Simulation of Blood Flow in the Human Brain using the Cell Processor

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University Erlangen-Nuremberg – System Simulation

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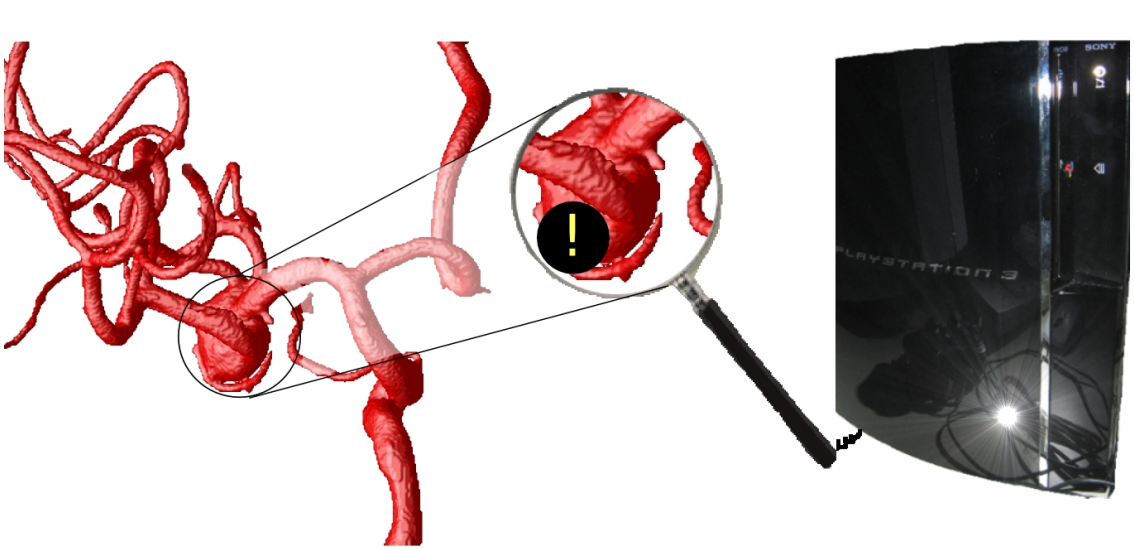


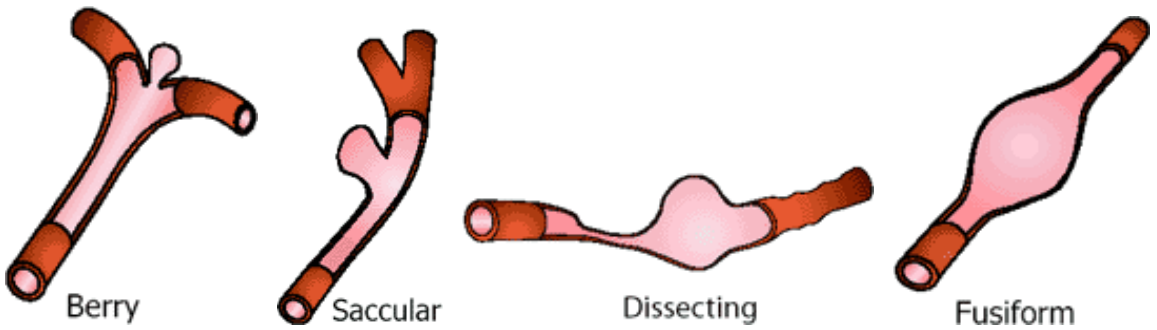
Outline

- Introduction
- The Cell Processor
- Implementation
- Results
- Outlook

Introduction

Aneurysms

- dilatation (local balooning) of the blood vessel
- localized mostly at larger arteries in soft tissue (e. g. aorta, brain)
- can be diagnosed by modern imaging techniques
- can be treated by clips, coils, etc



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[1] from The Toronto Brain Vascular Malfunction Study Group

Introduction

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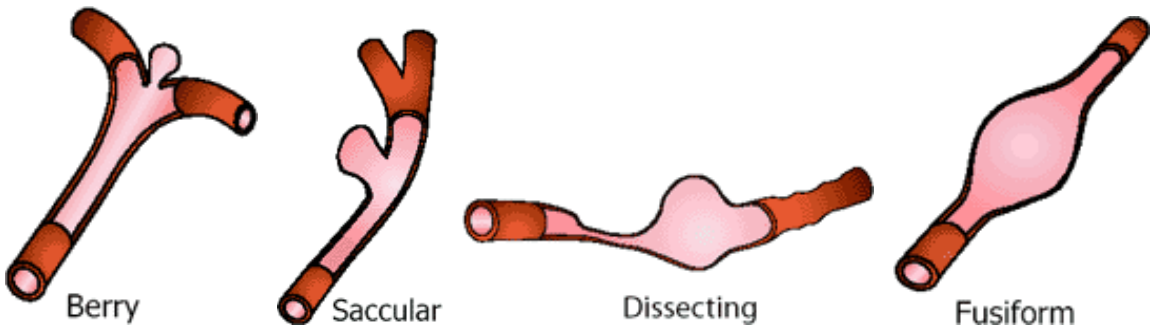

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Stenosis

- abnormal narrowing in a blood vessel

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Introduction

Motivation

- aneurysms are a major public health issue in every developed nation
- the flow situation could be crucial for further treatment of the patient

