HPC with Unstructured Meshes on Novel Architectures

Introduction

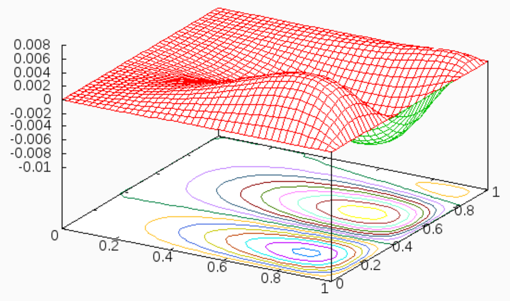
- Main focus on many-core parallel solvers for discretized linear and non-linear partial differential equations.
- Analyses performed on a set of applications with unstructured discretization based on tetrahedral meshes.
- Evaluations and analyses on both ARM and Intel platforms.

Applications Description

Jacobi solver

The Jacobi solver is a micro-app. We consider the potential problem,
$-\nabla^T\lambda(x)\nabla u(x) = f(x) \quad \forall x \in \Omega, +$ Dirichlet B.C. on $\partial\Omega$.

Solution of, $-u^{\prime\prime}(x,y) = x^2 * sin(2.5 * \pi * y)$

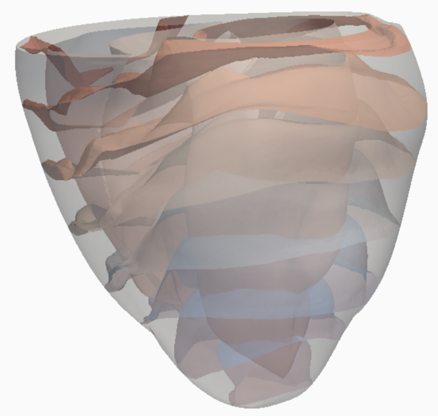


- Domain discretization with triangular elements and linear shape functions.
- Using finite element approach -> linear system of equations $K\underline{u} = \underline{f}$ with a symmetric and positive definite $n \times n$ matrix K.
- Stored in the compressed row storage (CRS) format.

Eikonal Slover

The Eikonal equation is a special case of non-linear Hamilton-Jacobi partial differential equations (PDEs). In this work, we consider the numerical solution of this equation on a 3D domain with an inhomogeneous, anisotropic speed function:

$$\begin{cases} \sqrt{(\nabla\varphi)^\top * M * \nabla\varphi} & = 1, \quad \forall x \in \Omega \subset R^3 \\ \varphi(x) & = T(x), \forall x \in B \subset \Omega \end{cases}$$

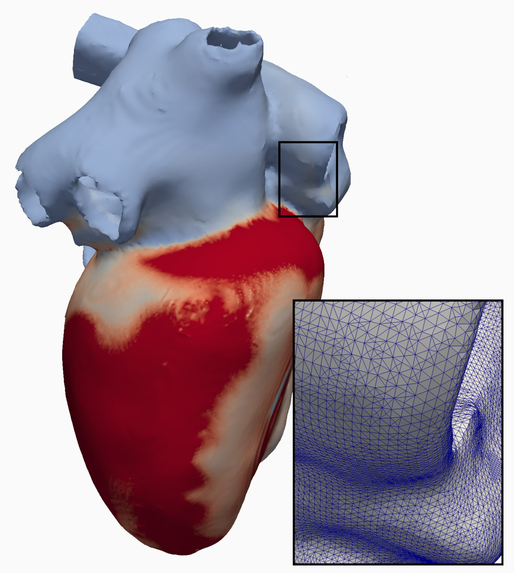


- φ(x) is the travel time at position x from a collection of given (known) sources on the boundary of the domain.
- M(x) is a 3 * 3 symmetric positive-definite matrix encoding the speed information on Ω.
- B is a set of smooth boundary conditions which adhere to the consistency requirements of the PDE.

CARP

The Cardiac Arrhythmia Research Package (CARP), is a full-sized application for solving the cardiac bidomain equations, consisting of three main components:

- Parabolic solver.
  - Determining the propagation of electrical activity, by the change in transmembrane voltage from the extracellular electric field and current state of the transmembrane voltage.
- Elliptic solver.
  - Determines extracellular potential from transmembrane voltage at each time instant.
- Ionic Model.
  - Is a set of ordinary differential equations in the cell membrane (Ca+,Na+,...).



