AGH UNIVERSITY OF SCIENCE AND TECHNOLOGY

Application of Heterogeneous Computing to CAFE Simulations of Production Processes

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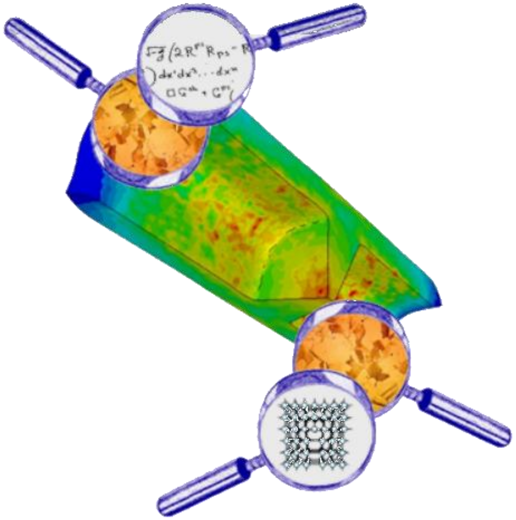
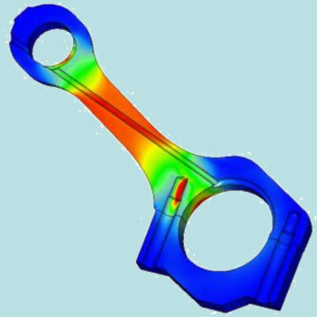
Agenda

1. Motivation
2. Aim of the work
3. Tools
   - DMR Multiscale Computations
   - Heterogeneous architectures
4. Implementation details
   - Cellular Automata for Grain Growth
   - Finite Element Method for Heat Transfer
5. Results and discussion



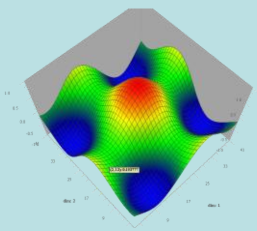
4D MODELING

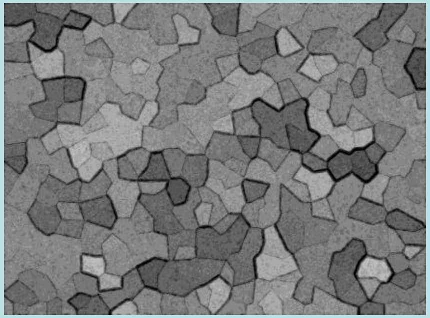
Finite Element Method



- Shape
- Loads
- Stresses
- Strains
- Temperatures

optimization

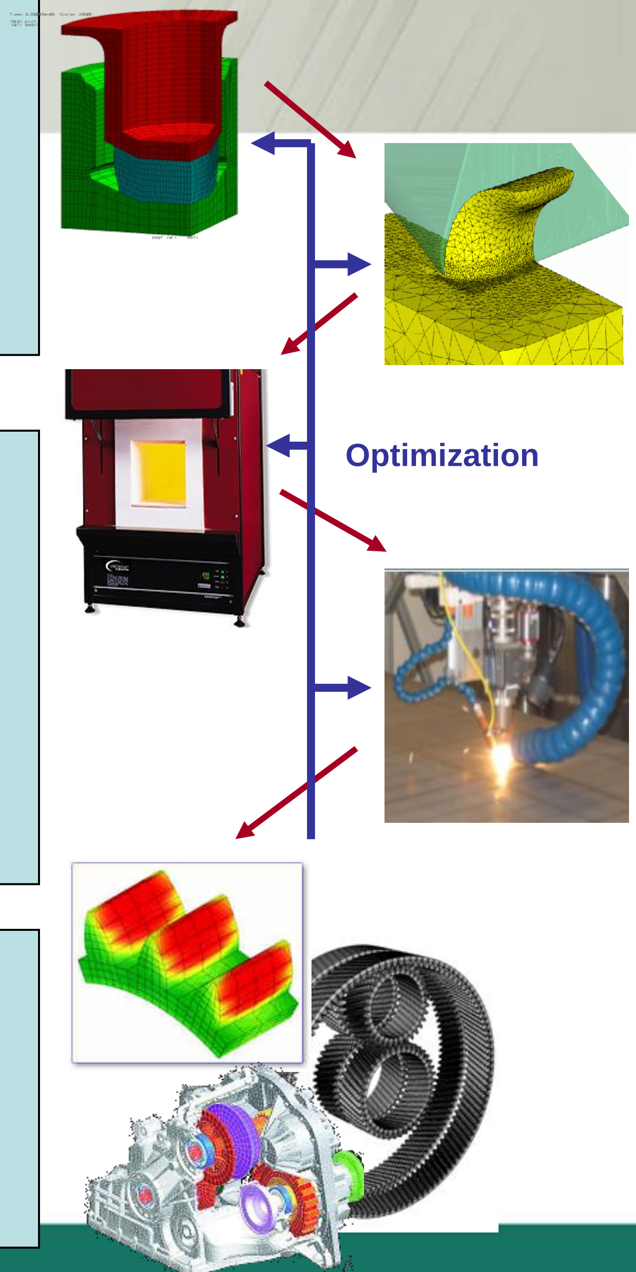




- Microstructure
- Grain size
- SRX
- DRX

- R_e,
- R_m,
- fatigue resistance,
- crash resistance,
- etc.

4D

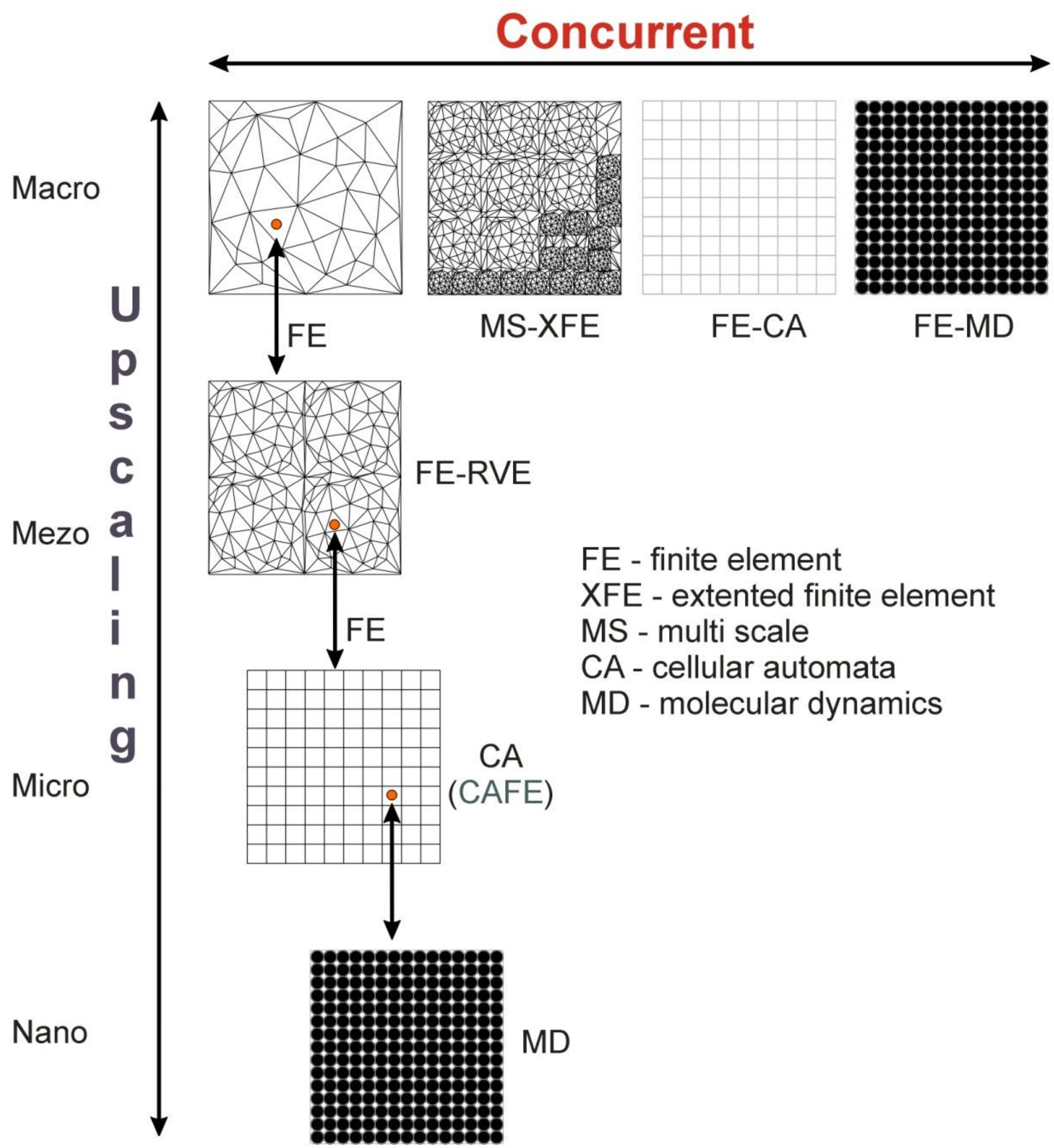


Concurrent

Problem is solved simultaneously at several scales (in practice two-scales) by an a priori decomposition.