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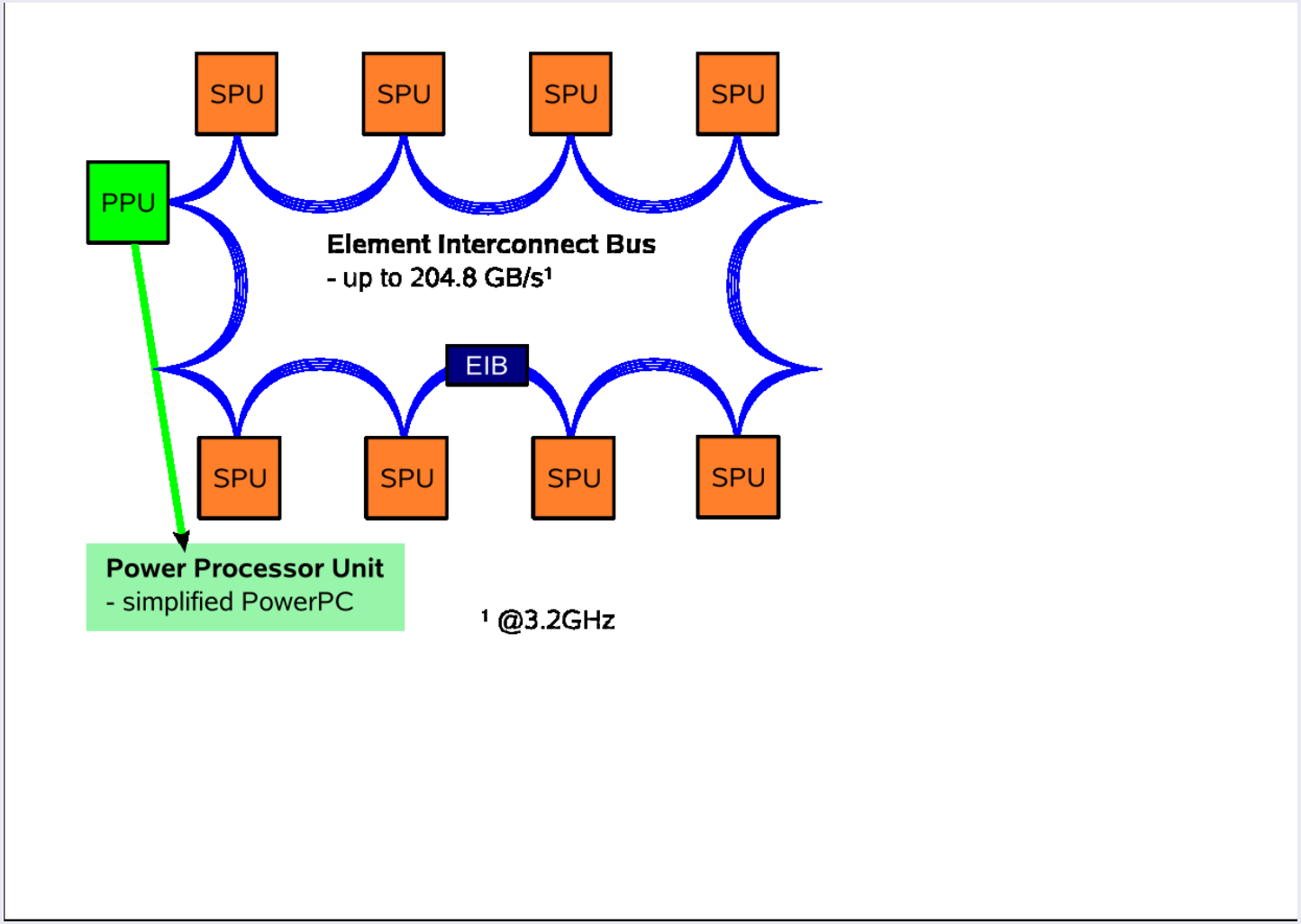
Challenges

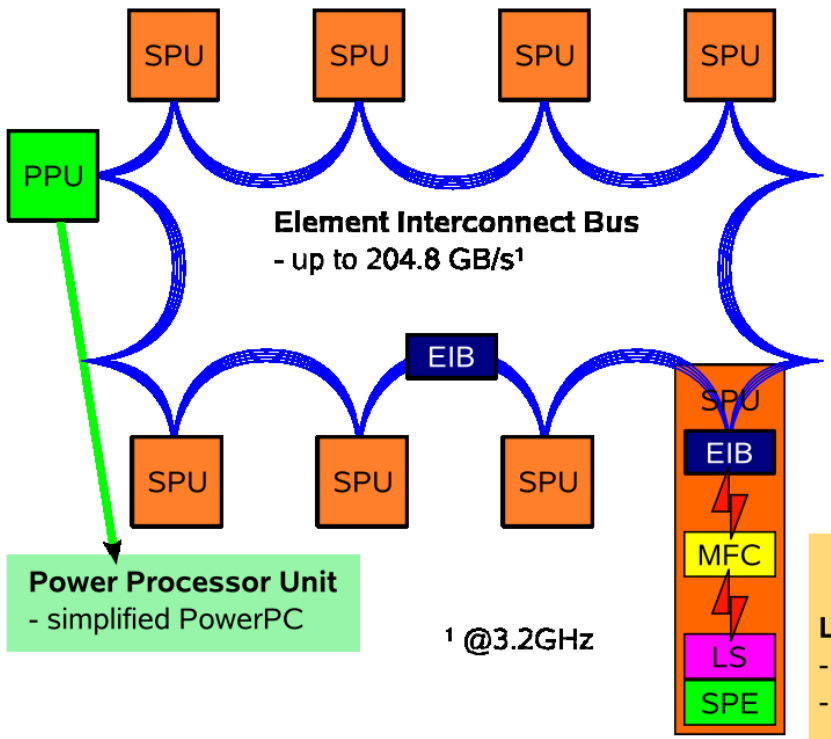
- current imaging techniques result in data sets of 512^3 and more
- long run times on desktop PCs and workstations
- for intra-surgery planing the algorithm should perform quasi real-time

A short overview of the Cell processor



The Cell Processor

A short overview of the Cell processor



Synergistic Processor Unit

Local Store
- "main memory" of SPE
- 256 kB only

Synergistic Processor Element
- SIMD vector processor
- 128 SIMD registers (128 bit)
- 204.8 GFlop/s¹ max. for 8 SPEs

