Energy to Solution vs Time to Solution, towards energy-aware HPC applications

E. Calore[1] S. F. Schifano[1] R. Tripiccione[1]

[1] INFN Ferrara and Università degli Studi di Ferrara, Italy

COLA Workshop

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Outline

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Introduction

- Energy efficiency is quickly gaining importance in the HPC field
- Despite of this, optimization efforts are still mainly committed to minimize the time-to-solution
- On the other side, in other fields such us embedded devices, optimization efforts are more strongly committed towards minimizing the energy-to-solution

In this work...

...we explore, for several High-End and Low-Power architectures, the offered opportunities to tune the energy consumption, highlighting possible tradeoffs between two metrics: time- and energy-to-solution.

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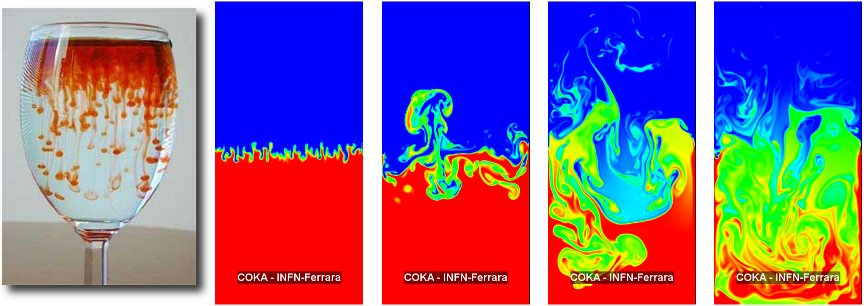
The D2Q37 Lattice Boltzmann Model

- Lattice Boltzmann method (LBM) is a class of computational fluid dynamics (CFD) methods
- LBM methods simulate a discrete **Boltzmann** equation, which under certain conditions, reduce to the **Navier-Stokes** equation
- **virtual particles** called **populations** arranged at edges of a discrete and regular grid are used to simulate a synthetic and simplified dynamics
- the interaction is implemented by two main functions applied to the virtual particles: **propagation** and **collision**
- D2Q37 is a D2 model with 37 components of velocity (populations)
- suitable to study behaviour of **compressible** gas and fluids optionally in presence of **combustion** effects
- correct treatment of Navier-Stokes, heat transport and perfect-gas ($P = \rho T$) equations

Simulation of the Rayleigh-Taylor (RT) Instability

Instability at the interface of two fluids of different densities triggered by gravity.



A cold-dense fluid over a less dense and warmer fluid triggers an instability that mixes the two fluid-regions (till equilibrium is reached).

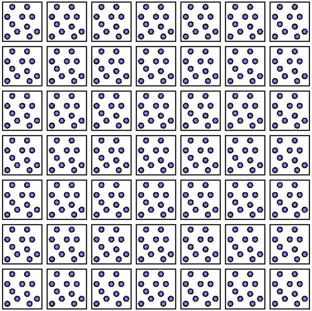
Computational Scheme of LBM

```
foreach time-step

  foreach lattice-point
    propagate();
  endfor

  foreach lattice-point
    collide();
  endfor

endfor
```



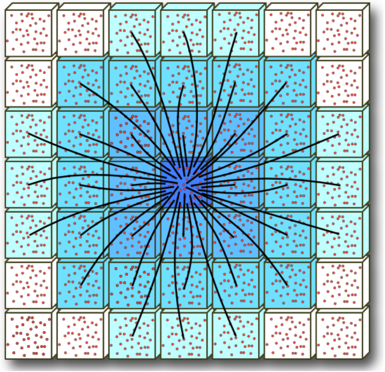
Embarassing parallelism

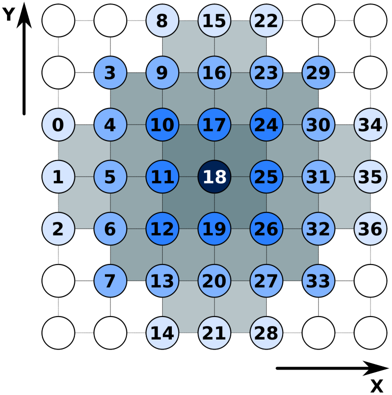
All sites can be processed in parallel applying in sequence propagate and collide.

Challenge

Design an efficient implementation able exploit a large fraction of available peak performance.

