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Performance modeling and optimization of a Lagrange-Remap algorithm on multicore processors

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Outline

The goal

Build a solver for compressible fluid dynamics (Euler equations) which will run efficiently on current and future computers

How can we get this ?

Understand HPC properties of the reference numerical method

- Analyze and understand the current solver performance

Improve the current solver to its limits

- Understand current processor micro-architectures
- Optimize the solver implementation for current processors micro-architectures
- Estimate the maximal achievable performance for this solver

Going further

- Predict performance on other and future architectures
- Design a solver based on a more efficient algorithm

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$\Rightarrow$ Building performance model

Specificity of our solver (Lagrange-Remap methods)

1 - Lagrangian step

Compute evolution of hydrodynamic quantities on a mesh moving at material velocity

2 - Remap step

Remap / interpolation from distorted mesh to fixed initial one

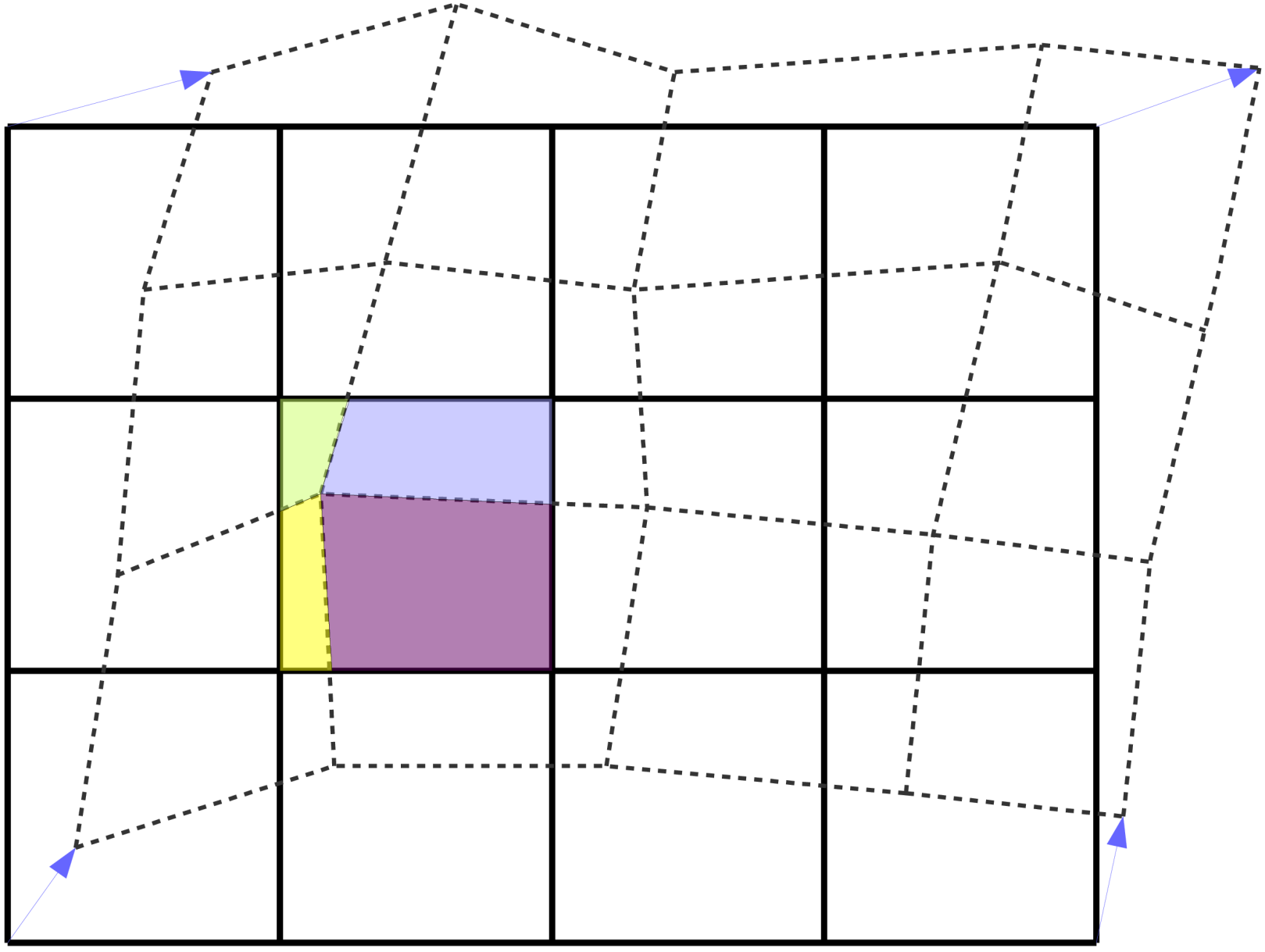


Figure: Sketch of Lagrange-Remap methods

Outline

What is performance modeling ?