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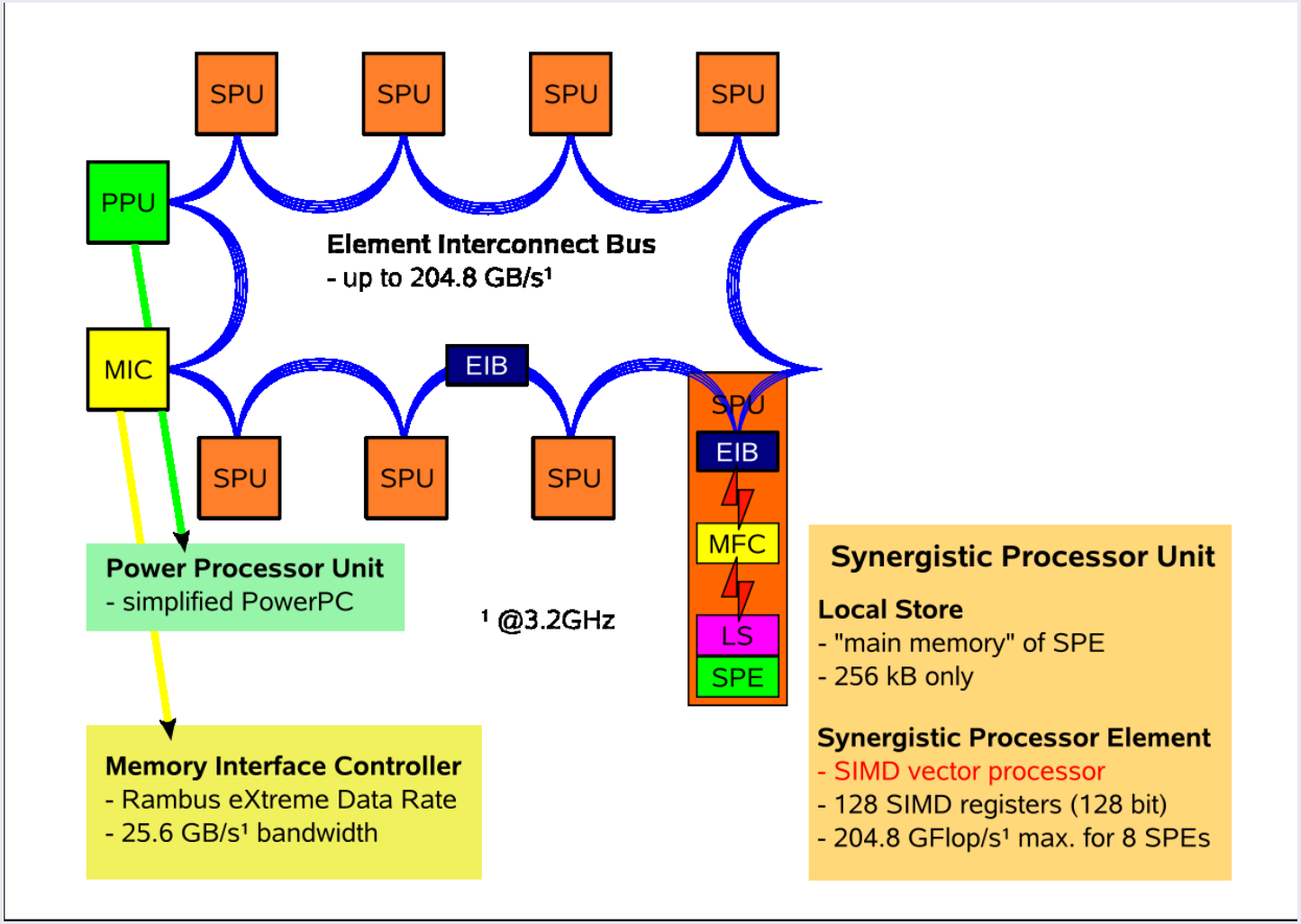