D2Q37: propagation scheme





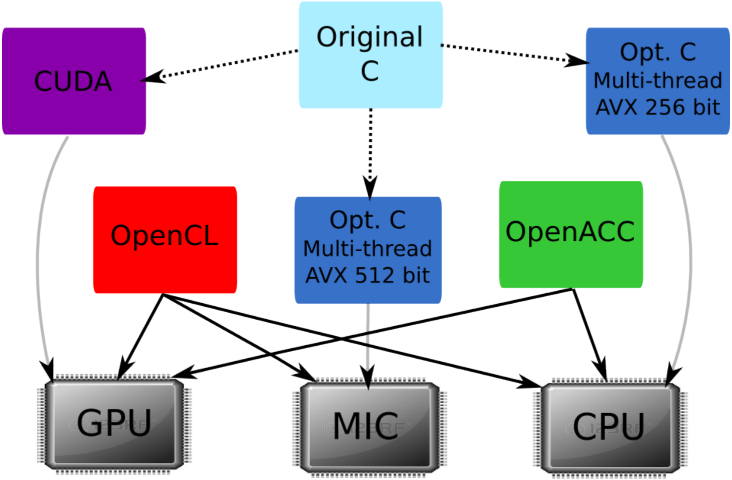
- perform accesses to neighbour-cells at distance 1,2, and 3
- generate memory-accesses with **sparse** addressing patterns

D2Q37 collision

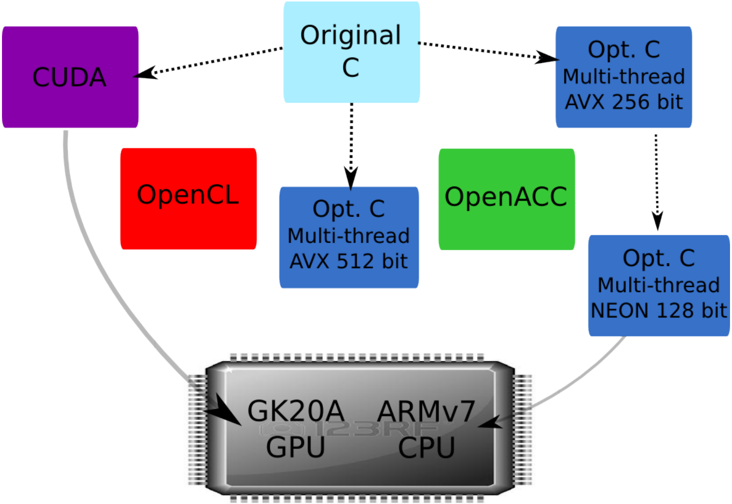
- collision is computed at each lattice-cell after computation of boundary conditions
- computational intensive: for the D2Q37 model requires $\approx$ 7500 DP floating-point operations
- completely local: arithmetic operations require only the populations associate to the site

- computation of propagate and collide kernels are kept separate
- after propagate but before collide we may need to perform collective operations (e.g. divergence of of the velocity field) if we include computations conbustion effects.

Initial Code implementations



Code implementations



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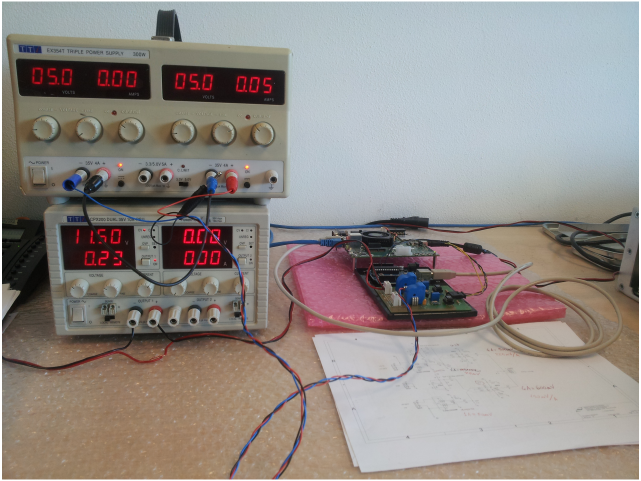
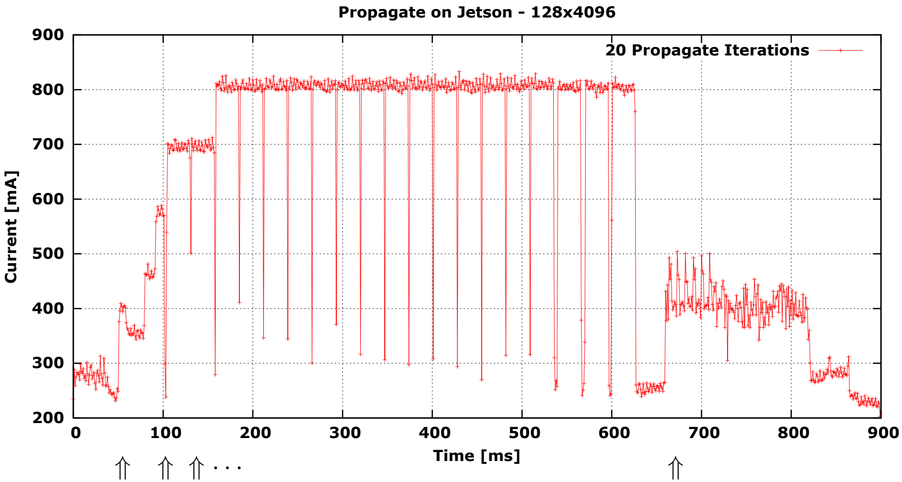
Setup to sample instantaneous current absorption