Definition

Build and use simple abstraction to estimate execution time of a chosen algorithm on a given computing architecture
$\Rightarrow$ Understanding the performance behavior of a code

Interests

- Define how efficiently a computer is used (current usage vs machine peak)
- Predict / extrapolate performance behavior on others architectures
- Provide optimization hints

Performance modeling: principle

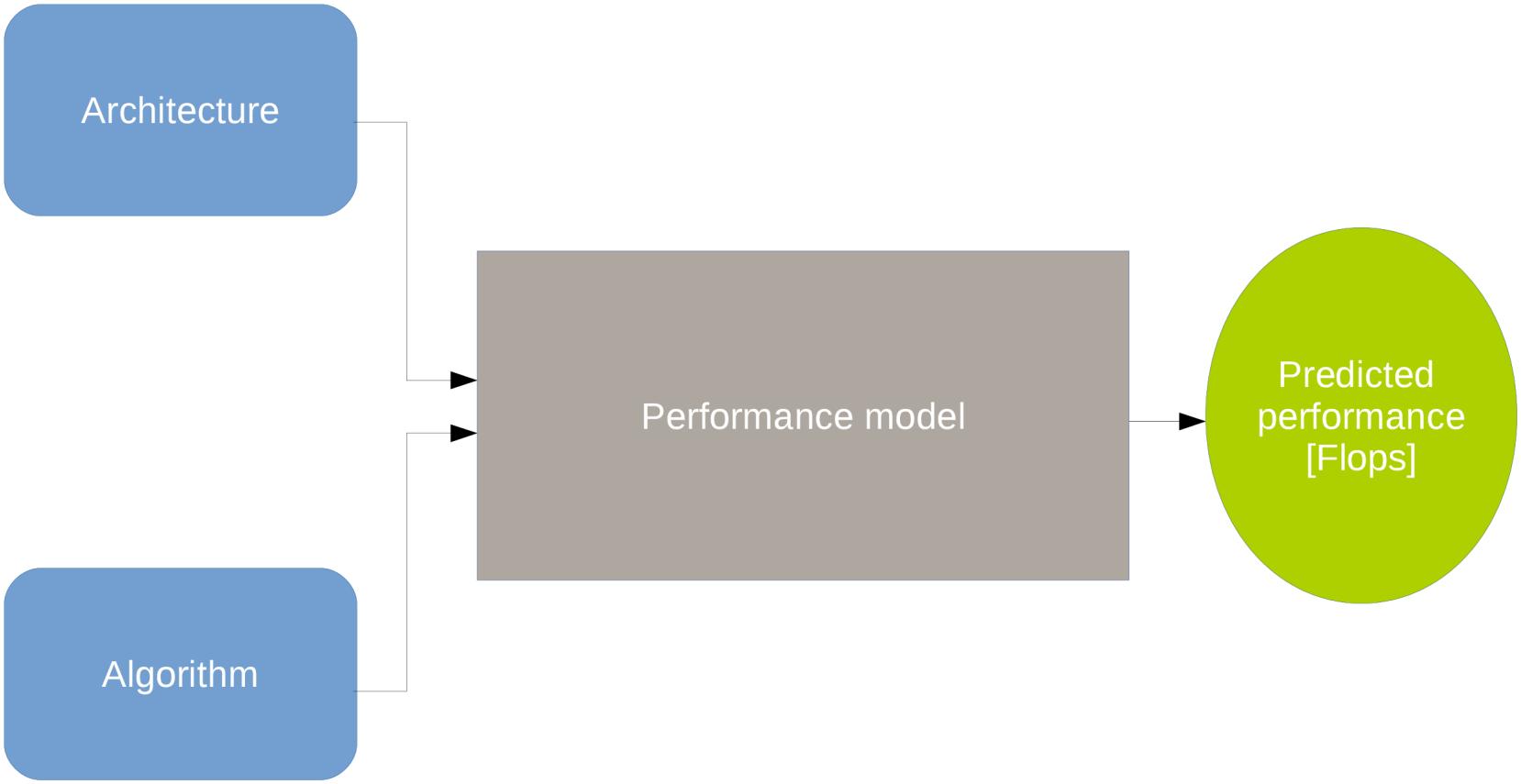


Figure: Input / output of a performance model

The Roofline model [Williams 2009]: metrics

Architecture

- **Bandwidth**:
  Data transfers rate from memory to computing units[GBytes/s]
- **Peak**:
  Absolute maximum performance of a computer[GFlops]

Algorithm

- **Arithmetic Intensity (AI)**:
  $AI := \frac{\text{number of operation}}{\text{quantity of data transfered}}$ [Flops/Byte]
- **Unbalance factor (instruction mix)**:
  Reduction performance factor due to not perfect matching between algorithm and architecture [%peak]

