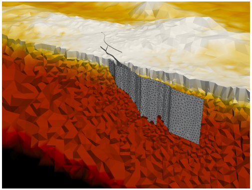
Key Assumption on Exascale Software:

Grand challenge applications require tailoring of existing codes to the specific challenge and cannot rely on general-purpose solutions.

ExaHyPE Goal:

- enable medium-sized interdisciplinary research teams to realise extreme-scale simulations of grand challenges within one year
- focus on hyperbolic conservation laws
- concentrate on two specific grand challenges in the project:





ExaHyPE Work Programme

Petascale Prototype

Peano framework for parallel adaptive mesh refinement,
Space-time adaptive ADER-DG with a-posteriori sub-cell FV limiting

Extreme Parallelism and Performance

dynamic load balancing
hardware optimization of kernels

Novel Numerics for Astrophysics

positivity preserving ADER-DG on adaptive grids for non-ideal GRMHD with general EOS

Novel Numerics for Seismology

ADER-DG for dynamic rupture on space-time adaptive grids in heterogeneous, nonlinear material

Exascale Environment

energy efficiency (coop. with LRZ and RSC)
resilience, ... (coop. with FETHPC, etc.)

Grand Challenge Demonstrators

Astrophysics

MHD turbulence and instabilities
gravitational wave during inspiral
GW/EM emission after merger

Seismology

Seismic hazard assessment
uncertainty quantification

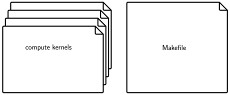
Towards an Exascale Hyperbolic PDE Engine

User API and Simulation Engine:

- user-defined hyperbolic PDEs
- definition of fluxes and eigenvalues
- toolkit-based code generation

```
computational-domain
  dimension                  = 2
  width                      = 1.0
  offset                     = 0.0, 0.0
  end-time                   = 0.4
end computational-domain

solver ADER-DG EulerFlowSolver
  unknowns   = 5
  parameters= 0
  order      = 7
  kernel     = generic::fluxes::nonlinear
  language   = C
  ...
end solver

shared-memory
  ...
end shared-memory

optimisation
  fuse-algorithmic-steps    = on
end optimisation
```

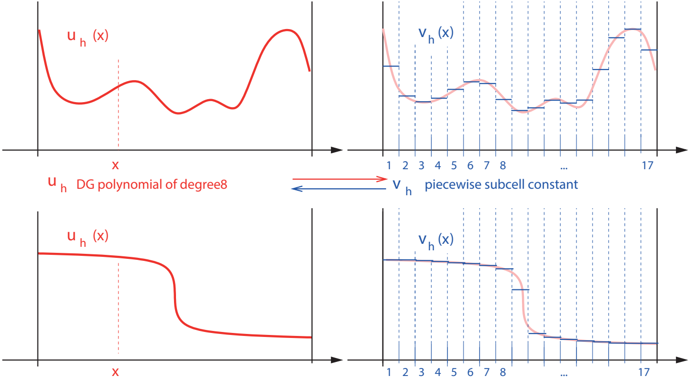
```
void flux(Q, f, g) {
  // @todo Please implement
  irho = 1.0/Q[0];
  ...
  f[0] = Q[1];
  f[1] = irho * Q[1] * Q[1] + p;
  f[2] = irho * Q[1] * Q[2];
  f[3] = irho * Q[1] * Q[3];
  f[4] = irho * Q[1] * (Q[4] + p);

  g[0] = Q[2];
  g[1] = irho * Q[2] * Q[1];
  g[2] = irho * Q[2] * Q[2] + p;
  g[3] = irho * Q[2] * Q[3];
  g[4] = irho * Q[2] * (Q[4] + p);
}

void eigenvalues(Q, normal, lambda) {
  // @todo Please implement
}

void adjustSolutionValues(x, w, t, dt, Q) {
  // @todo Please implement
  if(t == 0.0) {
    Q[0] = 1.0;
    Q[1] = Q[2] = Q[3] = 0.0;
    Q[4] = exp(x[0]*x[0]+x[1]*x[1]);
  }
}
```



Towards an Exascale Hyperbolic PDE Engine

DG with FV-based Subcell Limiting:

- high-order DG method, high accuracy and compute-bound regimes
- a-posteriori identification of troubled cells
- FV recomputation and DG reconstruction



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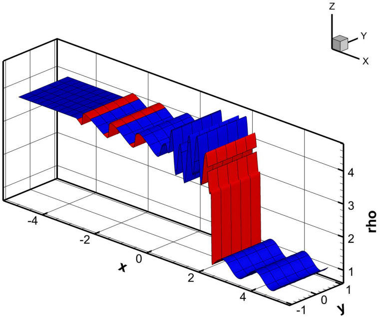
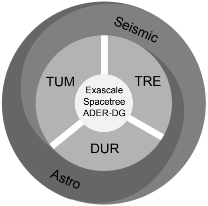


ExaHyPE Participants and PIs



University Participants:

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- Durham University: Tobias Weinzierl
- Università degli Studi di Trento: Michael Dumbser
- Frankfurt Institute for Advanced Studies: Luciano Rezzolla
- Ludwig-Maximilians-Universität München: Alice-Agnes Gabriel, Heiner Igel

Industry Participants:

- RSC Group (Russia): Alexander Moskovsky

Project Management and Dissemination:

- BayFOR – Bavarian Research Alliance: Robert Iberl