A Generic Profiling Infrastructure for the Hyperbolic PDE Solver Engine ExaHyPE
Part II

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The project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 671698 (ExaHyPE).

Introduction

What this presentation is not about:

- **Numerics** deep dive into ADER-DG, Limiting, etc. (first $\sim$ 30 pages of the thesis)
- No beautiful **pictures**, convergence **plots**, application **examples**, ...
- **Demo session** ;-(

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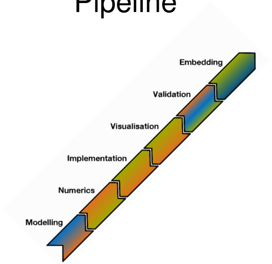
What this presentation is about:

- Review: **Context** and **motivation** behind the project
- Theory on **hardware performance monitoring** (HPM)
- A **generic profiling infrastructure** for ExaHyPE
- Preliminary profiling results and case studies focusing on metrics-driven performance engineering

Context & Motivation

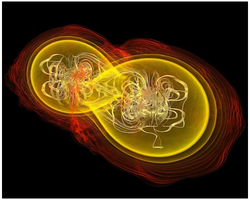
Important aspects in the context of Scientific Computing:

Simulation Pipeline



Exascale Computing

Hyperbolic Balance Laws



ExaHyPE: The Project

Vision:

- Three pillars of scientific progress:
  Theory, Experiment and **Simulation**
- Programming (exascale) supercomputers is a key challenge
- The ExaHyPE project seeks to address the **software aspect** of supercomputer development
  - Development of new mathematical and algorithmic approaches
  - Initial focus on applications in geo- and astrophysics
  - In correspondence with Europe's **2020 exascale strategy**
- Goal: Become **the engine** for large HCL simulations!

ExaHyPE: The Project

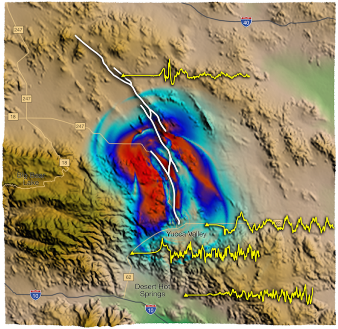
Objectives:

- **Energy efficiency** on tomorrow's supercomputing hardware
- Scalable algorithms through well-balanced **dynamic adaptivity**
- **Compute-bound** simulations in spite of slow memory and networks
- Extreme parallelism on **unreliable hardware**

ExaHyPE: The Project

Benefit:

- Simulation of **risk scenarios**
  - Assess the effects of earthquake and aftershocks
  - Quantify seismic hazards
- Enable fundamental **scientific findings**
  - Study some of the longest-standing mysteries in astrophysics. . .
  - . . . and other disciplines
- **Open-source** (BSD3,)

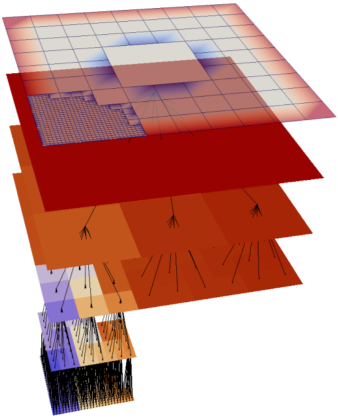


Simulation of the 1992 Landers Earthquake
(via Alexander Heinecke, 2014)

ExaHyPE: The Project

Approach:

- High-order space-time Discontinuous Galerkin method (**ADER-DG**) with a-posteriori FVM based subcell limiting
- Dynamically adaptive Cartesian grids (**AMR**), space filling curves and dynamic load balancing (**Peano**)
- Hardware specific optimization of dominant compute kernels (**libxsmm**)



Adaptive grids in Peano
(via Tobias Weinzierl, 2014)

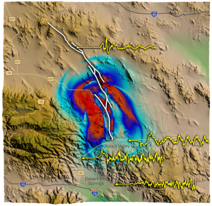
ExaHyPE: Applications

Hyperbolic Balance Laws:

$$\frac{\partial}{\partial t}\,[\boldsymbol{u}]_v + \frac{\partial}{\partial x_d}\,[\boldsymbol{F}(\boldsymbol{u})]_{vd} = [\boldsymbol{s}\,(\boldsymbol{u})]_v$$

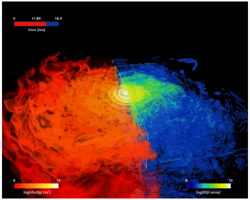
Initial focus:

Geophysics



Simulation of ground shaking of the 1992 Landers Earthquake

Astrophysics



Simulation of the merger of two magnetized neutron stars

Profiling for ExaHyPE: Motivation

You can't optimize for what you don't measure!