The Roofline model: definitions

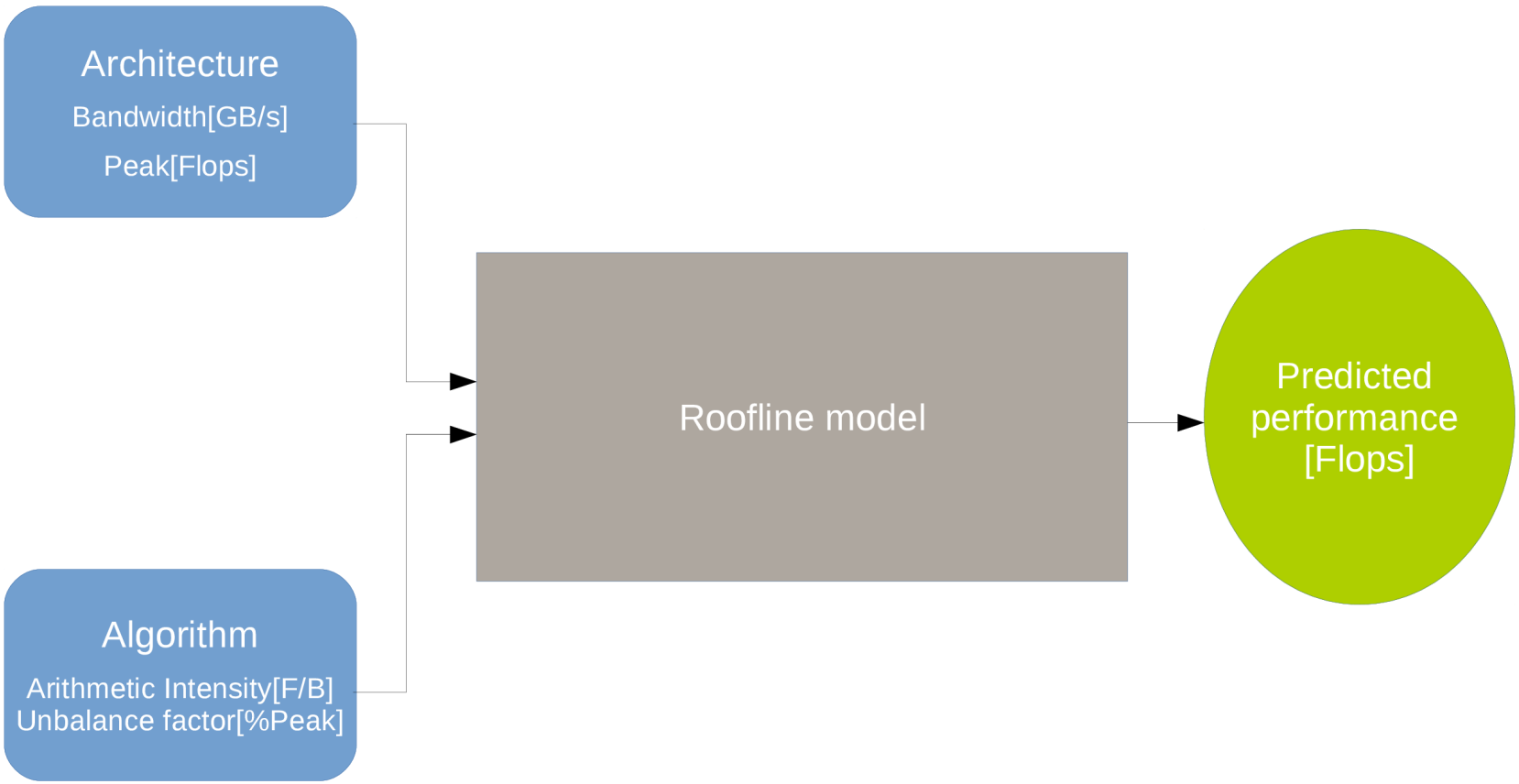
(ideal) Roofline model

$$\begin{aligned} \text{Perf(ideal)} &= f(Peak, bandwidth, AI) \\ &:= min(Peak, bandwidth \times AI) \end{aligned}$$

