GPU acceleration of the Simple Cell Mapping algorithm

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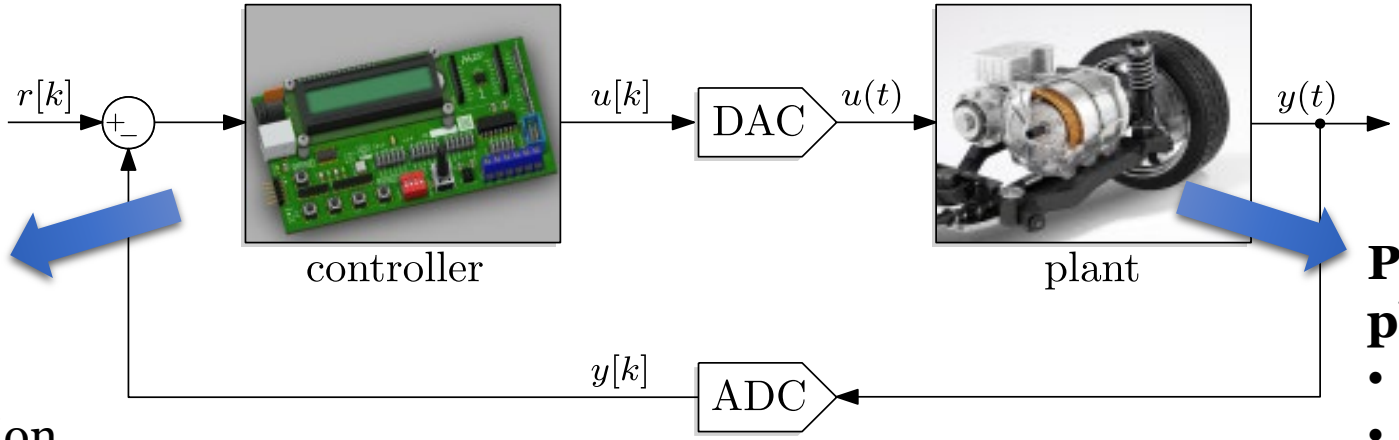
Introduction

- Structure of a mechatronic system:



Digital phenomena:
- Sampling
- Quantization
- Number representation

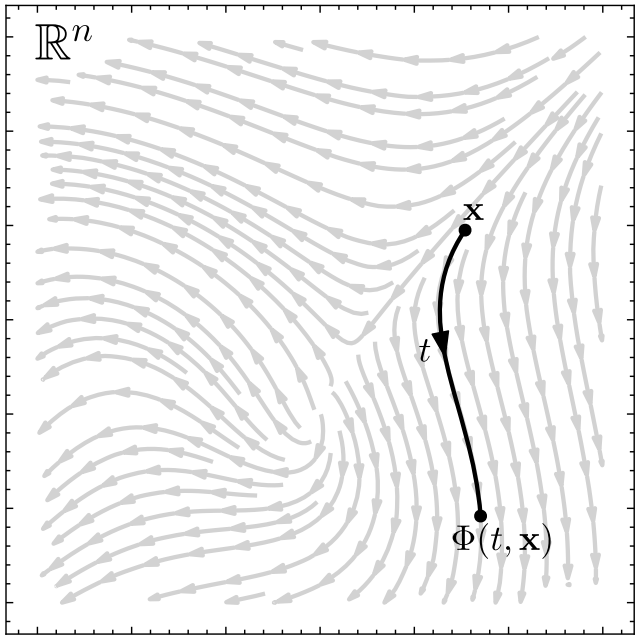
Properties of the physical system
- Friction effects
- Actuator saturation
- Nonlinearities

- Dynamical analysis
  - Linearization (locally)
  - Globally: various numerical methods → high computational costs
- This research: parallel computing application in mechatronics