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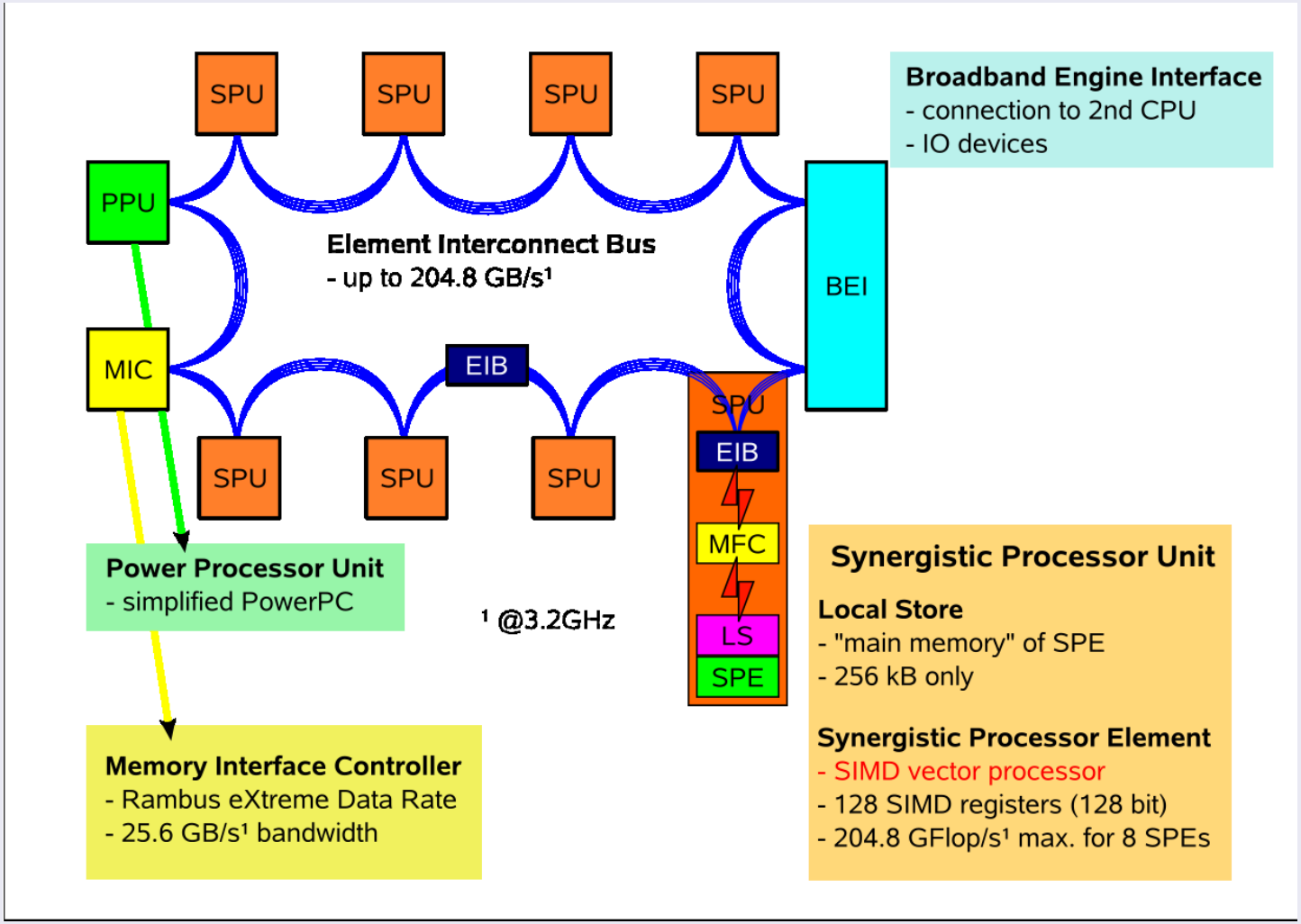
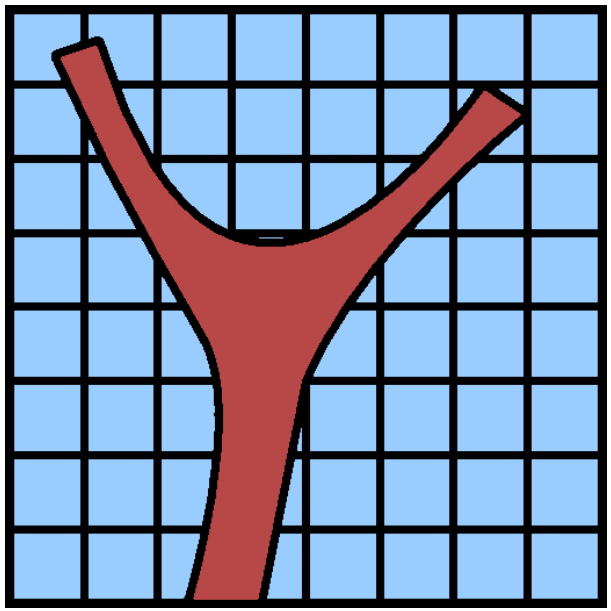
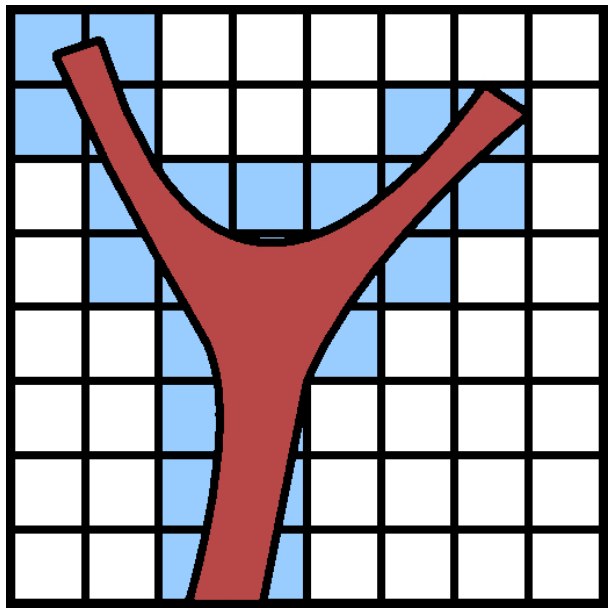


Implementation

Domain decoupling

Divide whole domain into equally sized patches ($8 \times 8 \times 8$) and only allocate and calculate patches including fluid cells.

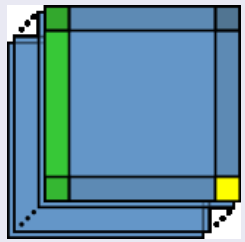




Implementation

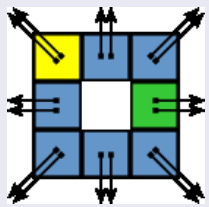
Our Data Structure

- **Patch itself**
  - $8 \times 8 \times 8 \times 19$ distribution functions



- **Halo**
  - copies of values that need to be exchanged
  - 30 planes and 12 lines
  - streaming becomes quite tricky