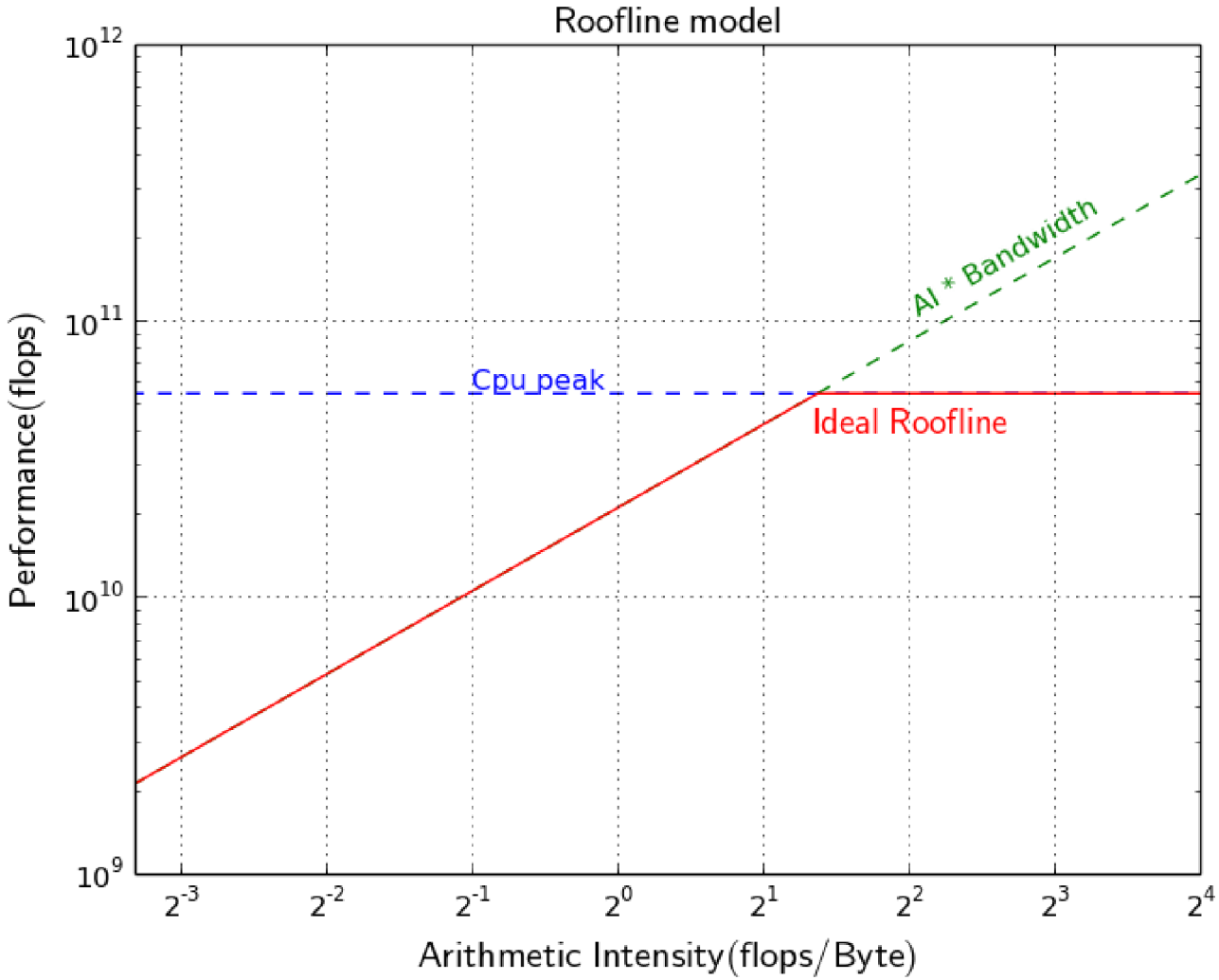
(effective) Roofline model

$$\begin{aligned} \text{Perf(effective)} &= f(\text{Peak}, \text{bandwidth}, \text{AI}, \text{unbalance factor}) \\ &:= min(\text{Peak} \times \text{unbalance factor}\ ,\ \text{Bwd} \times \text{AI}) \end{aligned}$$

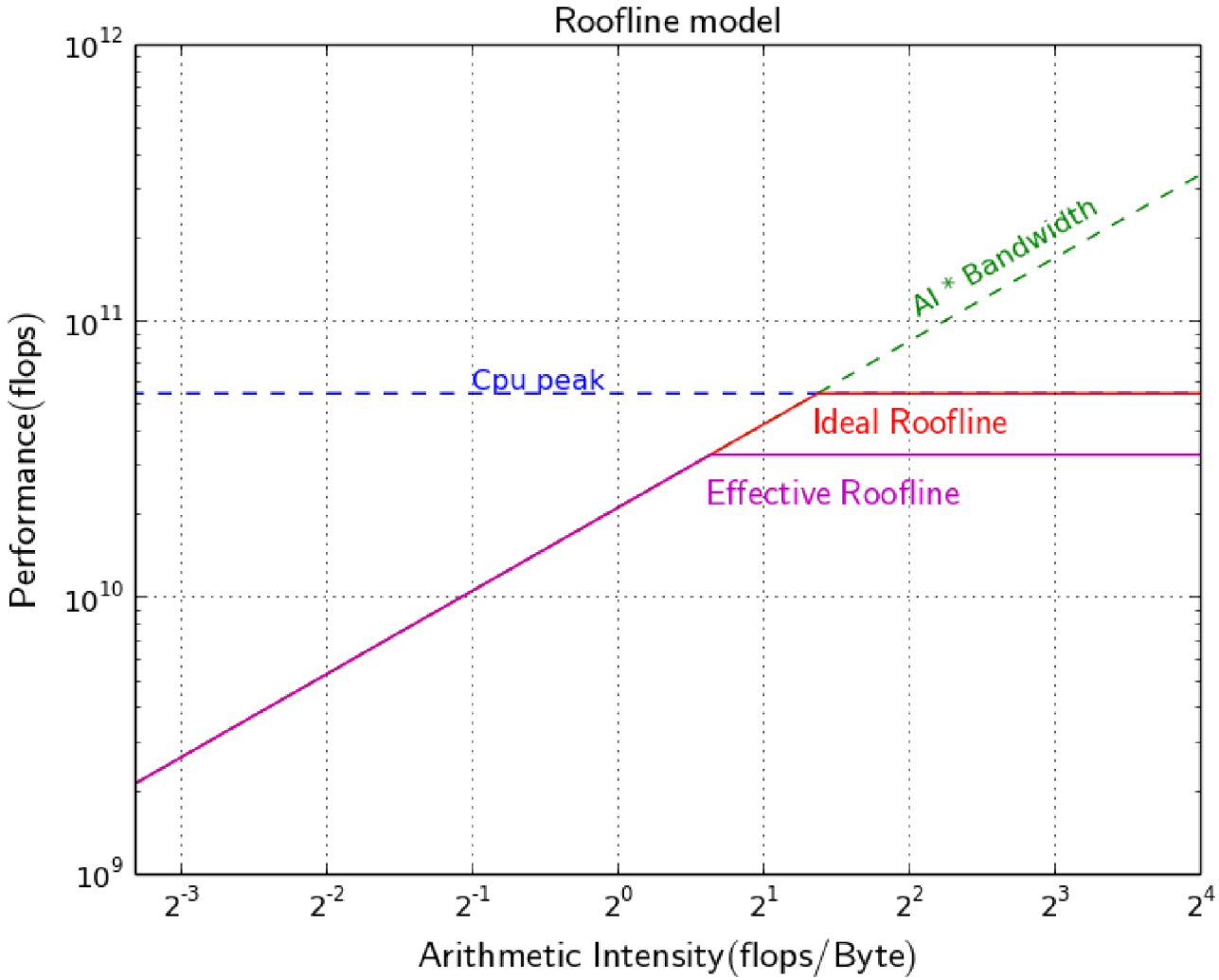
Roofline: principle



Roofline: graphical representation



Roofline: graphical representation



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Experimental protocol

Code

`Shy`

Tools

- `likwid`
- `IACA`

Test architectures

- SandyBridge i3-2130 (2 cores / 4 threads)
- Haswell i5-4590T (4 cores / 4 threads)