One current to voltage converter...
...plus an Arduino UNO (microcontroller + 10-bit ADC + Serial over USB)



Current to Voltage + Digitization with Arduino + USB Serial

Acquired data example with default frequency scaling



Iterations can be counted

This is a D2H transfer

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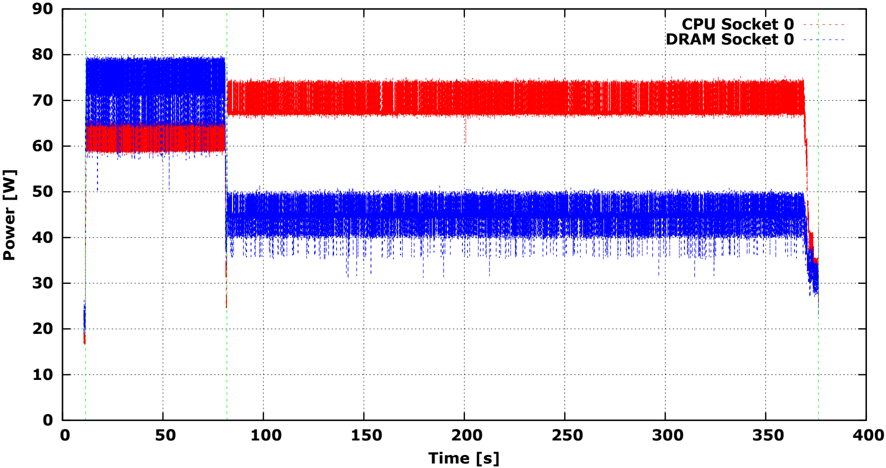
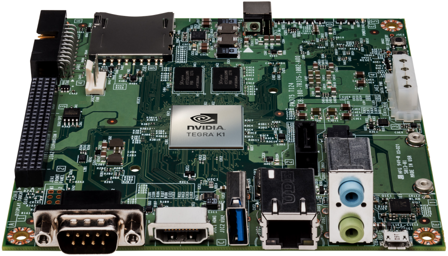
Acquired data example using RAPL counters



Intel Haswell CPU energy counters acquired at 100Hz and converted in Watt; acquisition performed with a custom developed wrapper to the PAPI library.

Outline

NVIDIA Jetson TK1



SoC: Tegra K1

- CPU: NVIDIA "4-Plus-1" 2.32GHz ARM quad-core Cortex-A15, with battery-saving shadow-core
- GPU: NVIDIA Kepler "GK20a" GPU with 192 SM3.2 CUDA cores

Awarded for the Best Paper

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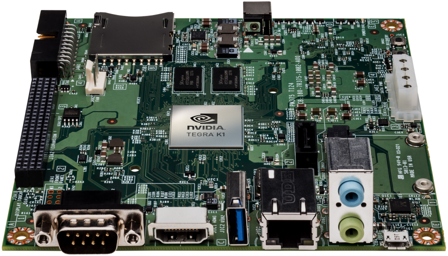