Upscaling

Constitutive models at higher scales are constructed from observation and models at lower, more elementary scales.



Digital Material Representation

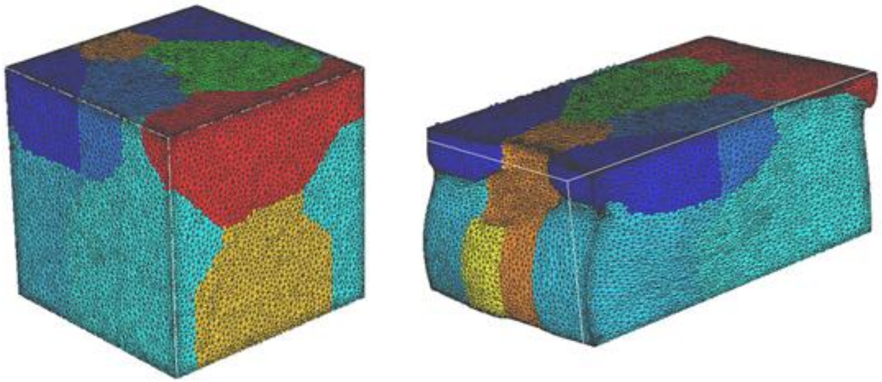


Fig. Initial 3D DMR with uniform mesh and deformed mesh

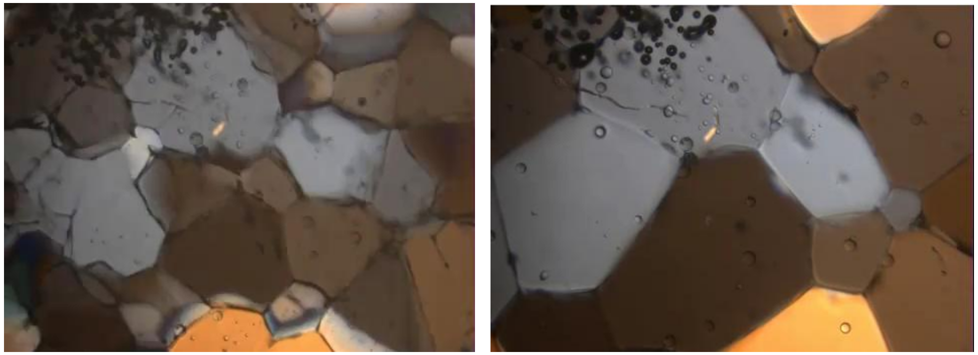


Fig. Example of grain growth

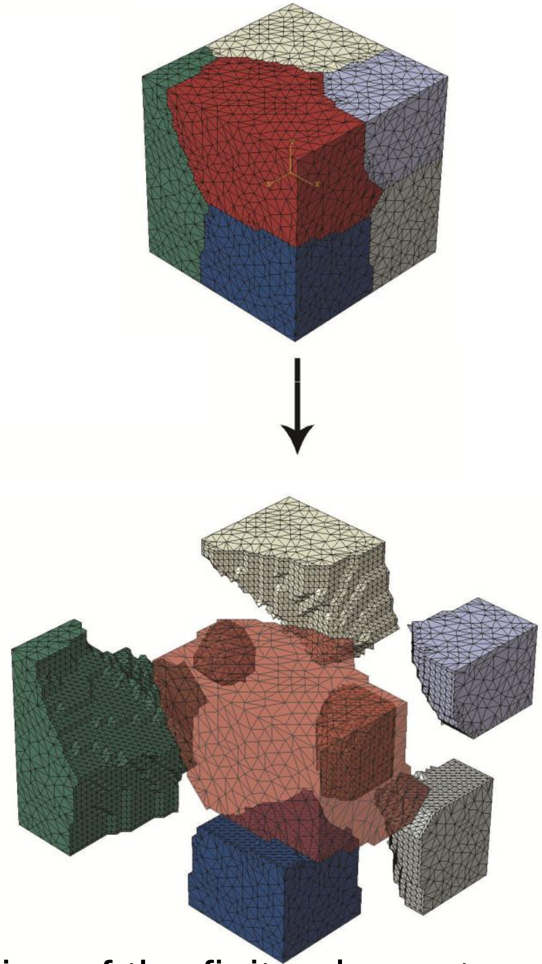
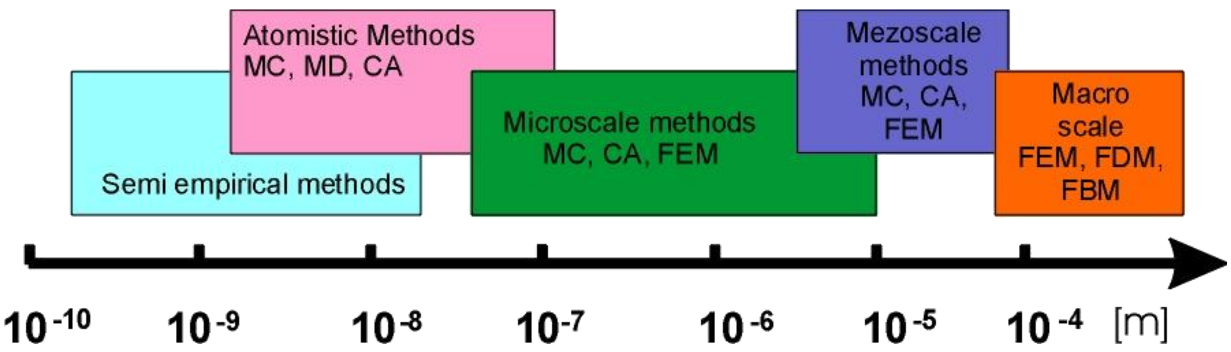
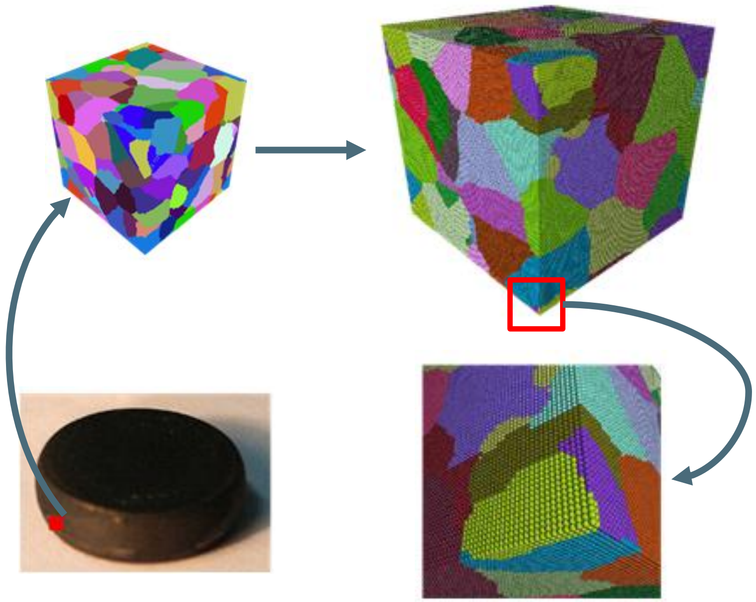


Fig. Illustration of the finite element mesh generated on the basis of the DMR.