Dataflow diagram of the remap step

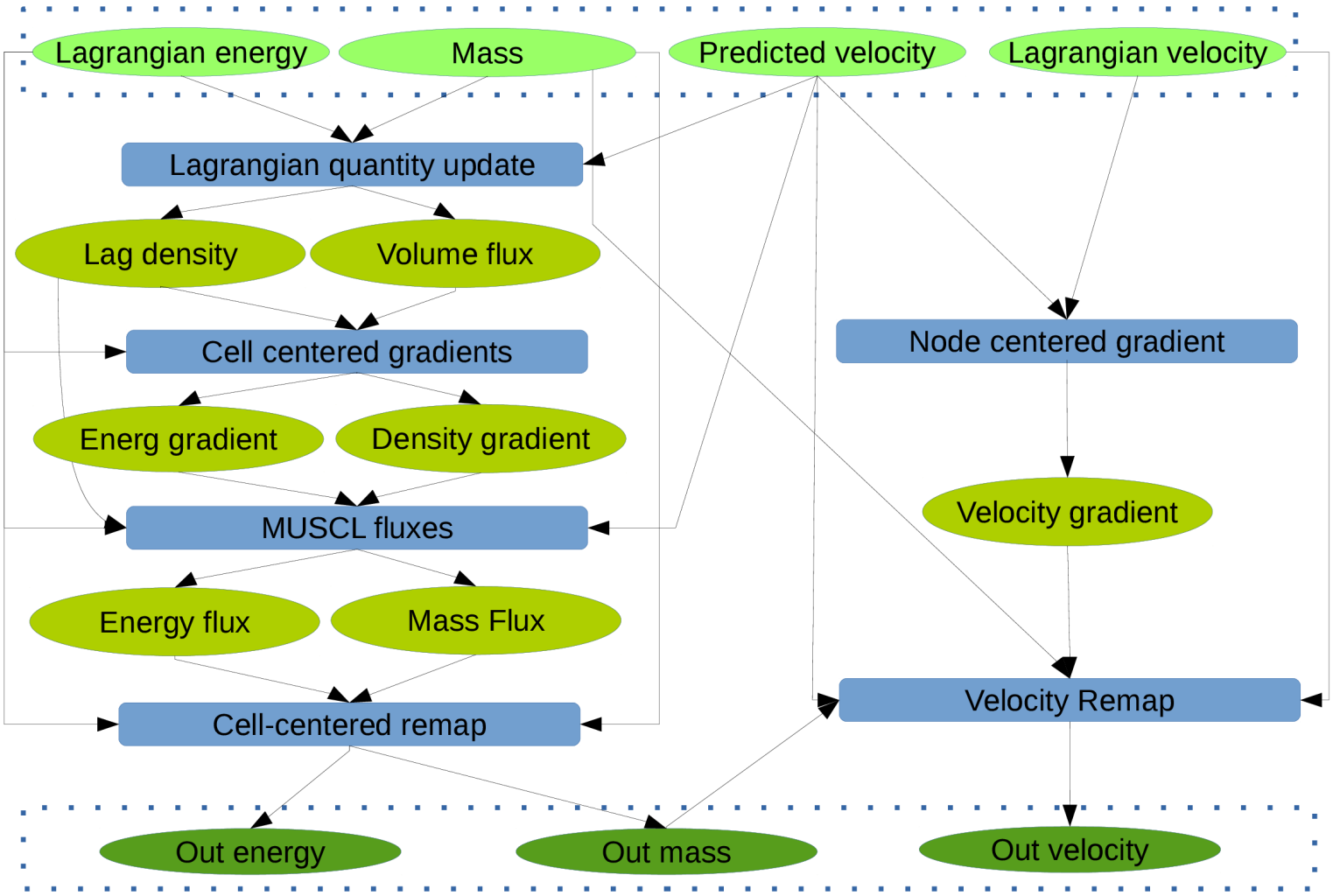
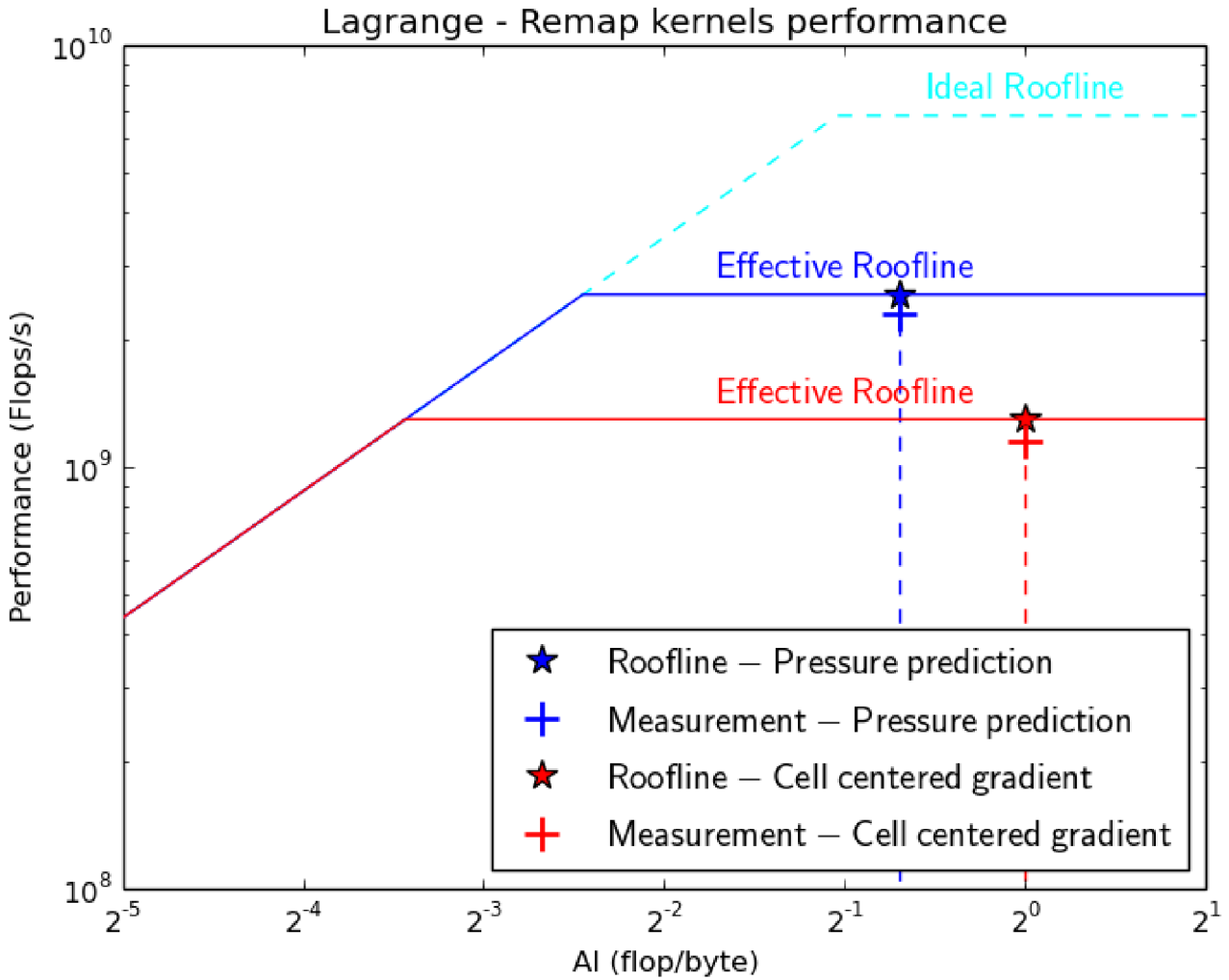