Profiling provides metrics to

- obtain a **baseline**,
- **guide** and **track progress** of optimization efforts,
- **compare** current status to other state of the art solutions.

We don't need a third one of these on campus!

Profiling and Energy-Aware ...

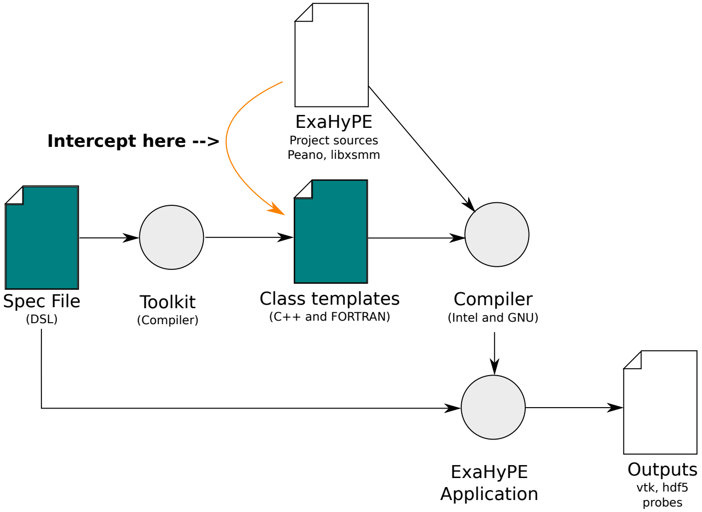
On the Importance?

x86 in contemporary HPC

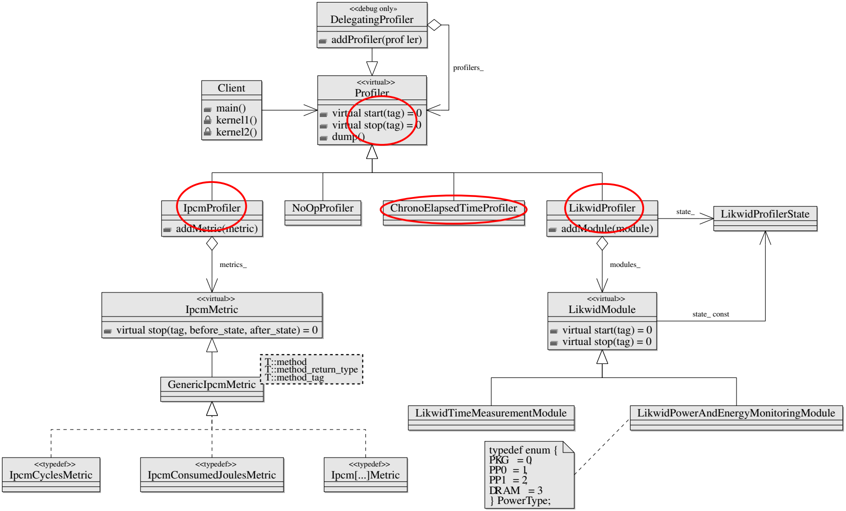
HPM in x86

Energy Monitoring in x86

Profiling for ExaHyPE: Architecture



Profiling for ExaHyPE: Architecture



Implementations

Profiling for ExaHyPE: Metrics

What we can measure at the moment:

- Kernel call counts
- Cycles and wall clock time
- RAM reads/writes
- **Flop/s** (estimate)
- **Energy consumption** (Core, RAM, package; estimate)
- Cache hits/misses/ratio (I, L2, L3)
- **Cycles lost** due to cache misses (L2, L3)
- Instructions retired
- Branch prediction ratio
- ...

Overheads

Complete Simulation

Kernel-by-kernel breakdown

The seventh order itch

Finding the juiciest fruits

Conclusion

Key aspects:

1. Exascale Computing is about both hardware and **software**
2. ExaHyPE as an **answer to future challenges** in Scientific Computing
3. **Frameworks** are necessary to manage the increasing complexity in HPC
4. Profiling is important: **Measure, then optimize!**

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