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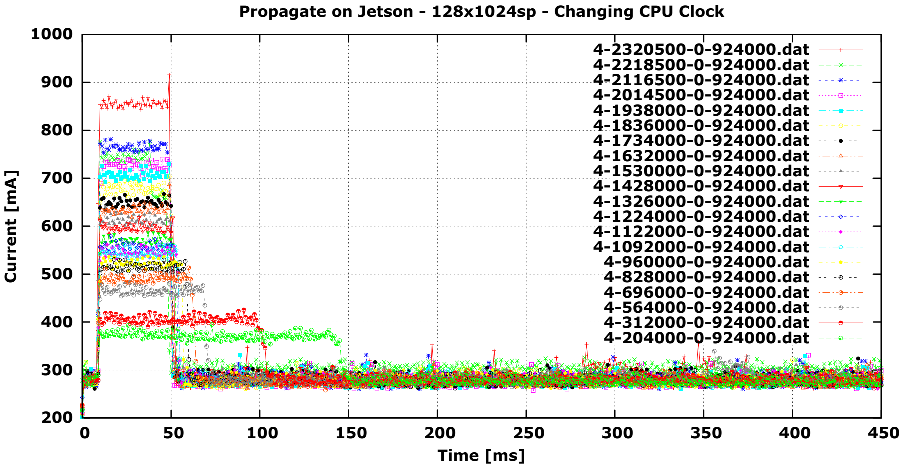
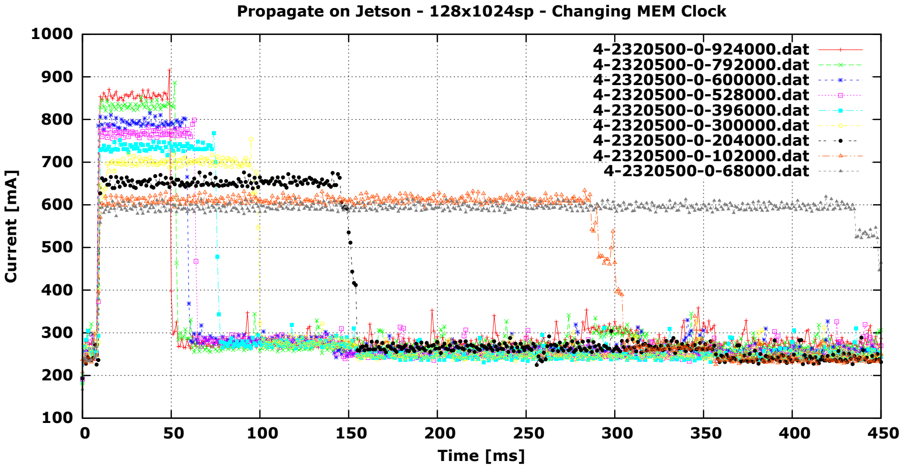
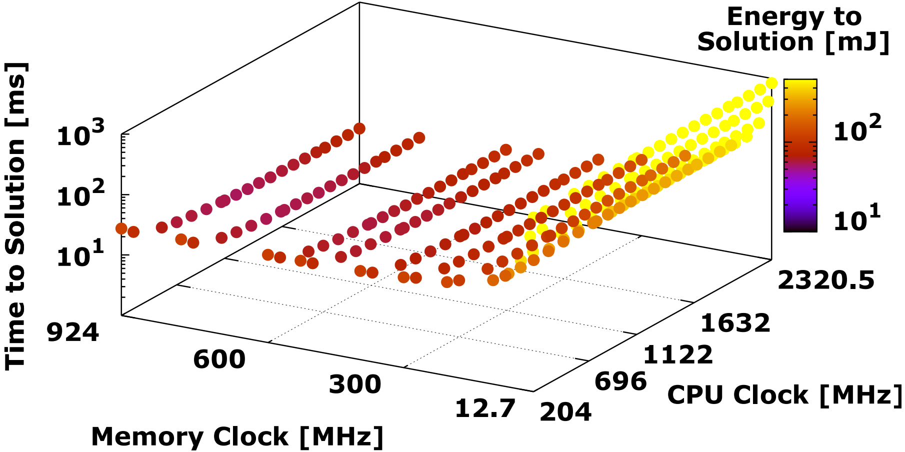
Propagate changing the G cluster clock



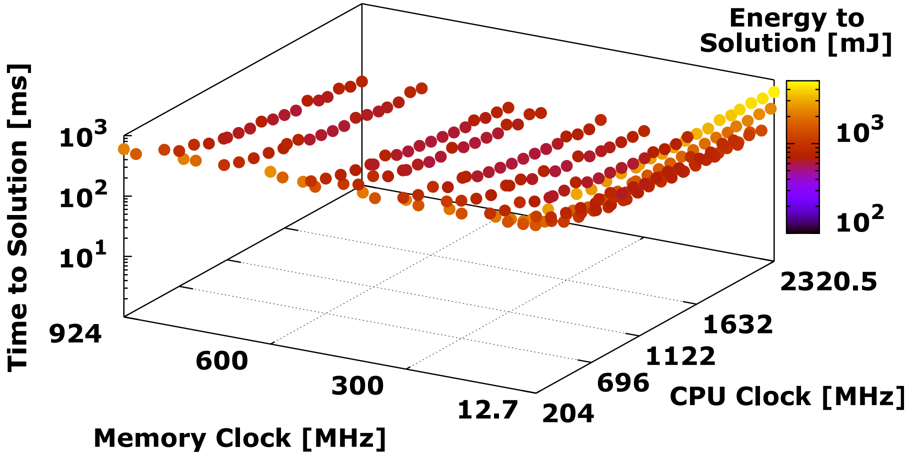
Propagate changing the MEM clock



Time and Energy to solution (Propagate)



Time and Energy to solution (Collide)



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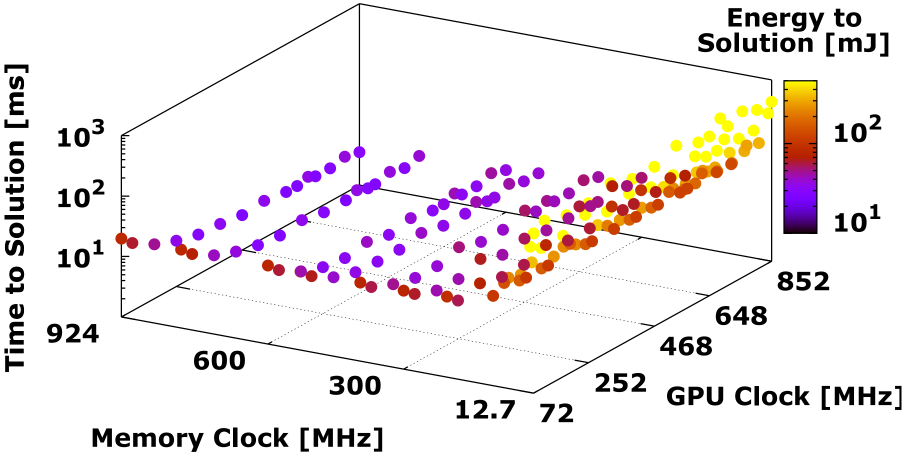