Figure: Dataflow diagram of the remap step

Roofline model vs measured performance

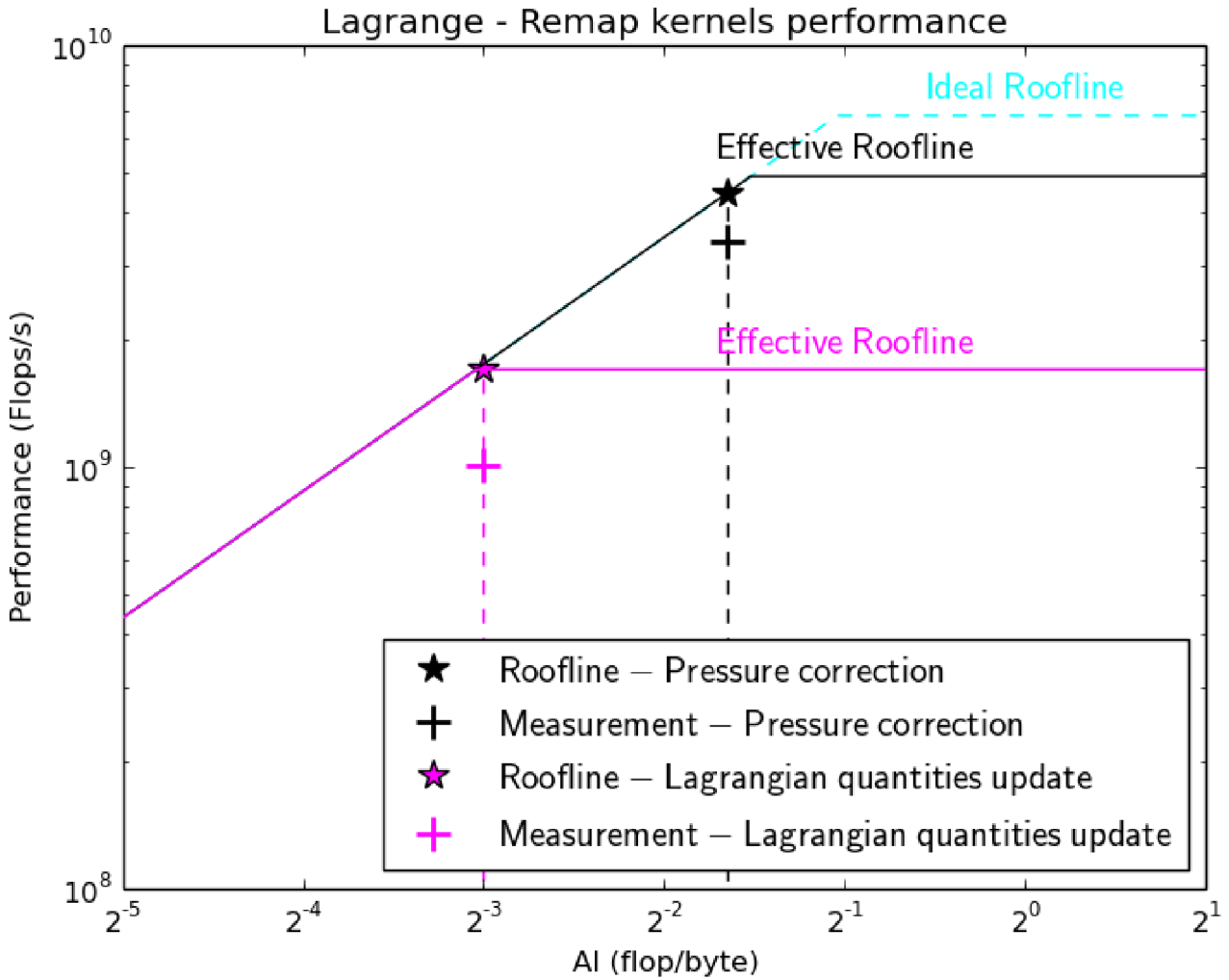


error

11%

12%

Roofline model vs measured performance



error

30%

70%

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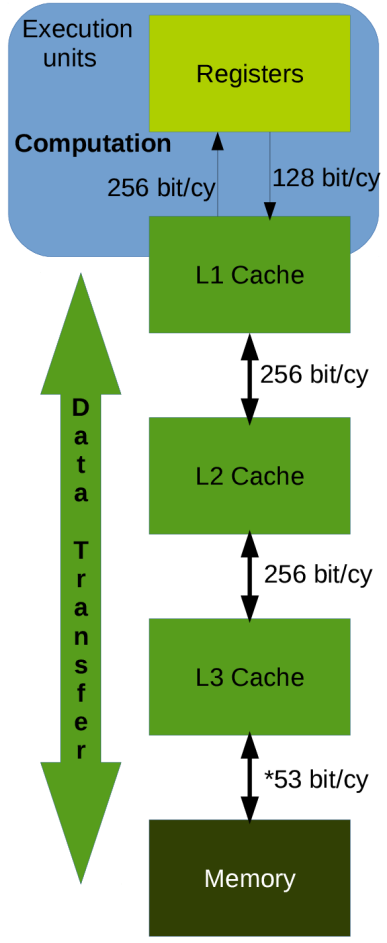
Execution Cache Memory model [Hager & Treibig 2010]