- **Remote Halo**
  - pointers to the neighbors' copies



- similar data for lattice type information

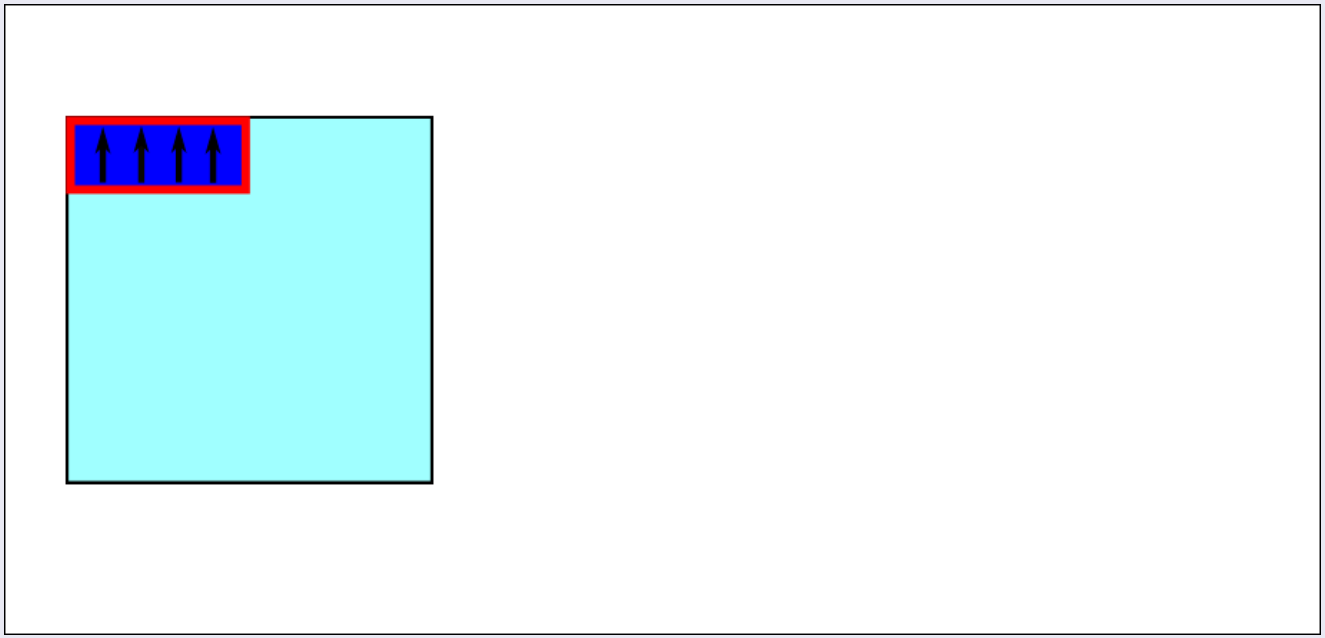
Implementation

Updating a Patch on a SPU

1. fetch...
   - distribution functions
   - LBM-cell type information
   - remote halo pointer structure
2. fetch...
   - halo planes from neighbors (T, B, N, S, E, W)
   - halo lines from neighbors (TS, NE, BW ...)
3. set source / sink
4. stream (and bounce) values (including values from halo planes)
5. correct pressure outflow
6. calculate collision
7. prepare new halo structure from calculated values
8. store patch and halo data

Implementation

Example of SIMDized Bounce-Back: Get new north vector



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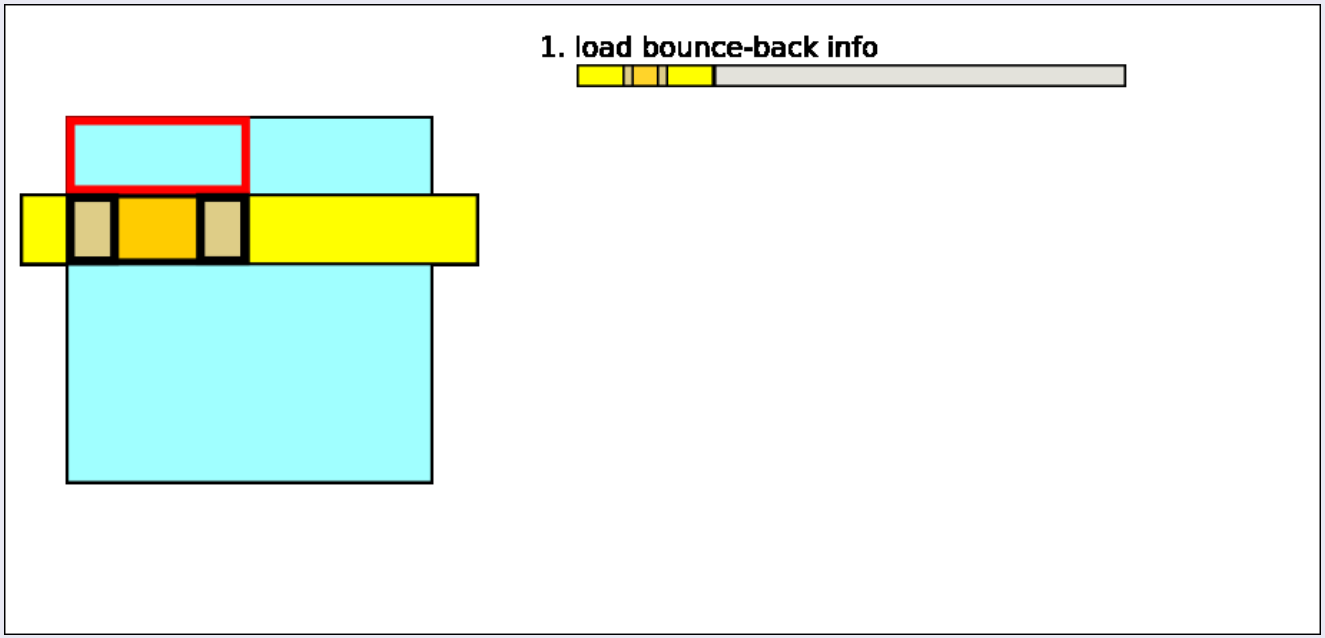