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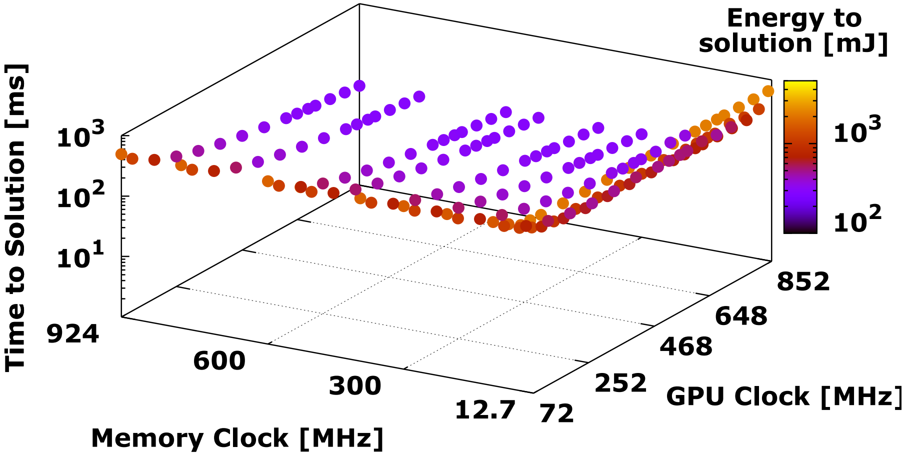
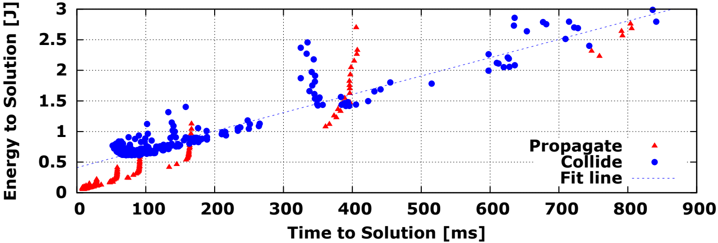
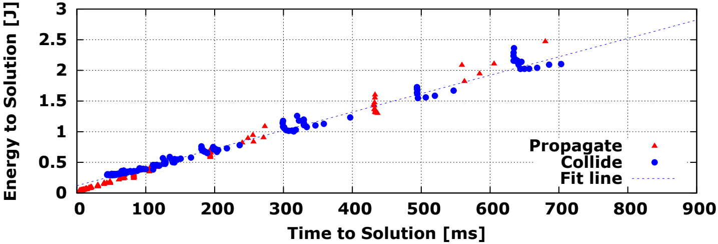


Energy to Sol. vs Time to Sol. CPU(top), GPU(bottom)





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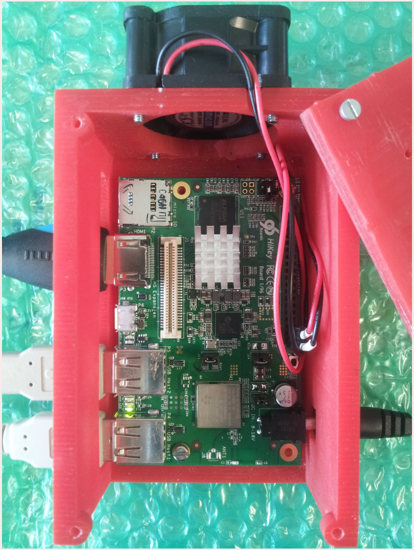
96Boards - HiKey



SoC: HiSilicon Kirin 6220

- CPU: 8 core ARM Cortex-A53 running at 1.2GHz (64-bit aarch64)
- GPU: ARM Mali 450-MP4 GPU
- MEM: 1GB of 800MHz LPDDR3

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3D printed case to fit a fan (Thanks to V. Carassiti and A. Cotta Ramusino, INFN Ferrara)

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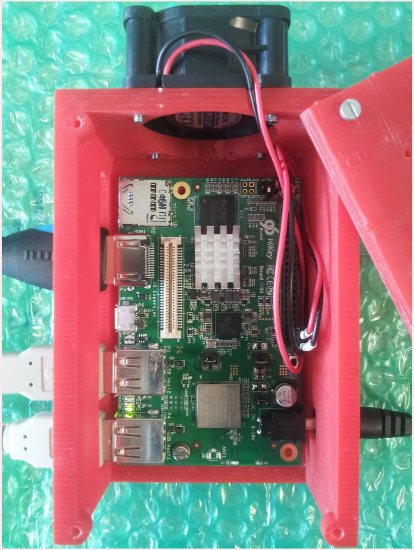