ECM (Execution Cache Memory model): refinement of the Roofline model by introducing data transfers through caches



Metrics: time [cycles / cache line update]

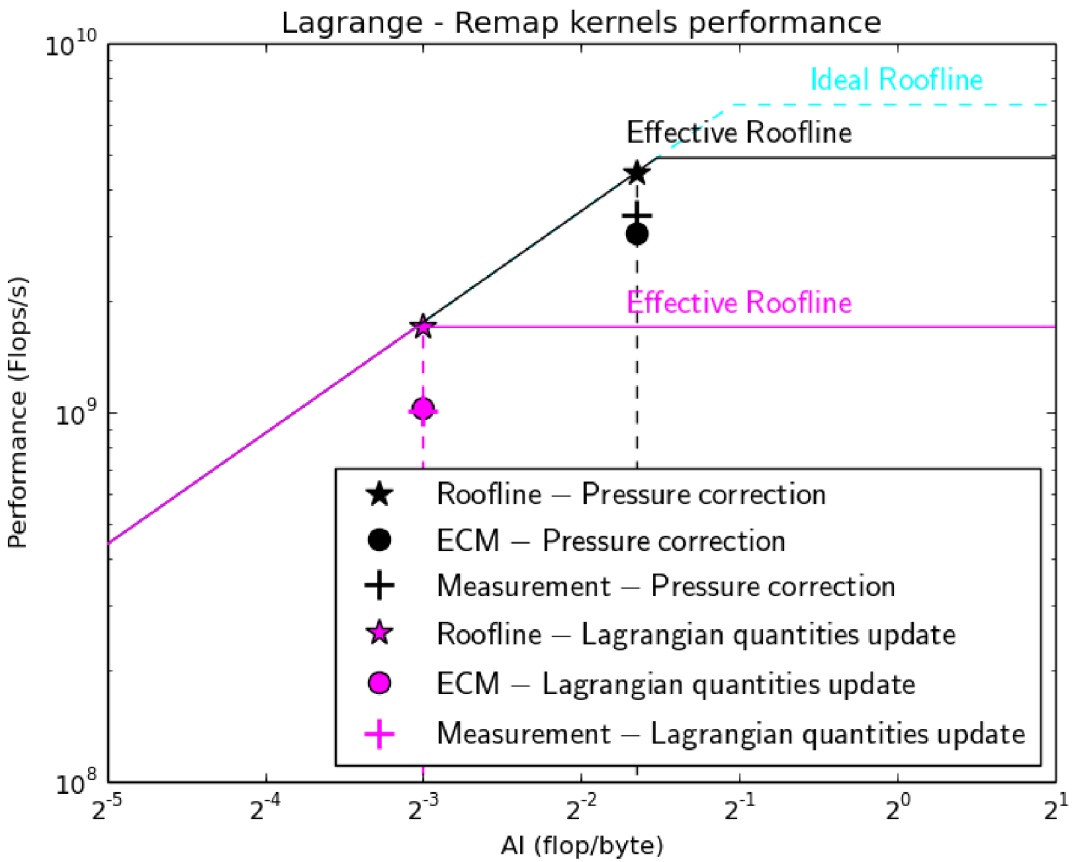
- Time for pure computation (assuming data are in L1 Cache))
- Times for data transfers through the different cache levels L1-L2, L2-L3, L3-Ram