DMR Multiscale Computations

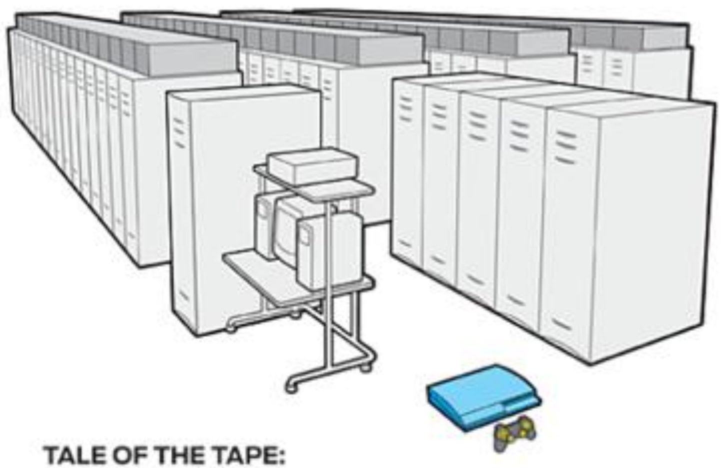
FE^2
CAFE
MSFE
….





- ✓ Software development
  - Algorithms
  - Parallelization
- ✓ Microstructure simplification
  - (SS)RVE
- ✓ Hardware usage
  - heterogeneous computing

Heterogeneous architectures - idea



TALE OF THE TAPE: SUPERCOMPUTER VS. GAME CONSOLE

	SANDIA LAB'S ASCI RED	SONY PLAYSTATION 3
DATE OF ORIGIN	1997	2006
PEAK PERFORMANCE	1.8 teraflops	1.8 teraflops*
PHYSICAL SIZE	150 square meters	0.08 square meter
POWER CONSUMPTION	800 000 watts	<200 watts

* For GPU; CPU adds another 0.2 teraflops

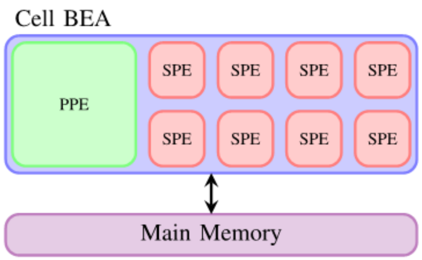
Illustration: George Retseck

- Physical constraints in the construction of standard processors
- Reducing energy consumption
- Maximizing performance

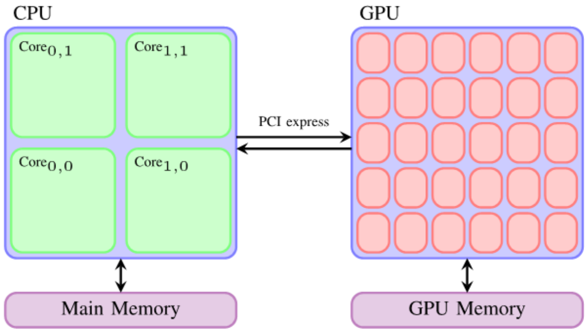
Using different processing cores

Heterogeneous architectures

CBEA



CPU in combination with GPU



CPU in combination with FPGA

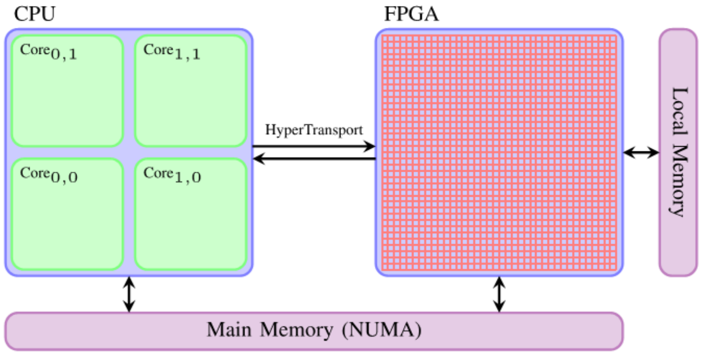
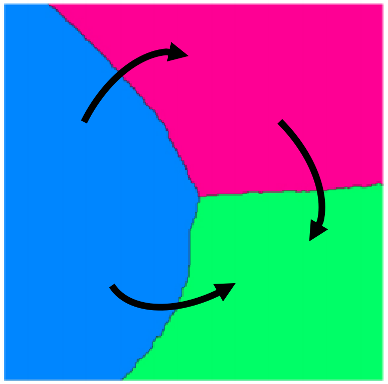


Fig. Brodtkorb A., Dyken C., State-of-the-art in heterogeneous computing, Scientific Programming, vol. 18

OpenCL

Main objectives



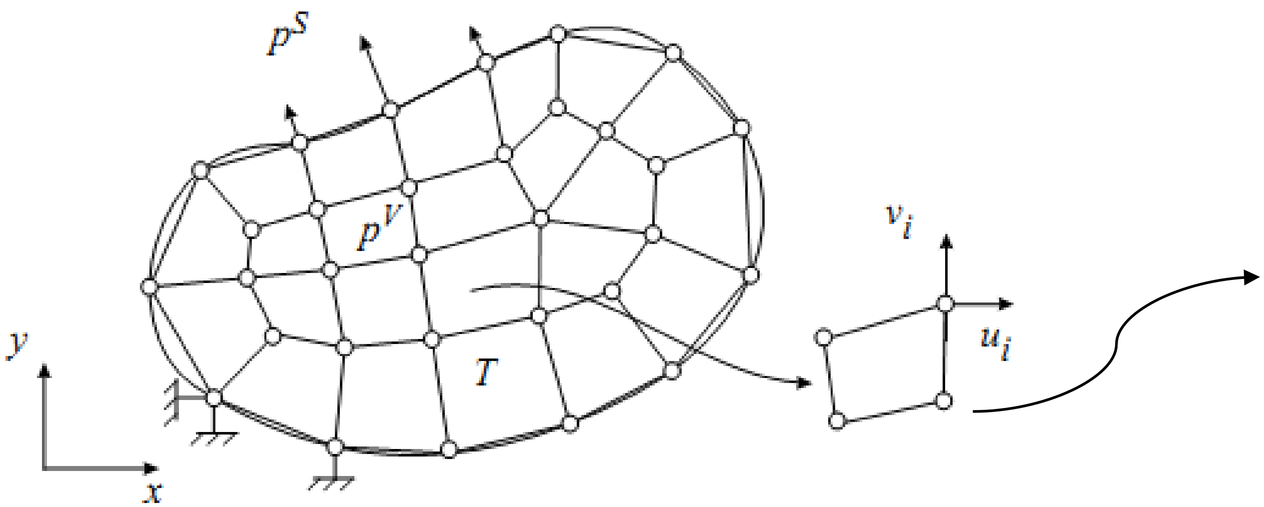
To propose efficient parallel multiscale CAFE approach, composed of CA (micro scale) and FEM (macro scale) methods, working on heterogeneous architectures

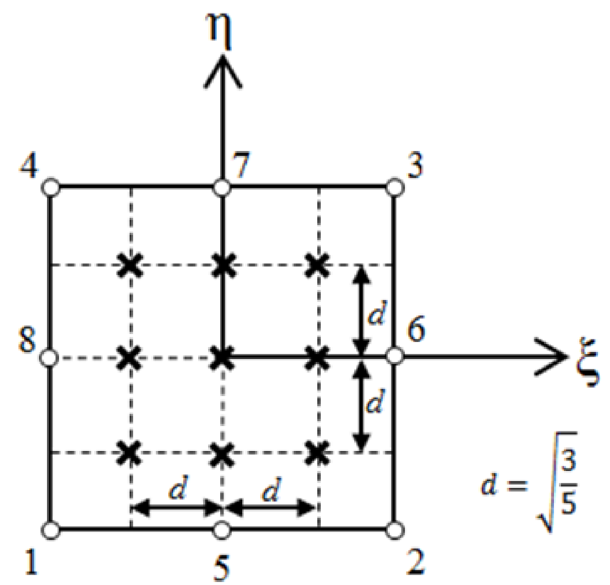
Implementation for heterogenous platform using OpenCL

OpenCL

To apply implemented CAFE approach to simulate selected real production process

Finite Element Method (FEM) – basic idea





Discretize the domain

Determine interpolation functions

Compute the element matrices and vectors

Assemble the element equations

Solve the global equation system

Cellular Automata – basic idea

The main idea of the cellular automata technique is to divide a specific part of the material into one-, two-, or three-dimensional lattices of finite cells.