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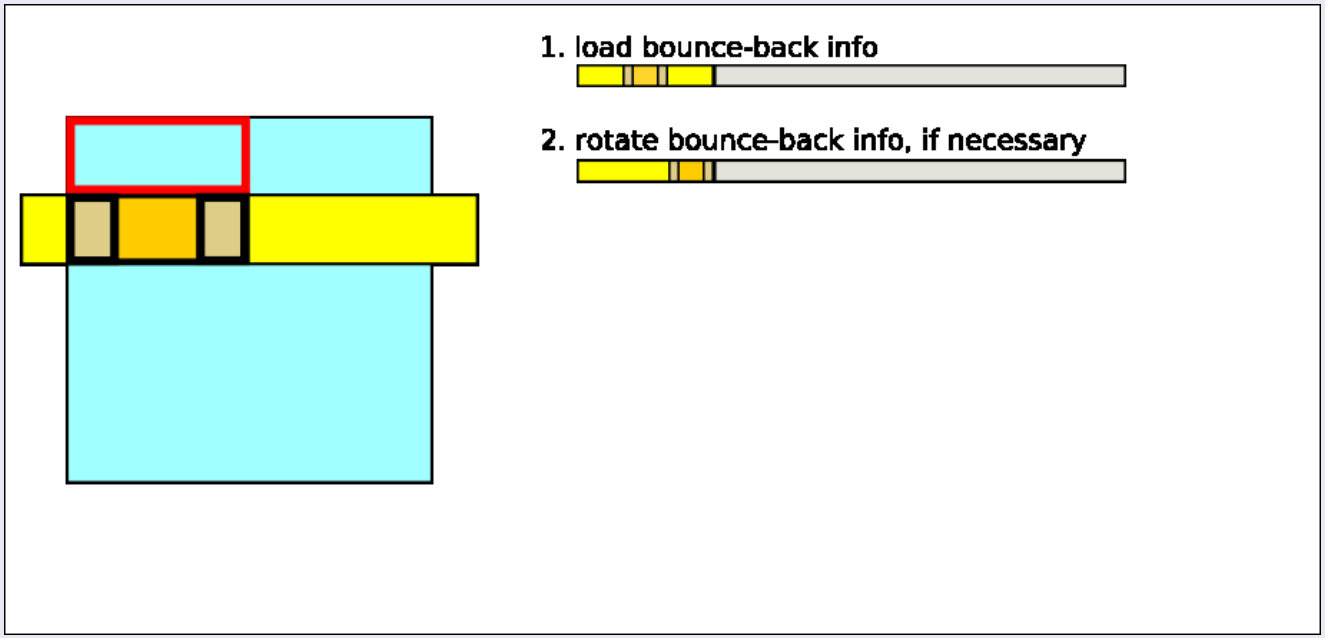

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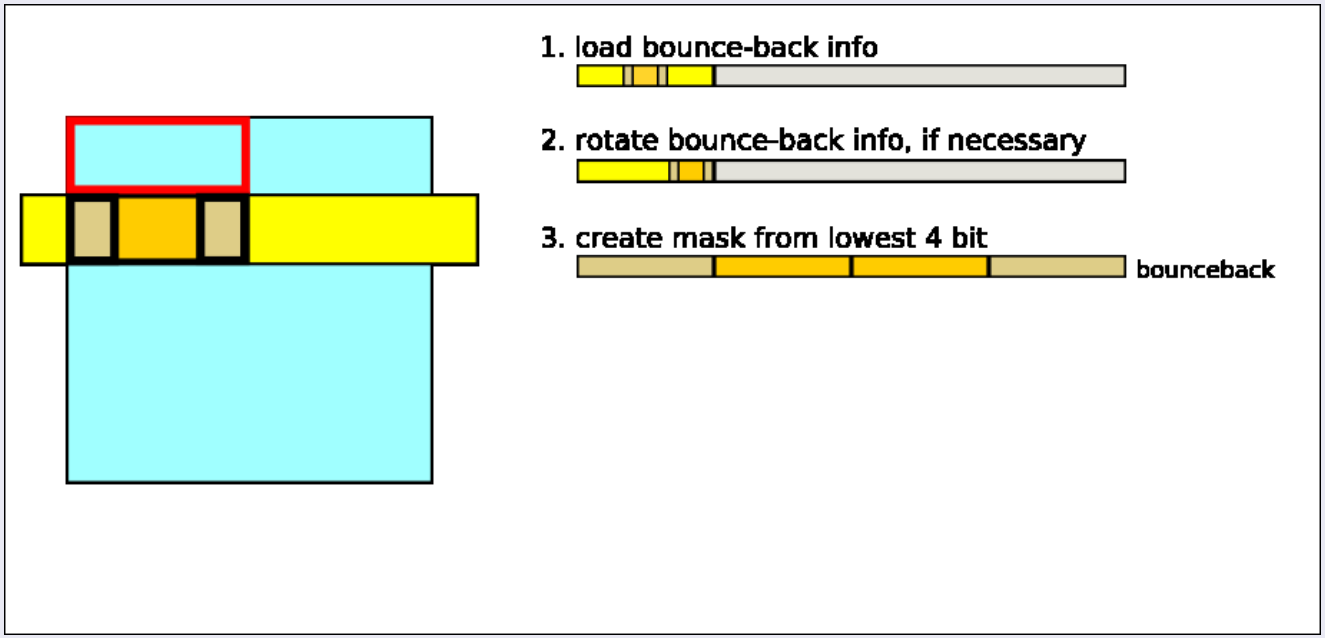

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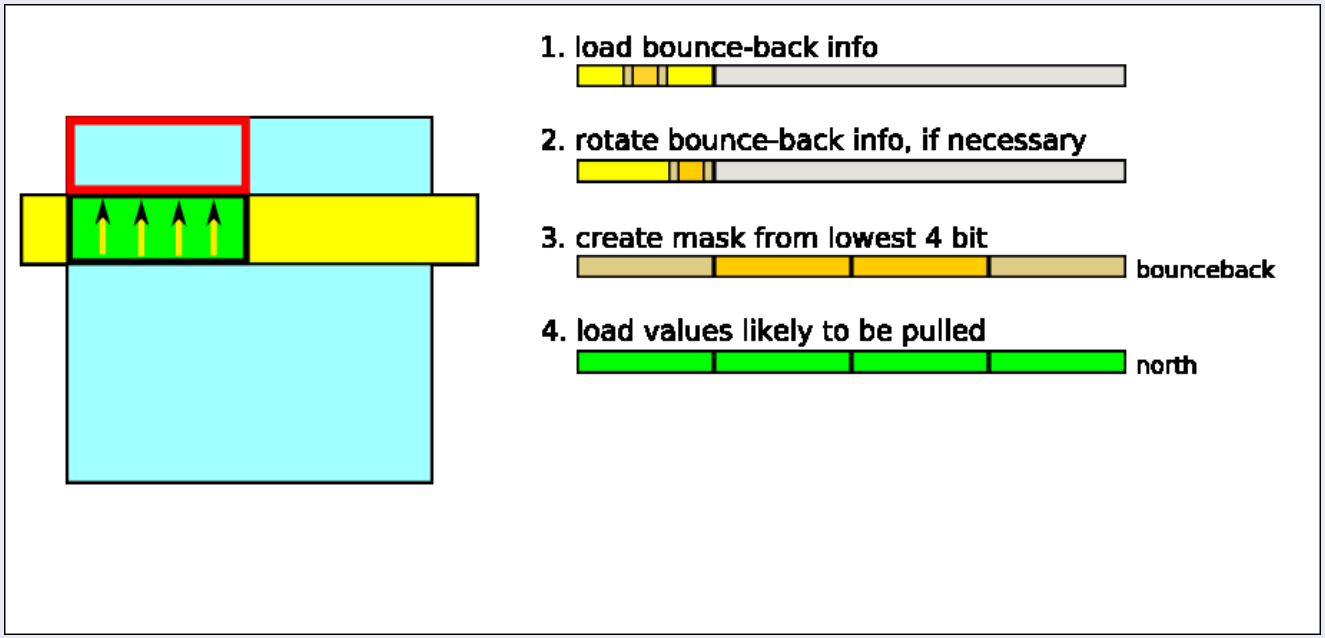