Machines

- **ThunderX** Cluster
  - 2x sockets Cavium ThunderX
  - 48x **ARMv8-A** cores @1.8GHz
- **Jetson TX1** Cluster
  - Nvidia Tegra X1 SoC
  - 4-Plus-1 quad-core **ARM Cortex A-57**
- Intel(R) **Xeon Phi(TM)** CPU 7210 @ 1.30GHz
- Intel(R) Xeon(R) CPU E5-2650 v4 @ 2.20GHz

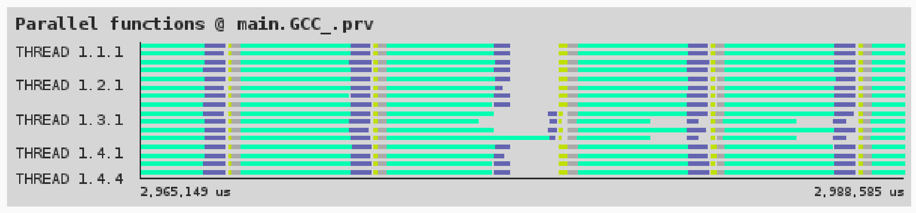
Tools

- **Extrae** - Trace generation (BSC).
- **Paraver** - Performance visualisation and analysis (BSC) [3].
- **Dimemas** - Simulation tool (BSC)
- Performance Application Programming Interface - **PAPI**.
- Linux profiling with performance counters.
- Likwid

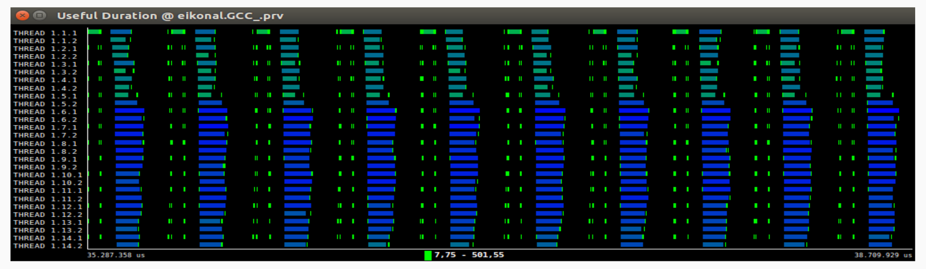
Analysis

Parallelization issues

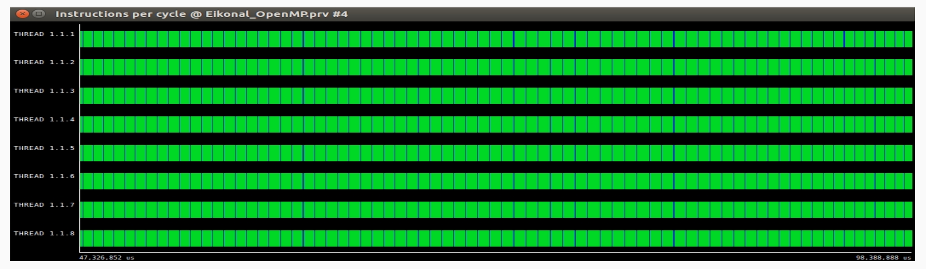
- Memory bandwidth limitation.
- Load imbalances.
- System noise.
- Process migrating.
- Network interconnection.
- Global problem size.
- MPI message transfer.
- Memory access latencies.



Jacobi parallel function Intel Xeon E5.



Eikonal computation duraction on Mont-Blanc Prototype (MPI).



Eikonal instructions per cycle on ThunderX (OpenMP).

Jacobi solver

- Problem size: 1024 x 1024.
- Number of iteration: 1000.
- Using 4-MPI with 4 Thread each.

Eikonal solver

- Two different meshes:
  - Rabbit heart 3 mill. tets.
  - Human heart 24 mill. tets.

Improvements

- Use of non-blocking MPI point-to-point communication.
- Overlapping communication and computation.
- Memory footprint reduction.
- Domain decomposition approach.

Eikonal Solver Results for Rabbit Heart on ARM and Intel

Efficiency drops after the second socket is used on ThunderX

#Cores	#Execution time (sec.)	#Speed-Up	#Efficiency
1	49.43	1	1
2	27.44	1.78	0.89
4	14.73	3.35	0.84
8	7.54	6.55	0.82
16	3.95	12.51	0.78
32	1.98	24.96	0.78
48	1.43	34.56	0.72
64	1.21	40.85	0.64

- Efficiency more than 70% until 48-cores on ThunderX and 64-cores on Xeon Phi.