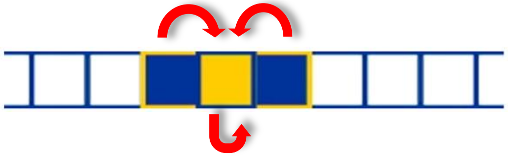


Fig. 1D CA

Fig. 2D CA

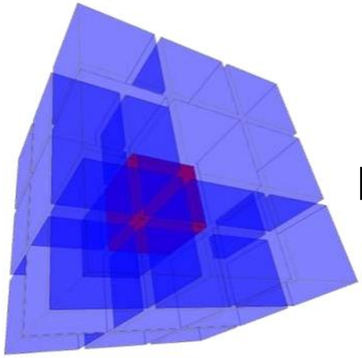
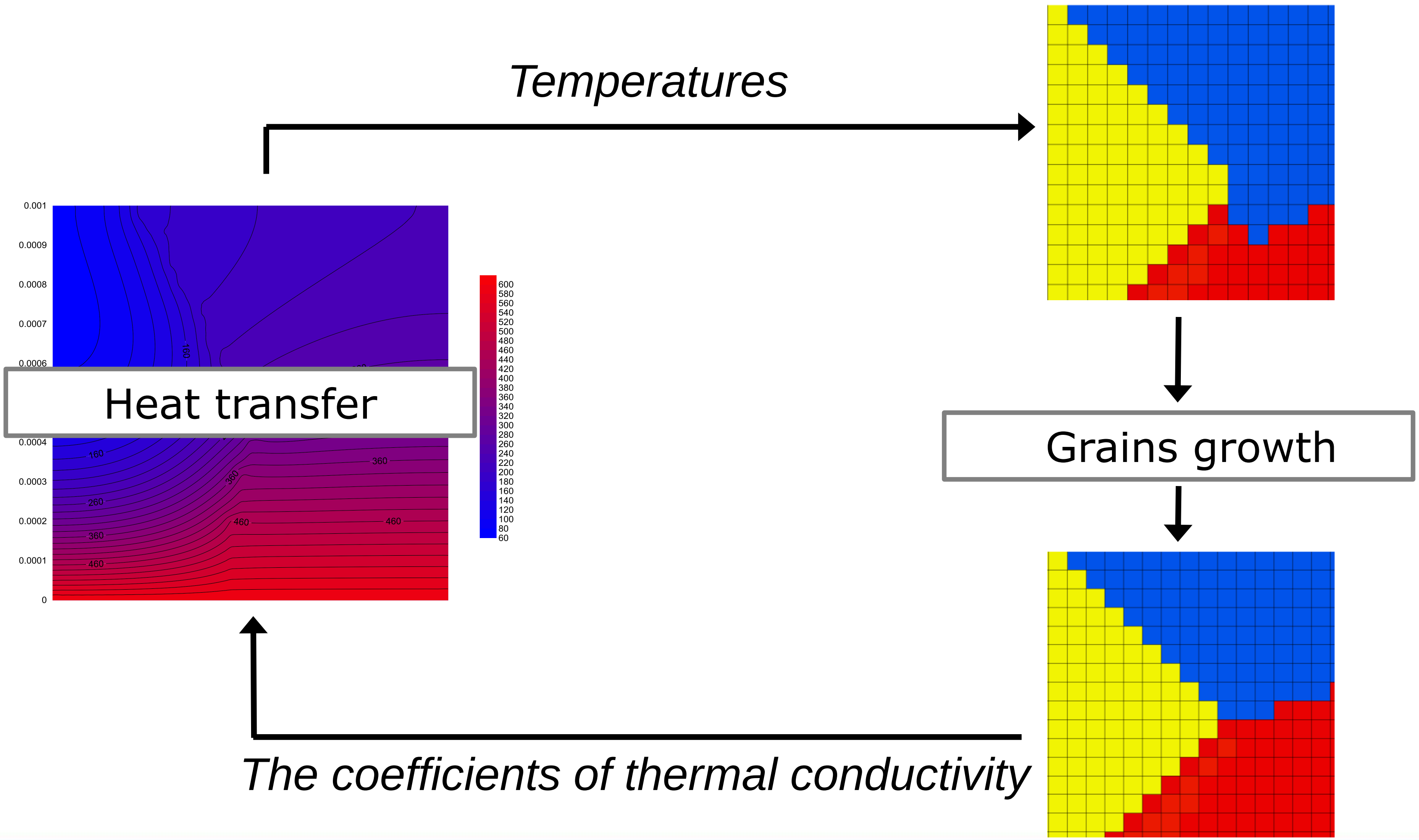


Fig. 3D CA

Each cell is characterized by its state and transition rules are defined to determine the new state of the cell on the basis of previous states of neighbours and the cell itself

CAFE construction – practice



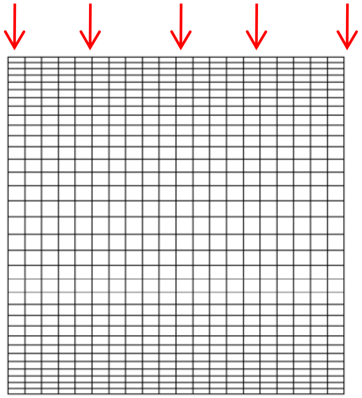
Numerical model

FEM

Heat equation

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial t}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_y \frac{\partial t}{\partial x}\right)-c_p\rho\frac{\partial t}{\partial \tau}=0$$