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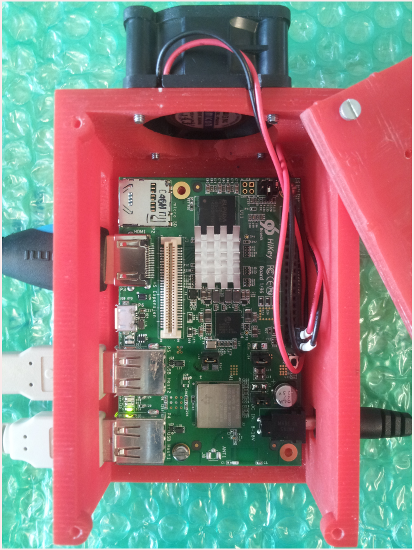

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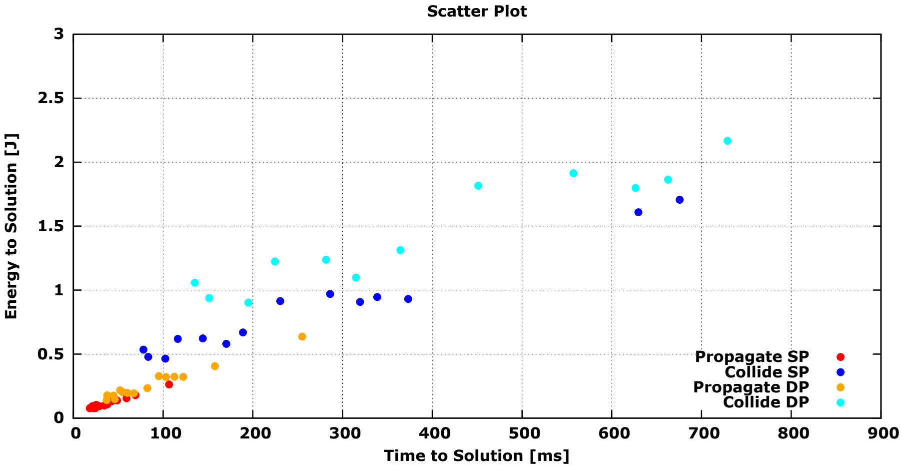
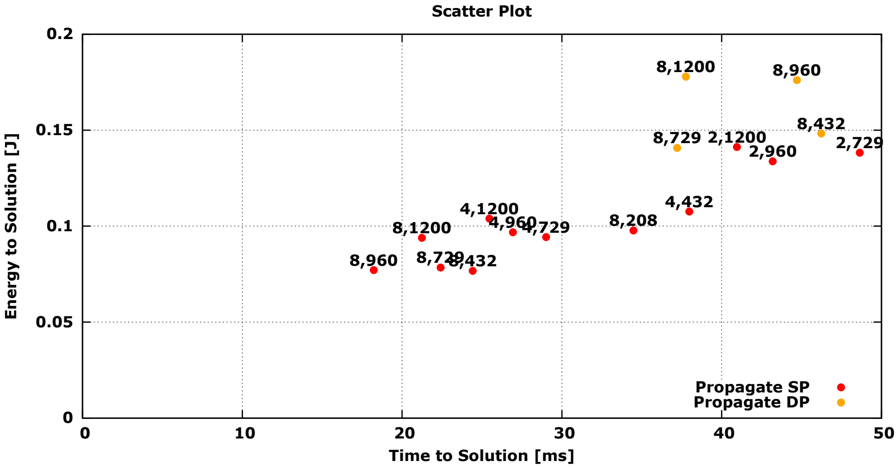
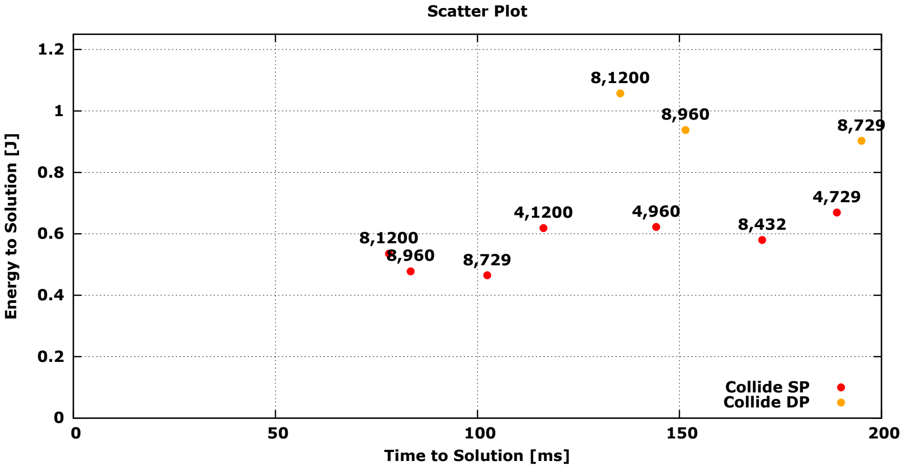
Energy to Solution vs Time to Solution (CPU) SP & DP