Efficency drops after all physical cores are used on Xeon Phi

#Cores	#Execution Time (sec.)	#Speed-Up	#Efficiency
1	64.1	1	1
2	35.7	1.97	0.89
4	20.4	3.14	0.78
8	10.6	5.50	0.75
16	5.5	11.65	0.73
32	2.81	22.81	0.71
48	1.85	34.64	0.72
64	1.42	45.14	0.70
96	1.09	58.8	0.61
128	0.90	71.22	0.55
256	0.68	94.2	0.36

Jacobi Solver Results

Jacobi execution on the Mont-Blanc Prototype with 2-thread/MPI

MPI Processes	Execution time (seconds)	Speed-Up	Efficiency
1	54.52	1	1
4	16.41	3.32	0.83
16	7.61	7.16	0.45
64	5.14	10.60	0.17

- Poor performance, memory bandwidth limitation and slow node interconnection.

Jacobi on ThunderX with 2-thread/MPI

MPI Processes	Execution time (seconds)	Speed-Up	Efficiency
1	212	1	1
4	21.60	9.81	2.45
16	13.60	15.58	0.97
64	5.00	21.2	0.66

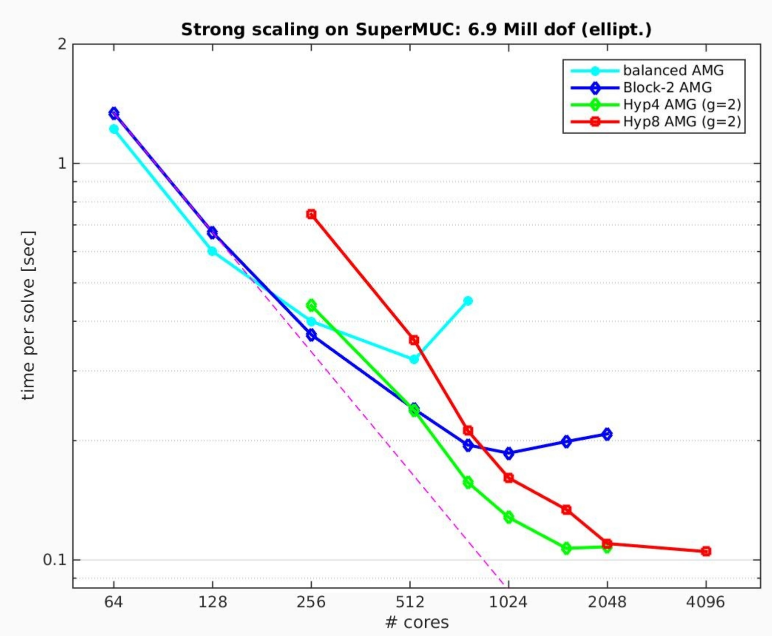
- Super-linear speed-up until we hit memory bandwidth.

CARP on ThunderX and SuperMUC

CARP on ThunderX for the rabbit heart mesh

#Cores	#Total time (sec)	#Elliptic	#Parabolic	#ODE
1	6382	5680	642.7	33.7
2	4656	4313	307.7	16.6
4	2675	2519	134.0	8.42
8	1390	1316	56.5	4.32
16	1080	1036	30.2	2.19
32	901	871	16.9	1.13
64	810	787	10.6	0.59
128	777	756	7.6	0.33

- Good scaling results up to 16-OpenMP thread per MPI on ThunderX.
- Electromechanic heart beat simulation on a realistic discretization with 45 Million tetrahedrons on SuperMUC using 16192-cores takes 8 minutes.