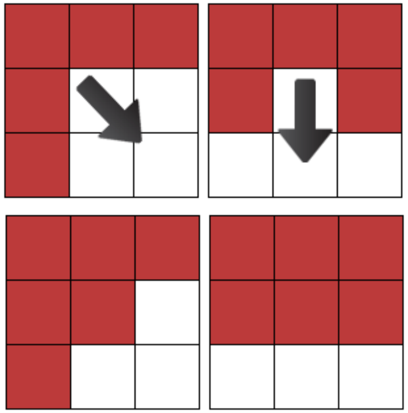
$$\vec{q}$$



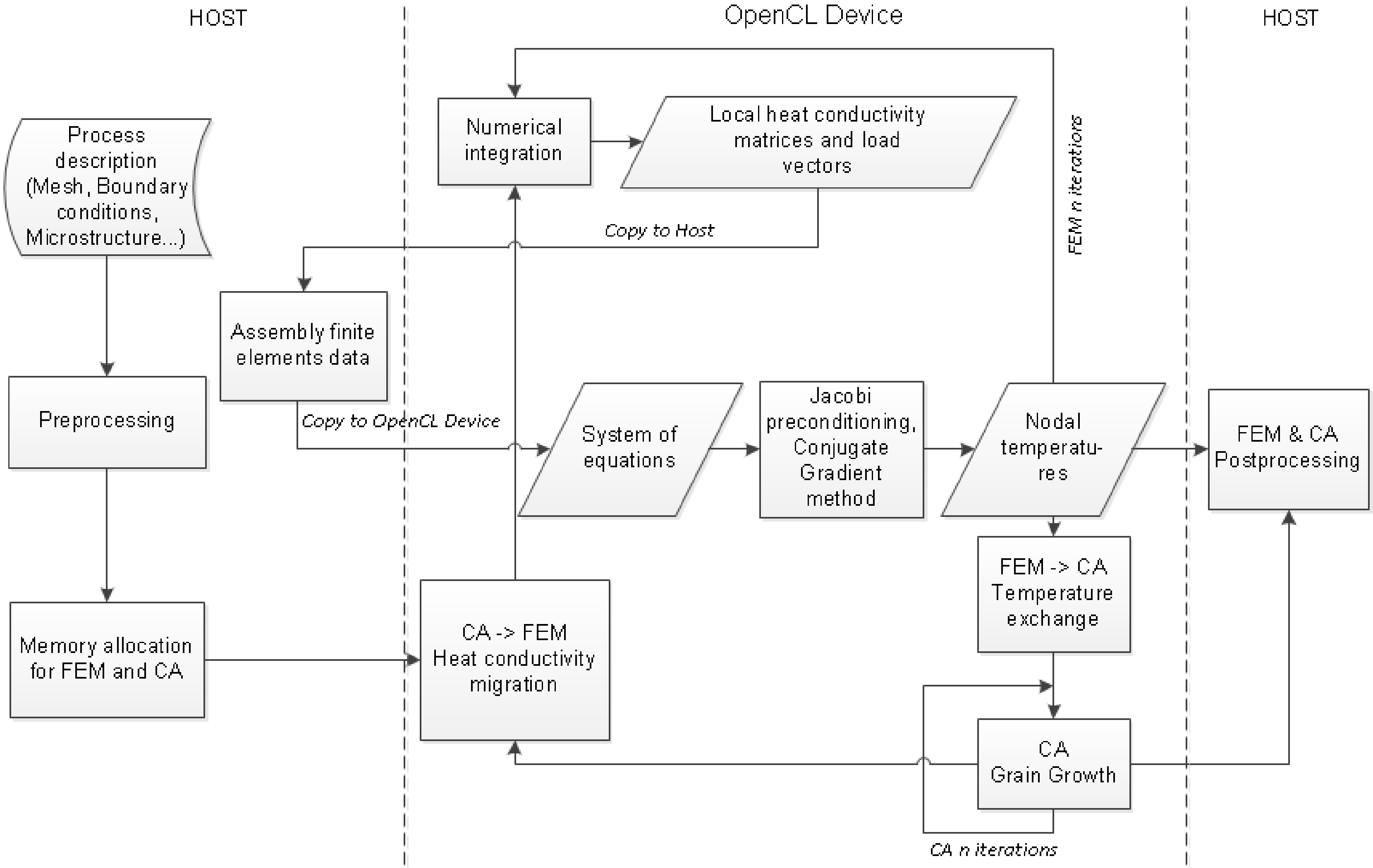
CA

Probability of state change

$$p=\exp\left(\frac{-Q_b}{RT}\right)\cdot\frac{K}{K_{\max}}$$

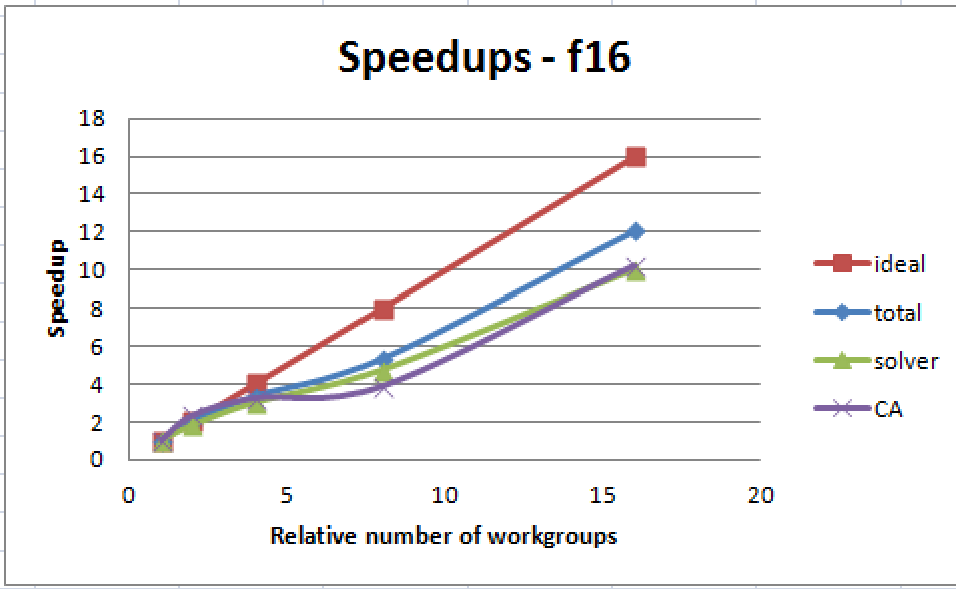


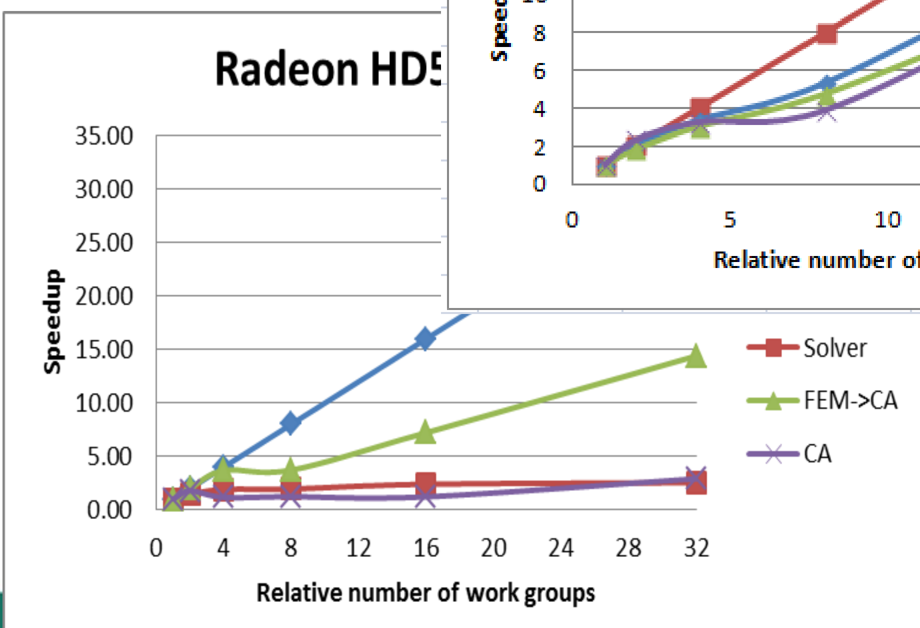
CAFE implementation details

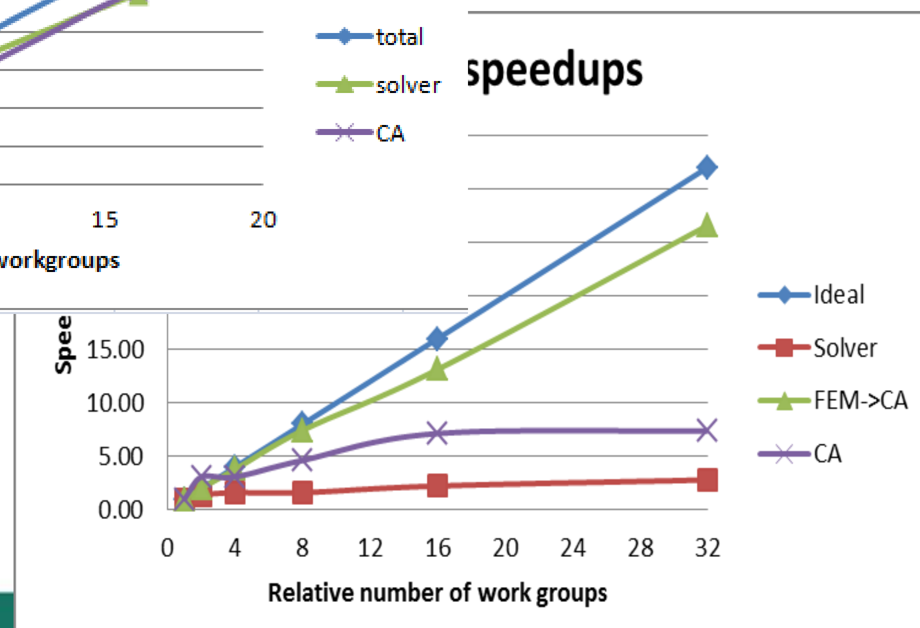


The quantitative results – diffrent devices

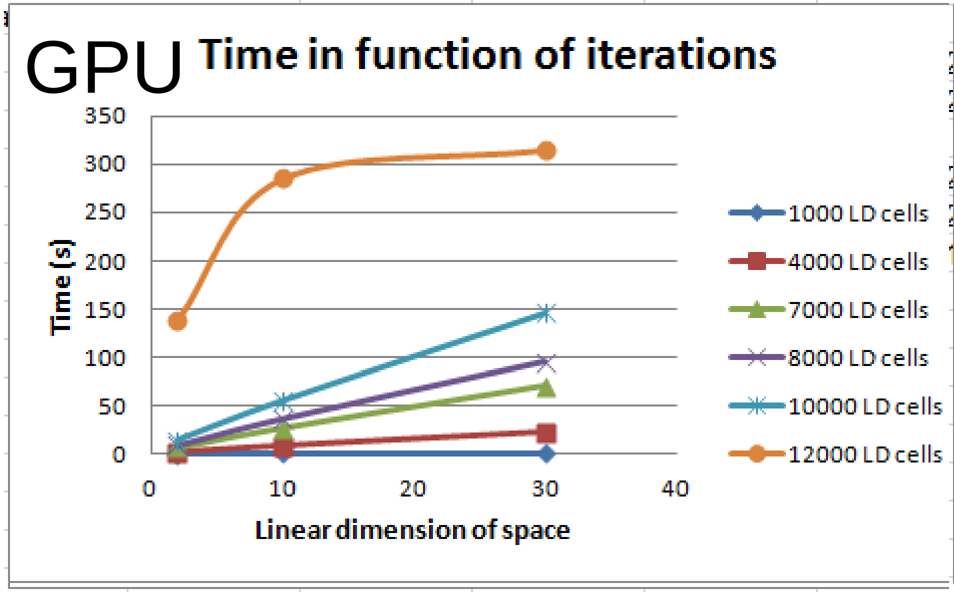
		Radeon HD5850									
		WG 4 / WI 4	WG 8 / WI 8	WG 16 / WI 16	WG 32 / WI 32	WG 64 / WI 64	WG 128 / WI 128	WG 256 / WI 256	WG 512 / WI 512	WG 1024 / WI 512	WG 2048 / WI 512
CA -> FEM		0.016	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.015	0.016	0.016
FEM	*Local*	1.325	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.048	0.030	0.000
	Global	0.219	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.093	0.078	0.092
	Solver	74.146	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.806	3.108	2.919
FEM -> CA		475.754	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9.126	4.696	2.356
CA		269.093	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	21.621	21.737	9.095
TOTAL TIME		**820,553**	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	**34,709**	**29,649**	**14,478**