Energy/Time to Solution Propagate SP & DP



Energy/Time to Solution Collide SP & DP



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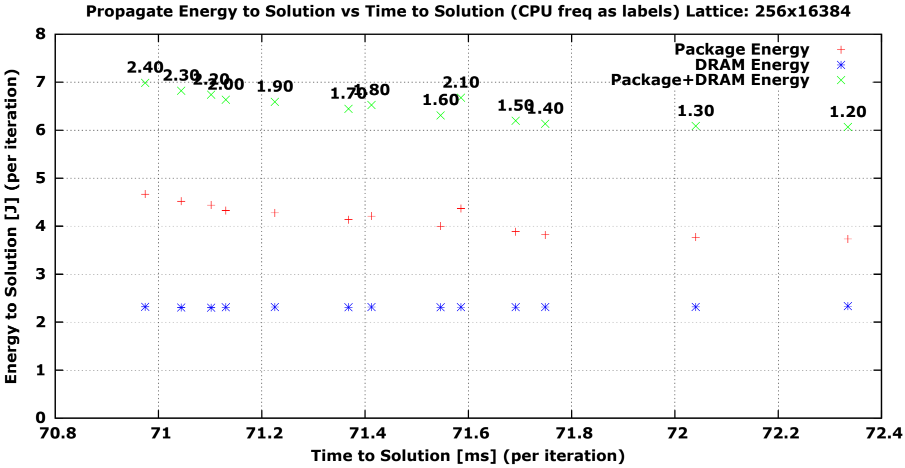
Energy/Time to Solution Propagate DP



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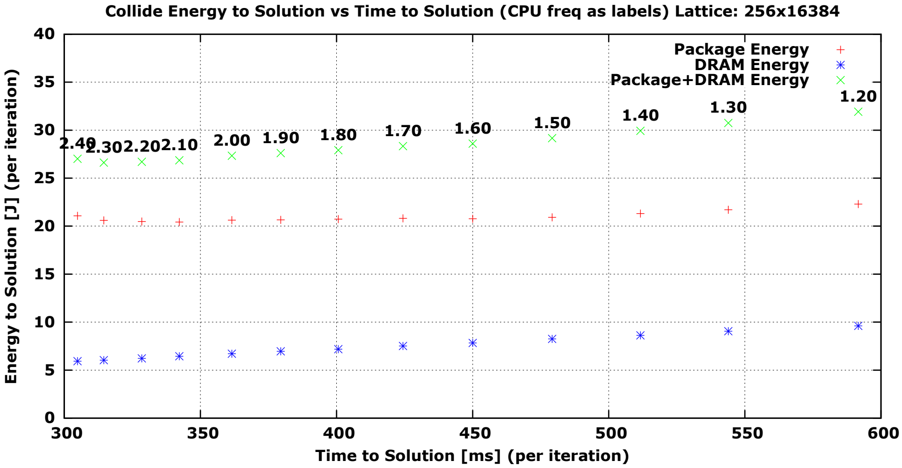

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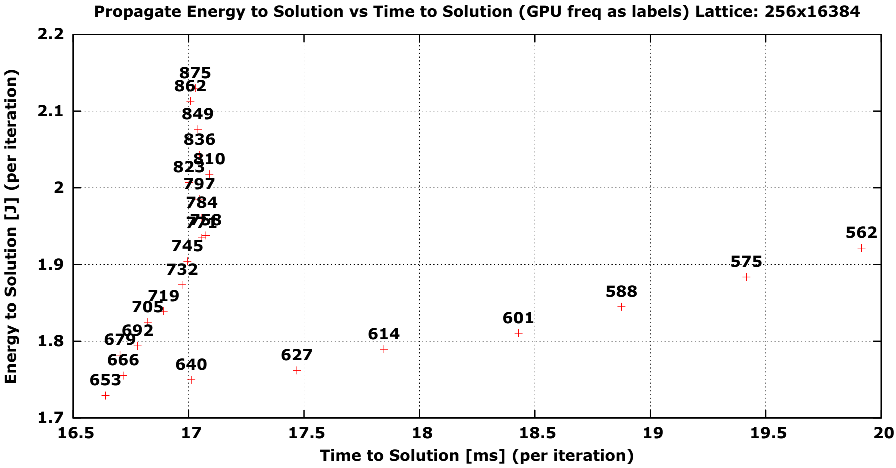