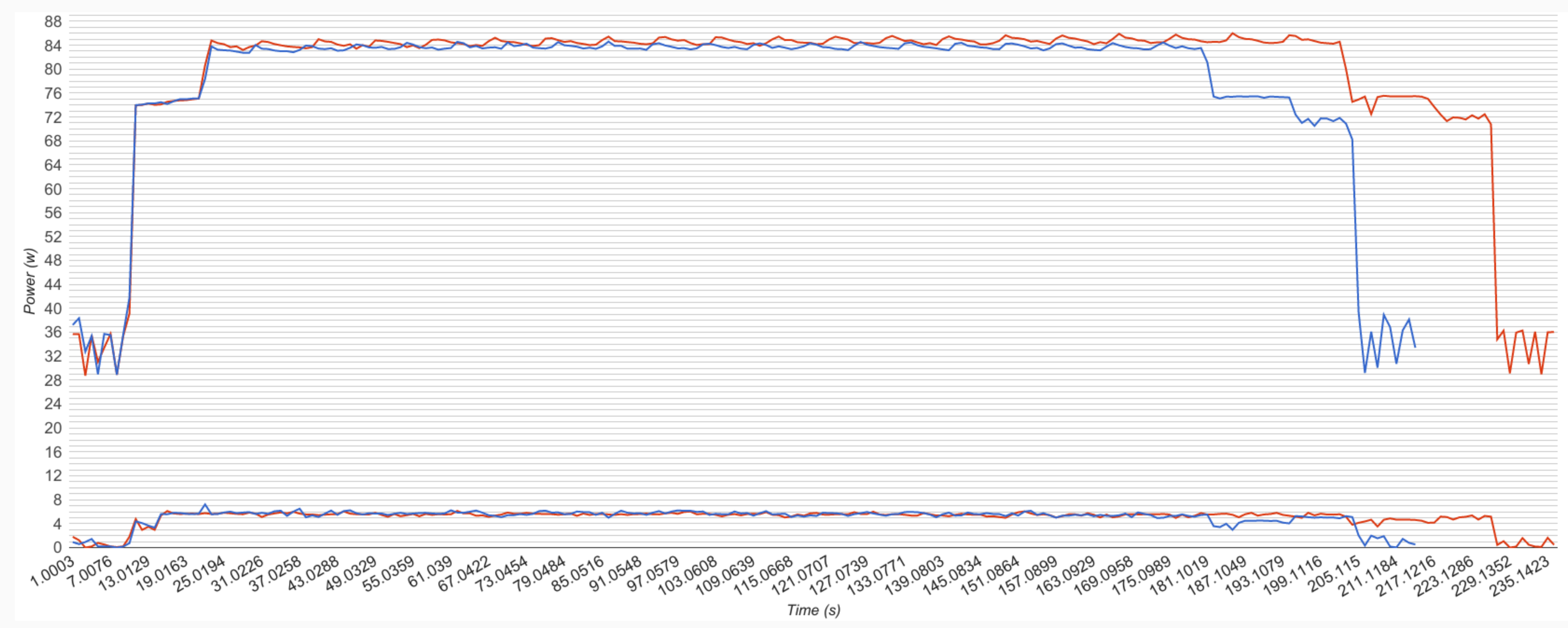


Energy Consumption

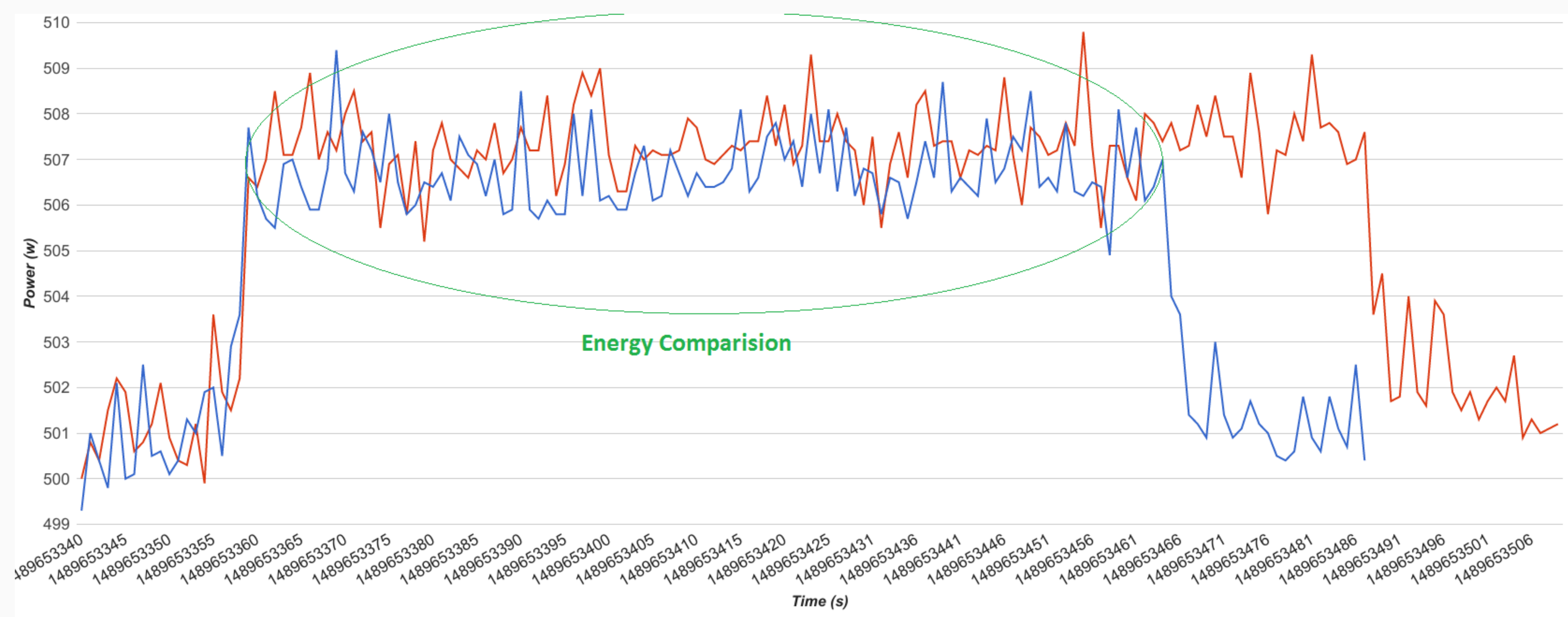
Energy Consumption values are gathered using:

- On-Chip Energy Measurements:
  - Using Performance Application Programming Interface (PAPI) [2].
- Physical Measurements:
  - Using external dedicated power monitoring tool Yokogawa WT230 Digital Power Meter.

Power consumption of Eikonal solver without memory reduction (RED), with memory reduction (BLUE) on Intel Xeon Phi @ 1.3GHz.



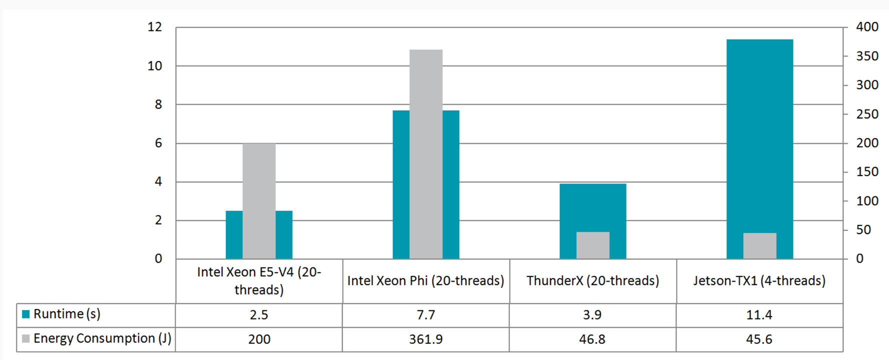
Power consumption of Eikonal solver without memory reduction (RED), with memory reduction (BLUE) on the ThunderX @1.8GHz.



- Real breakthrough in performance and energy consumption can be achieved only by **reducing the memory footprint** [1].

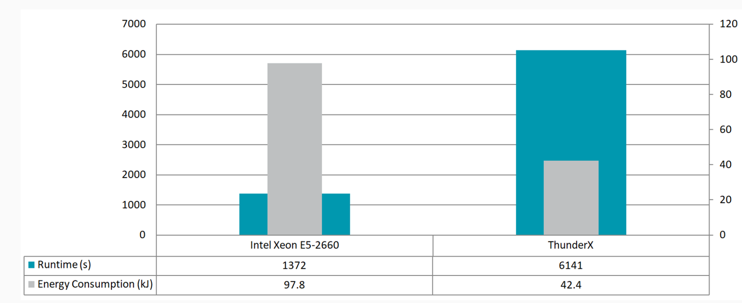
Comparison ARM vs. Intel Excluding Idle Energy Consumption

Eikonal Solver



- Performance is **1.5x lower** on ThunderX compared to Intel Xeon E5.
- Energy consumed is **4x less** on ThunderX compared to Intel Xeon E5.

CARP



- Performance is **4.4x lower** on ThunderX compared to Intel Xeon E5.
- Energy consumed is **2.3x less** on ThunderX compared to Intel Xeon E5.

Future Work and Funding

Future Work:

- Exploit more parallelism via XBraid.
- Analyses on ThunderX2 processors.
- MPI parallelisation fo Eikonal solver.

Funding:

References

[1] D. Ganellari and G. Haase. Reducing the memory footprint of an Eikonal solver. 2017 International Conference on HPCS.

[2] V. M. Weaver, M. Johnson, K. Kasichayanula, J. Ralph, P. Luszczek, D. Terpstra, and Sh. Moore. Measuring Energy and Power with PAPI. PASA Workshop, 2012.

[3] Pillet, V., Labarta, J., Cortes, T., Girona, S.. Paraver: A tool to visualize and analyze parallel code. In: Proceedings of WoTUG-18: transputer and occam developments. vol. 44, pp.17-31, 1995.