Main hypotheses

- Computations and data transfers may overlap
- Data transfers do not overlap

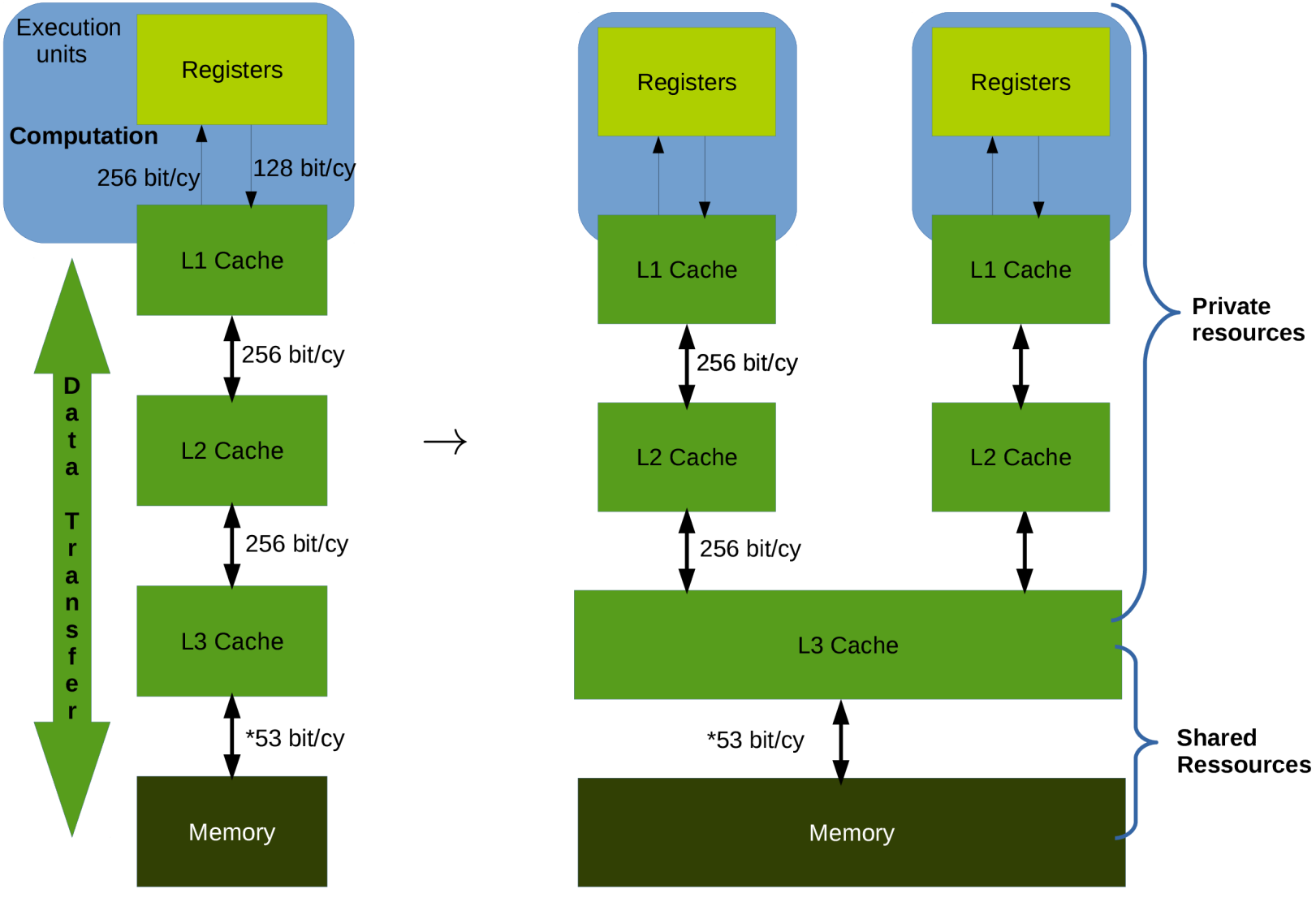
ECM model vs Roofline model vs measured performance

kernel name	time [cycles / cache line update]	
	prediction ECM	measurement
Pressure correction	170	174
Lagrangian q. update	59	58



modeling error	
Roofline	ECM
30%	2%
70%	2%

ECM: from one core to full node



ECM: multicore scalability

Kernel name	**Speed up 4 cores**	
	Prediction	Measurement
Lagrange kernels		
Pressure prediction	4	3.5
Pressure correction	1.4	1.6
Velocity update	1.5	1.5
Remap kernels		
Lagrangian q. update	1.2	1.6
Cell centered gradient	4	3.9
MUSCL fluxes	1.3	1.4
Cell centered remap	1.2	1.6
Node centered gradient	4	3.9
Velocity remap	1.5	1.5

Conclusions and on going works

Performance modeling

- Very useful analysis tools for understanding code performance behavior
- Provide qualitative / quantitative information depending on the used model

Highlighting some bottlenecks in the current solver

- Variable location (node and cell-centered)
- Multi dimensional remap in multiple steps
- Complex geometrical features

On going works

- Implementation of a new numerical scheme
- Performance modeling of this new scheme

Thanks for your attention!