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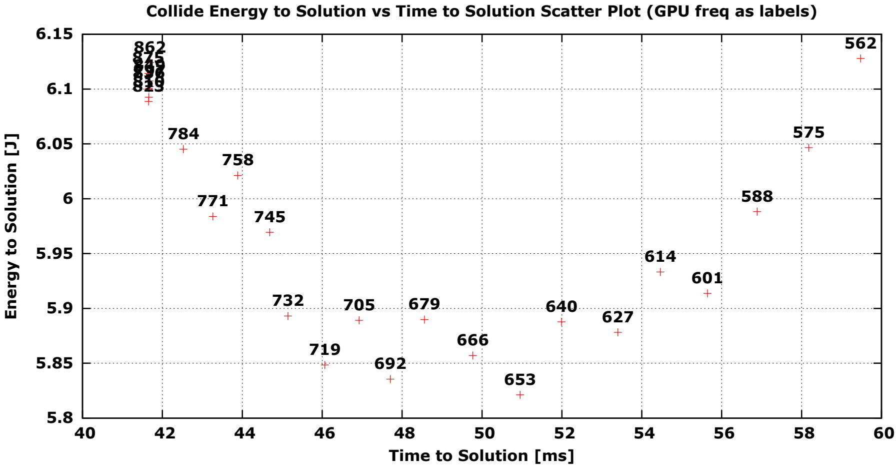

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Conclusions

- limited but not negligible power optimization is possible by adjusting clocks on a kernel-by-kernel basis (between $\approx 5 \cdots 25\%$).
- baseline power consumption (leakage current + ancillary electronics) is relevant (in particular for low-power processors $\approx 30\%$)
- options to run the processor at very low frequencies seem almost useless (at least for the adopted benchmark)

Future works

- perform similar measurements on different architectures (such as ThunderX ARM Processors)
- collect data for a fair comparison between architectures for several metrics
- investigate software tuning and multi-objective optimization techniques
- evaluate communication costs between different processors

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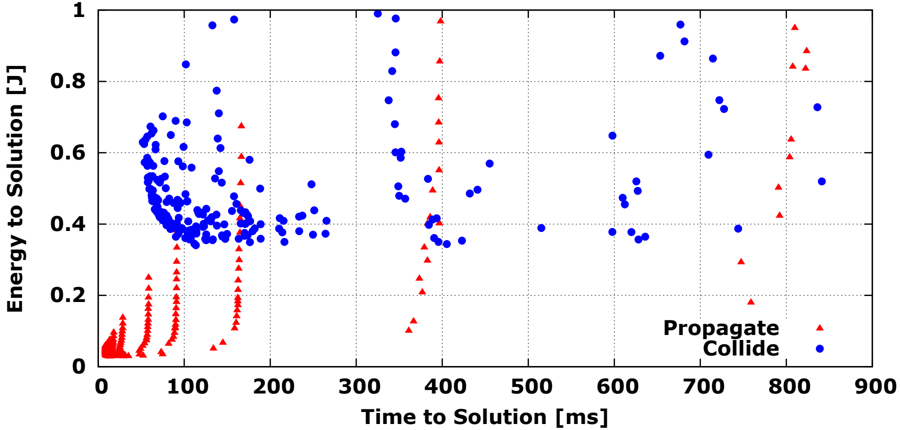
Thanks for Your attention

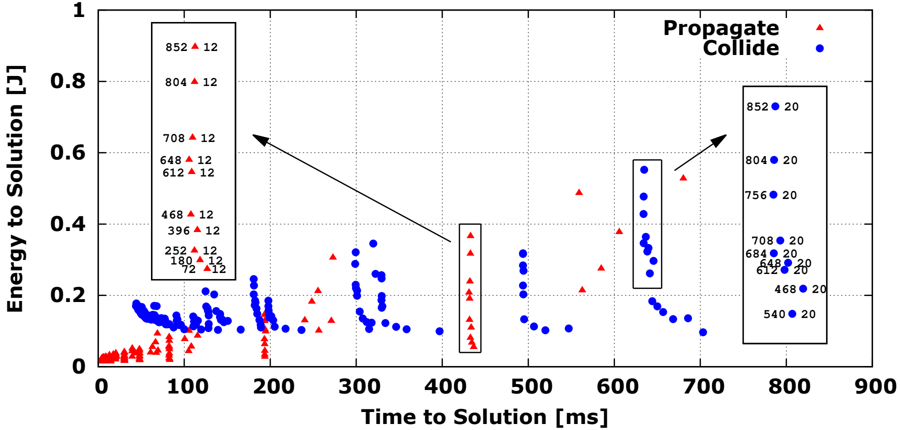
Processor	E_S [J] per iteration	T_S [ms] per iteration	EDP
NVIDIA GK20A	≈ 0.35	≈ 50	0.0175
ARM Cortex A15	≈ 0.75	≈ 50	0.0375
ARM Cortex A53	≈ 0.50	≈ 75	0.0375

Table: Collide Single Precision; lattice: 128x1024

Energy to Solution vs Time to Solution (CPU A15)



Energy to Solution vs Time to Solution (GPU GK20A)



Energy to Solution vs Time to Solution (GPU GK20A) zoom