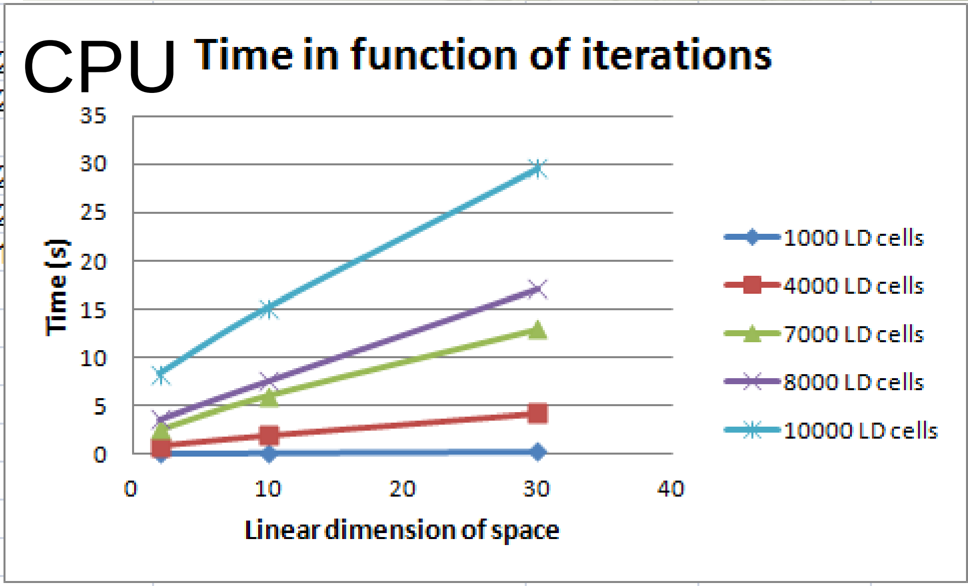


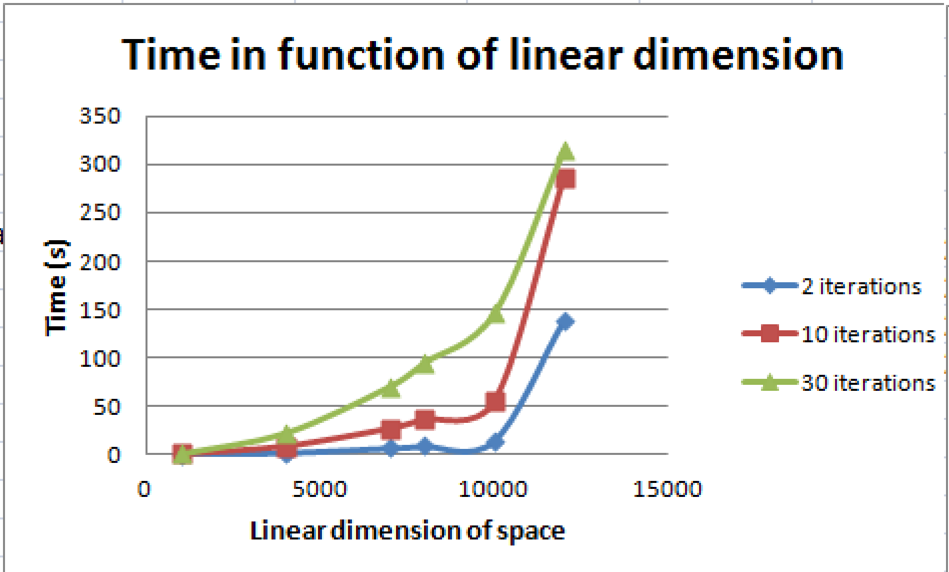


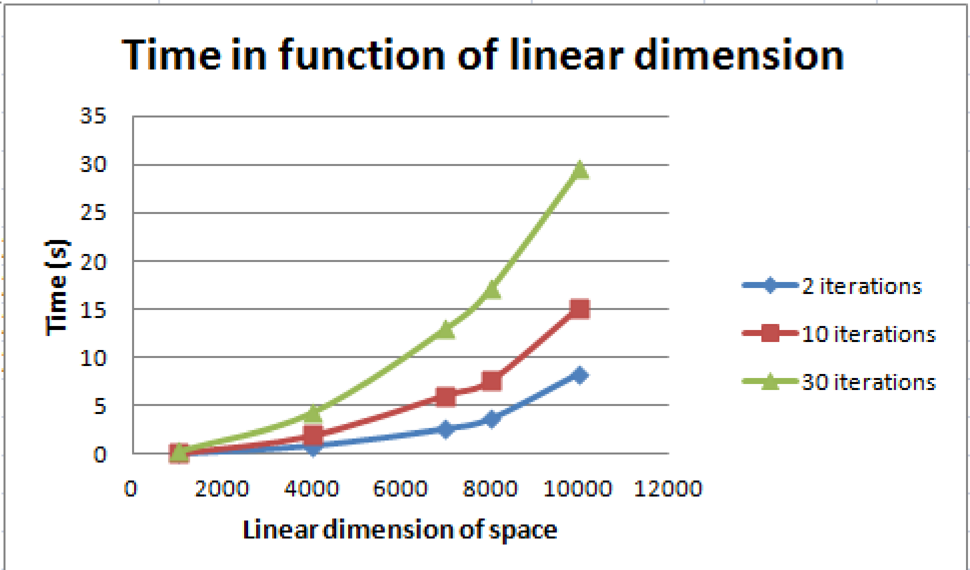


The quantitative results – diffrent number of iterations and LD



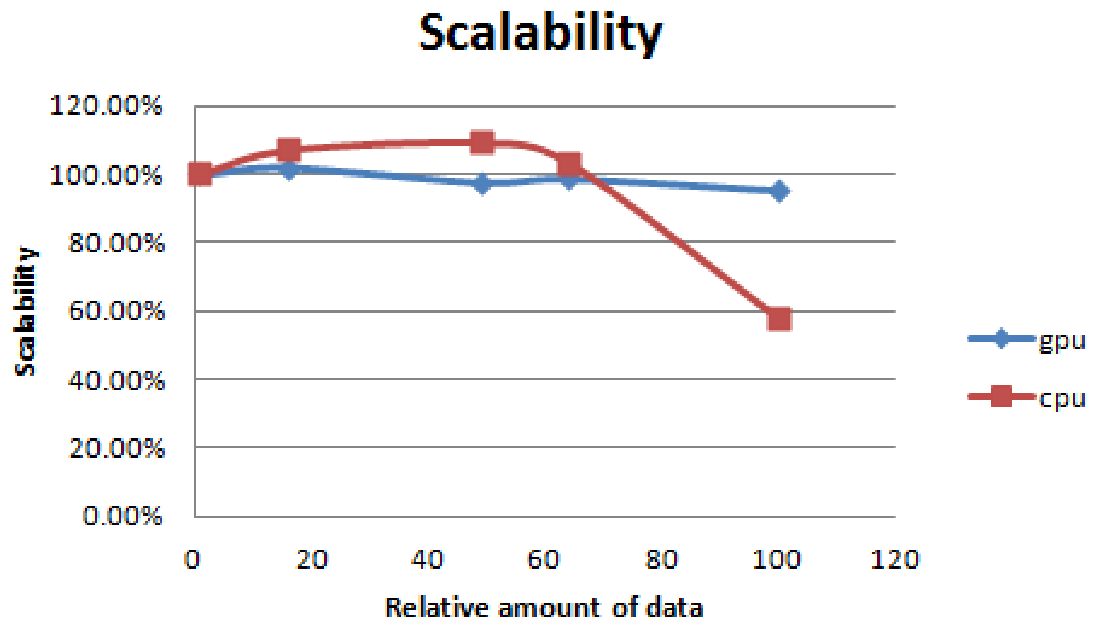




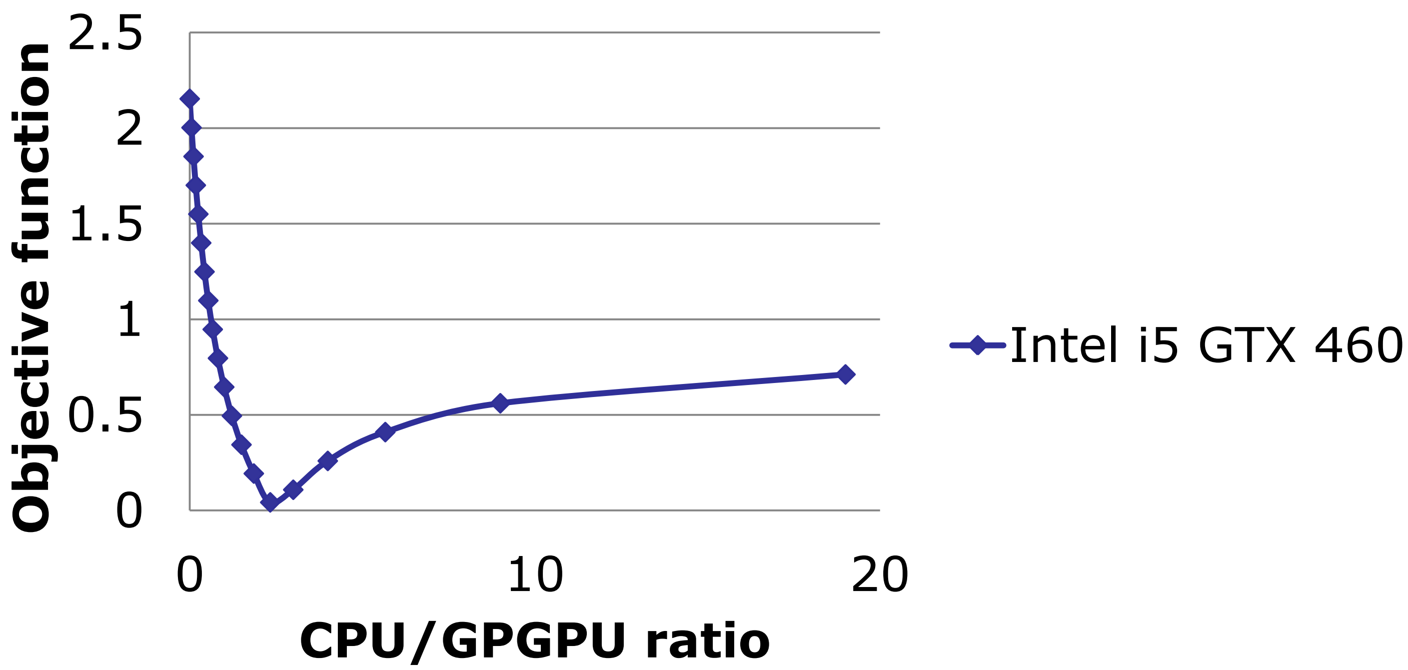


The quantitative results – scalability of CA calculations

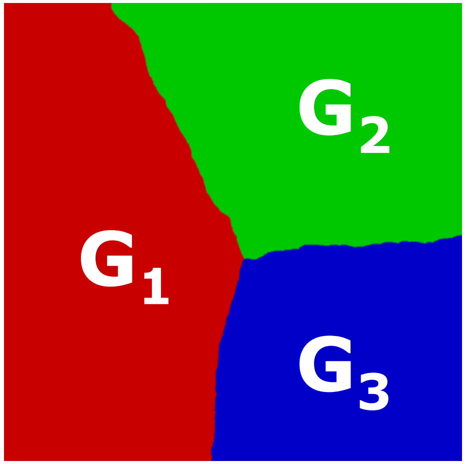
$$S_n = 1 - \frac{\frac{T_n}{T_1} - \frac{D_n}{D_1}}{\frac{D_n}{D_1}}$$