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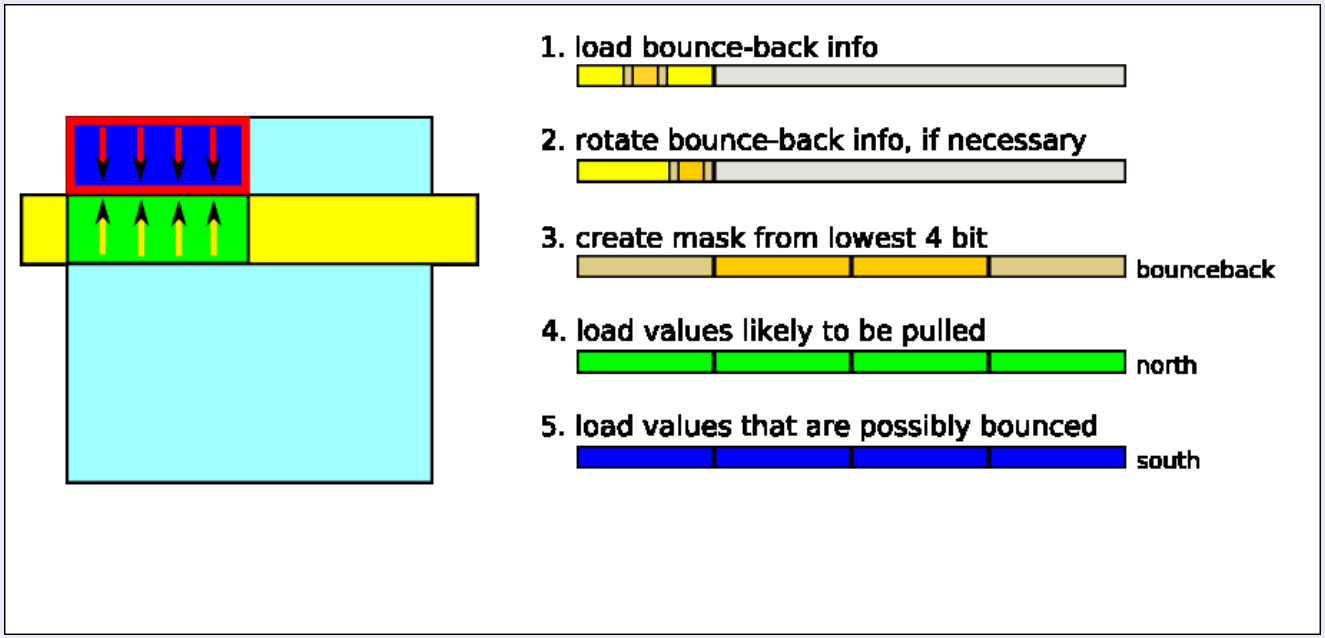

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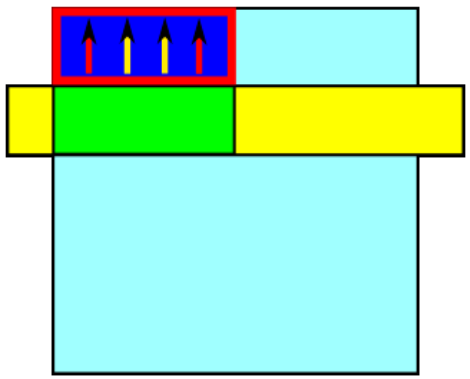

1. load bounce-back info
2. rotate bounce-back info, if necessary
3. create mask from lowest 4 bit — bounceback
4. load values likely to be pulled — north
5. load values that are possibly bounced — south
6. according to mask from 3., chose values

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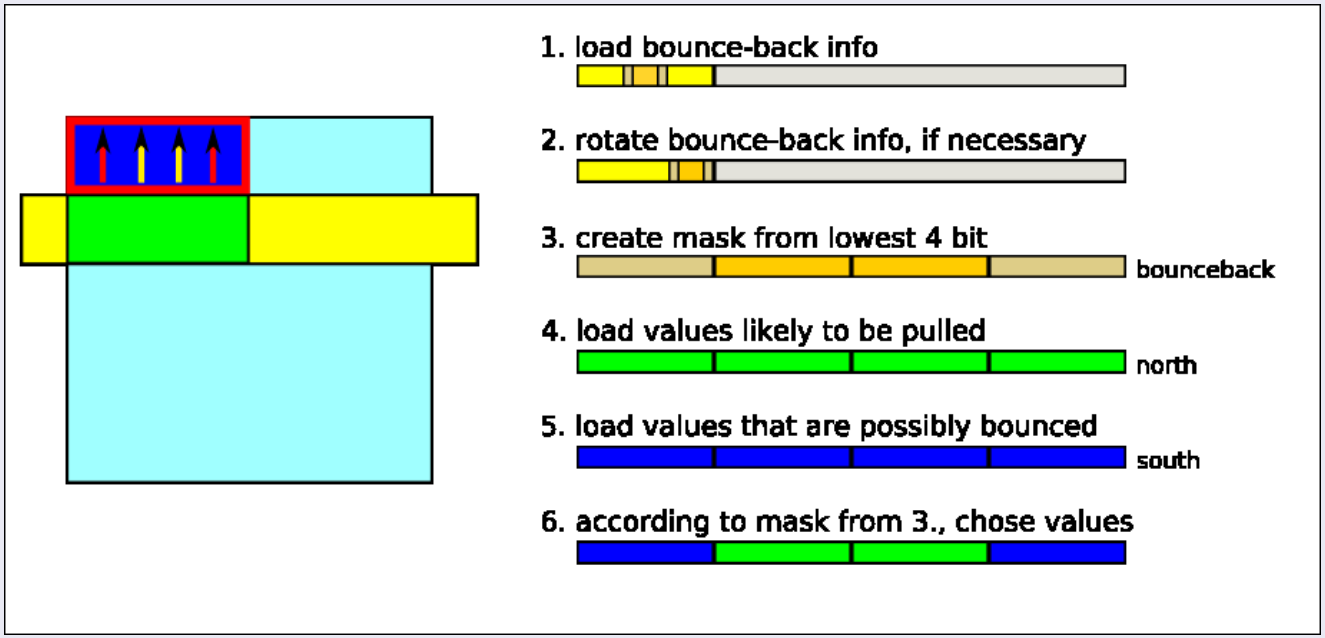


Remarks on SIMDized Bounce-Back

- streaming must take halo data into account $\Rightarrow$ complicated
- $18 \times 8 \times 8 \times 8 = 9216$ "decisions" per patch

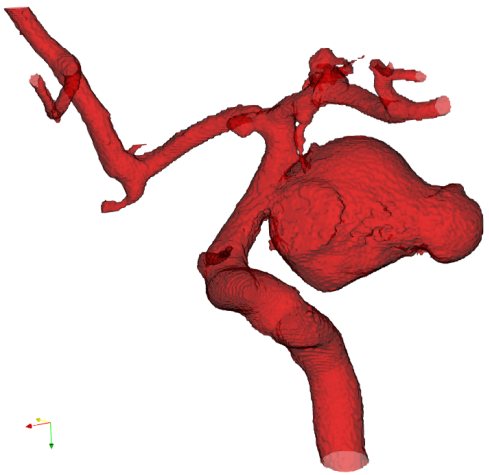
  $\Rightarrow$ scalar processing unbearably slow

Results

Single precision performance and memory for a real vessel geometry with size 250x250x220

	Core 2 Duo(3.0 GHz, both cores)[a]	Cell(3.2 GHz, 8 SPUs)
1 CPU	11.7 MFLUPS	
2 CPU	21.0 MFLUPS	
memory	128 MB	

[a] Measurements on Core 2 Duo (Woodcrest) done by Thomas Zeiser (RRZE) with the code from the Lattice Boltzmann Development Consortium



Results

Single precision performance and memory for a real vessel geometry with size 250x250x220

	Core 2 Duo(3.0 GHz, both cores)[a]	Cell(3.2 GHz, 8 SPUs)
1 CPU	11.7 MFLUPS	43.4 MFLUPS
2 CPU	21.0 MFLUPS	88.0 MFLUPS
memory	128 MB	106.3 MB

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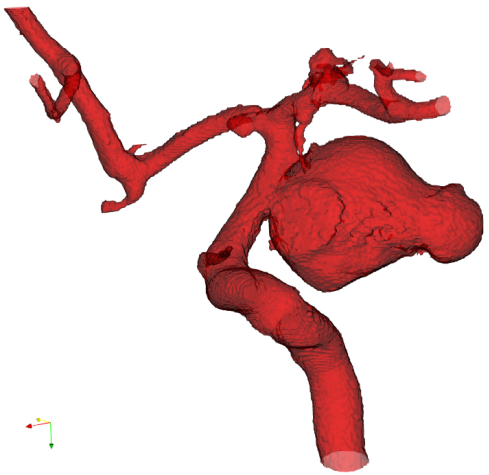

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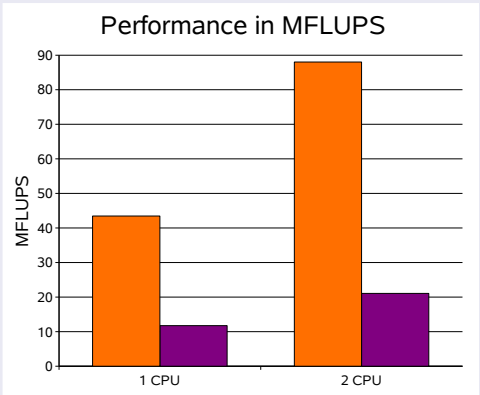
Single precision performance of Cell vs. Core 2 Duo for real geometry



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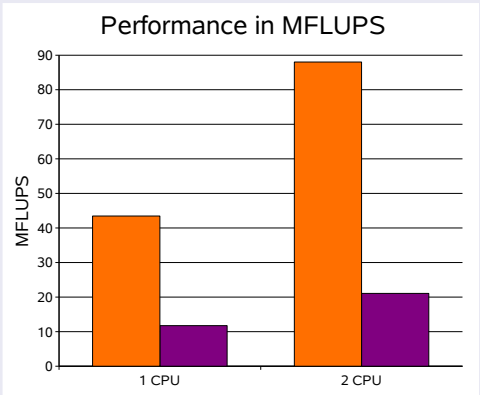

Comparison of standard C code to advanced Cell code for a channel

	Standard C Code	Advanced Cell Code
Core 2 Duo	10.2 MFLUPS	
1 SPU	2.0 MFLUPS	38.5 MFLUPS
8 SPU	15.8 MFLUPS	98.1 MFLUPS

Outlook

More to do...

- examine influence of rounding mode
- MPI parallelization
- add more difficult model / evaluation

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Acknowledgements

- thanks to Markus Stürmer for the implementation
- thanks to Thomas Zeiser for performance measurements
- thanks to IBM development center at Böblingen for access to Cell Blade
- thanks to ZAM / FZ Jülich for access to JUICE
- thanks to Professor Dörfler and Doctor Richter for medical advice

The End

Thank you very much for your attention!