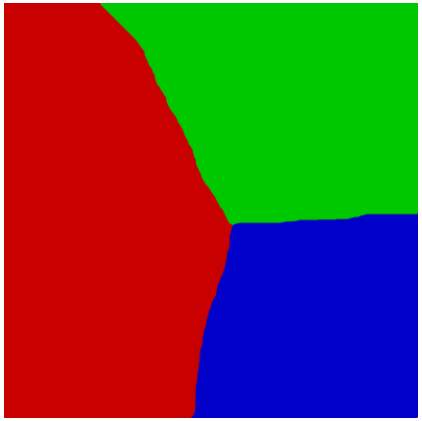
Scheduling between CPU and GPGPU



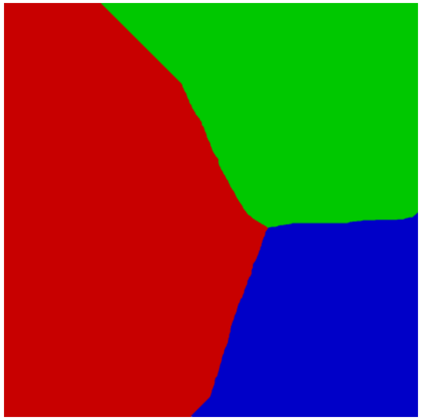
CA model verification



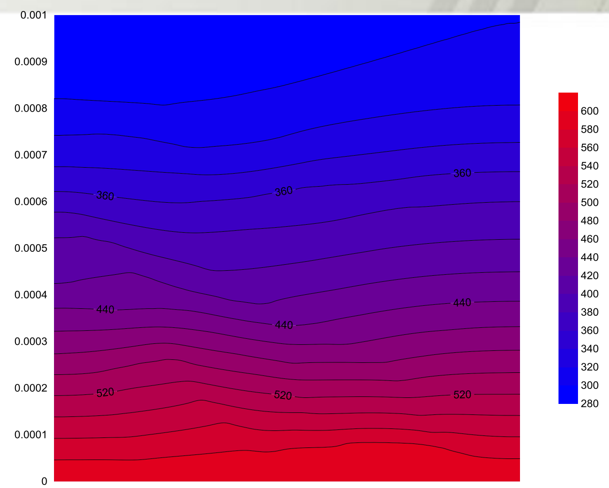
$$T_{G1} = T_{G2} = T_{G3} = const$$



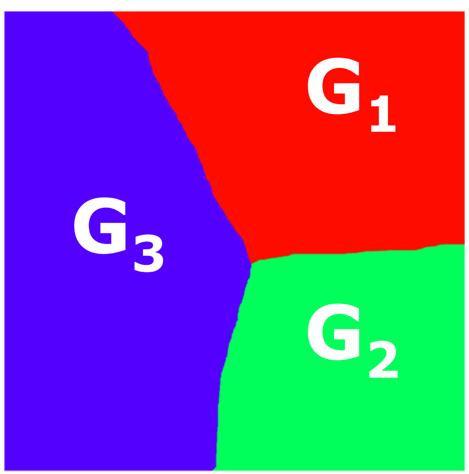
$$T_{G1} > T_{G2} > T_{G3}$$

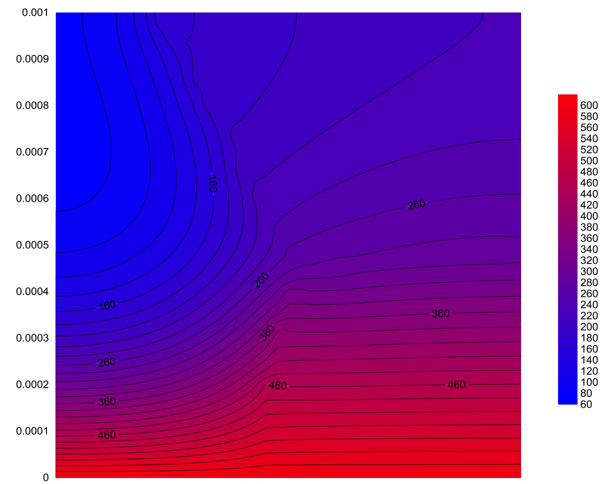


FEM model verification

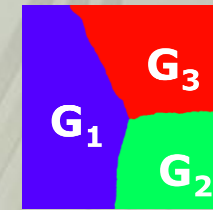


$$k_{G1} \gg k_{G2} \gg k_{G3}$$





The qualitative results of CAFE



$$k_{G1} > k_{G2} > k_{G3}$$

Fig. Temperature-controlled grain growth

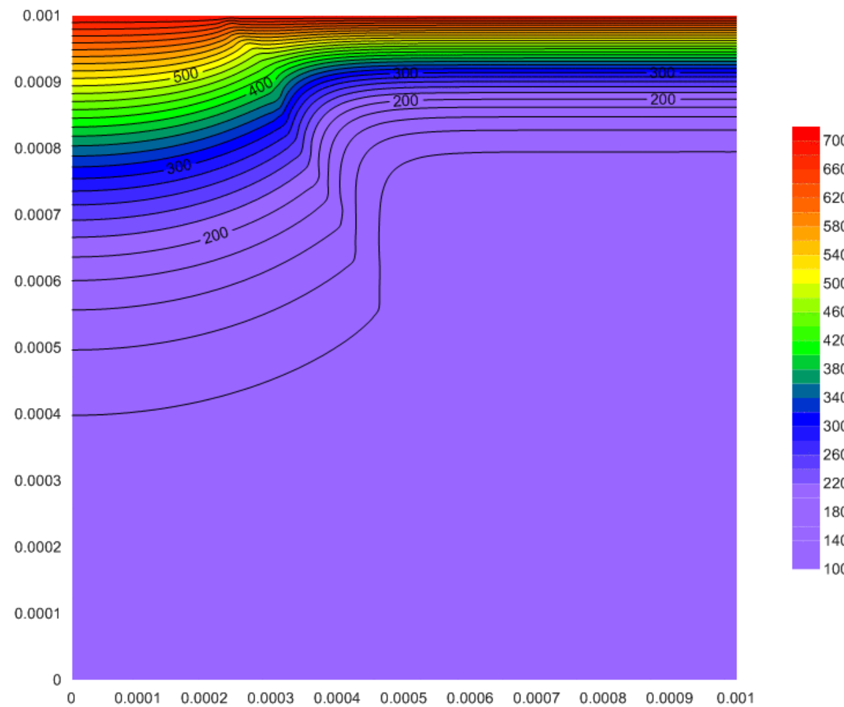
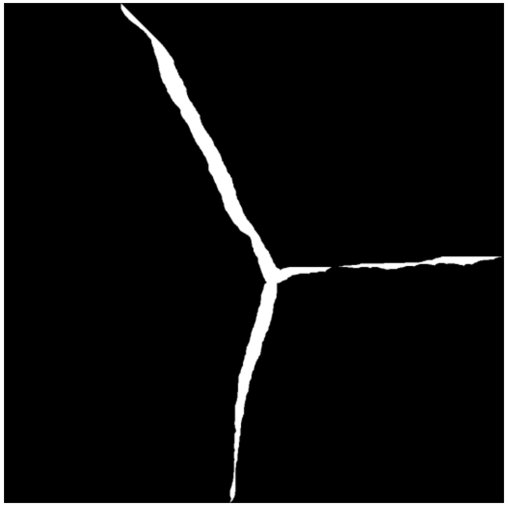
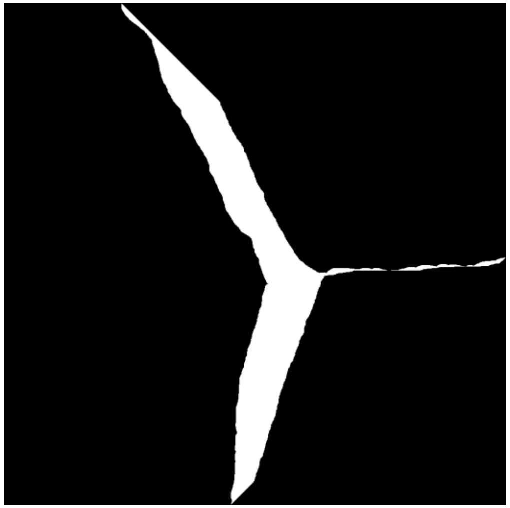


Fig. Heat transfer

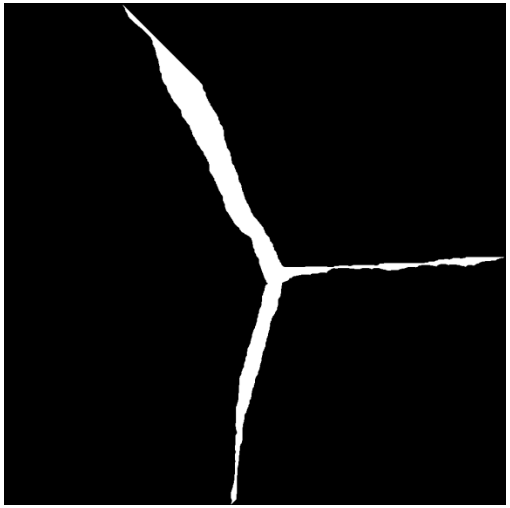
Results comparison



$T_{G1} = T_{G2} = T_{G3} = const$



$T_{G1} > T_{G2} > T_{G3}$



$CAFE$

Conclusions and further research

- Good qualitative results were obtained in comparison to physical simulations
- The character of material models implemented in micro scale strongly influences the efficiency of CA performance on GPGPU

- Deeper analysis of scheduling CA, FEM and CAFE
- Performance of computational tests on heterogeneous cluster environments