Fundamentals of the cell mapping

Dynamical system

$\Phi\colon \mathbb{R} \times \mathbb{R}^n \to \mathbb{R}^n$

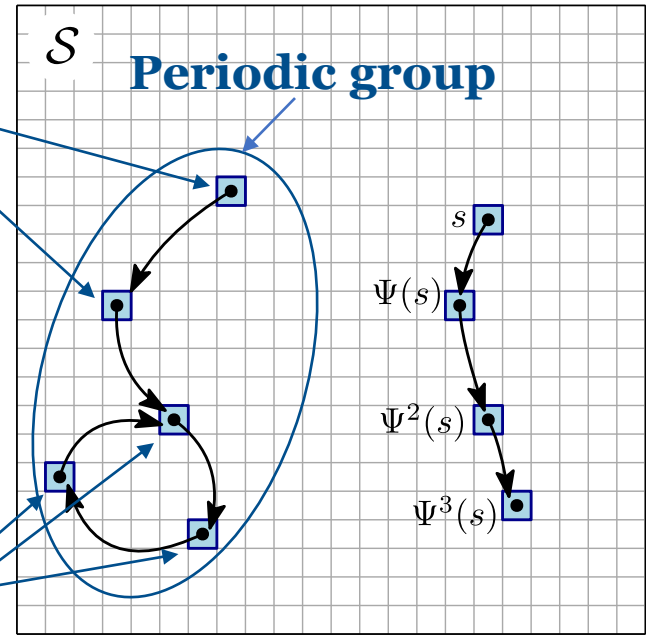


- Phase space: $\mathbb{R}^n$
- Flow map: Φ

Spatial and temporal discretization

Cell mapping

$\Psi\colon \mathcal{S} \to \mathcal{S}$



- Cell state-space: $\mathcal{S}$
- Cell-to-cell mapping: Ψ

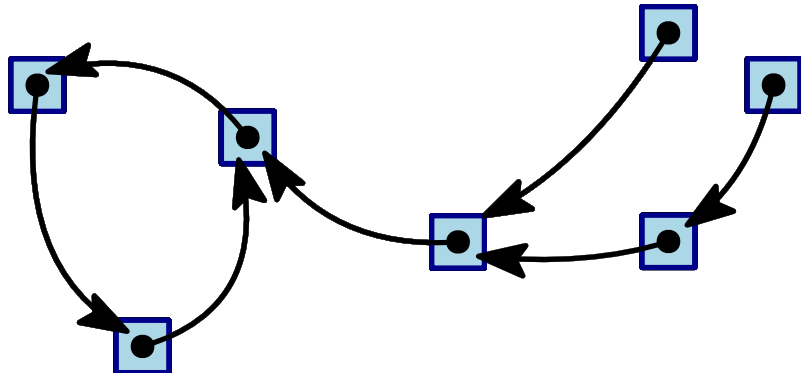
Simple Cell Mapping (SCM) algorithm

- Data structure of a cell:

```
struct Cell {
    unsigned int id;
    unsigned int group;
    Cell_type type;
    Cell_state state;
};
```

periodic/transient

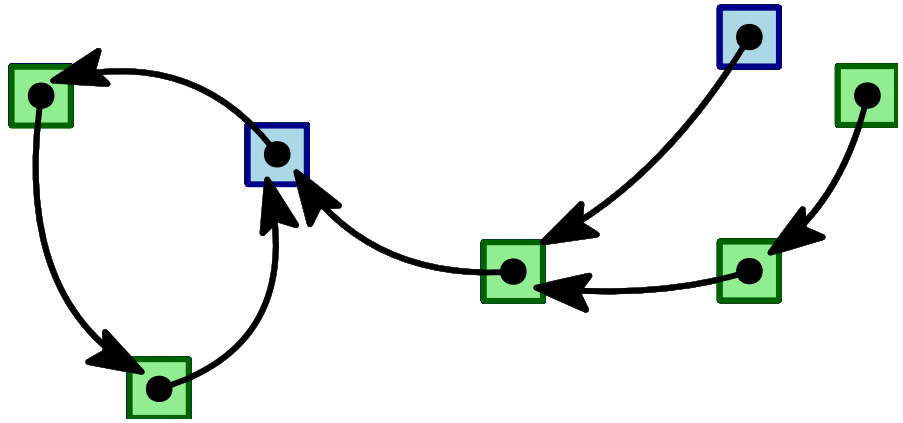
solved/under processing/unsolved



1. Start a cell sequence starting from an unsolved cell
2. For each cell in the sequence:
   - If unsolved: mark as under processing
   - If solved: append the new sequence to the previous solution
   - If under processing: new periodic group found

Challenges in parallellization

- **Idea: start solutions from multiple cells**
- Race conditions: solutions may merge
  - Memory access? (writing conflicting data to the same location)
  - Performance (more threads working on the same sequence)
  - Conflicting group IDs



Parallelization of the SCM algorithm

- Modified cell representation structure:

```
struct Cell {
    unsigned int id;
    unsigned int group;
    Cell_type type;
    Cell_state state;
};
```

```
struct Cell {
    Cell_type type;
    unsigned int group;
    Cell_state state[N_THREADS];
};
```

- Considerations:
  - Threads share the same cell array
  - Cell IDs are the array indices
  - Only the solution states are stored thread-by-thread
  - Group ID

Implementation in OpenCL

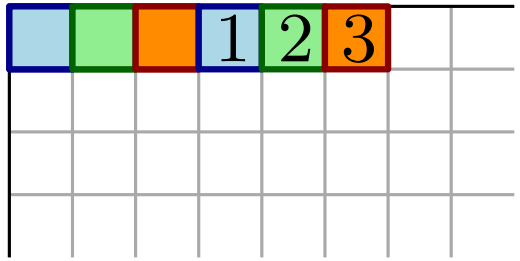
```
__kernel void solve(__global struct Cell *cells){
    // get global ID
    size_t gid = get_global_id(0);

    // calculate SCM solution
    unsigned int start = gid;
    unsigned int end = N_CELLS;
    for(unsigned int z=start; z<end; z+=N_THREADS){
        // ...

                    mem_fence(CLK_GLOBAL_MEM_FENCE);

        // ...
    }
}
```

- Cells in global memory
- Each work-item starts from a different cell
- Scanning through the cell state-space
- Synchronization during solving



Results

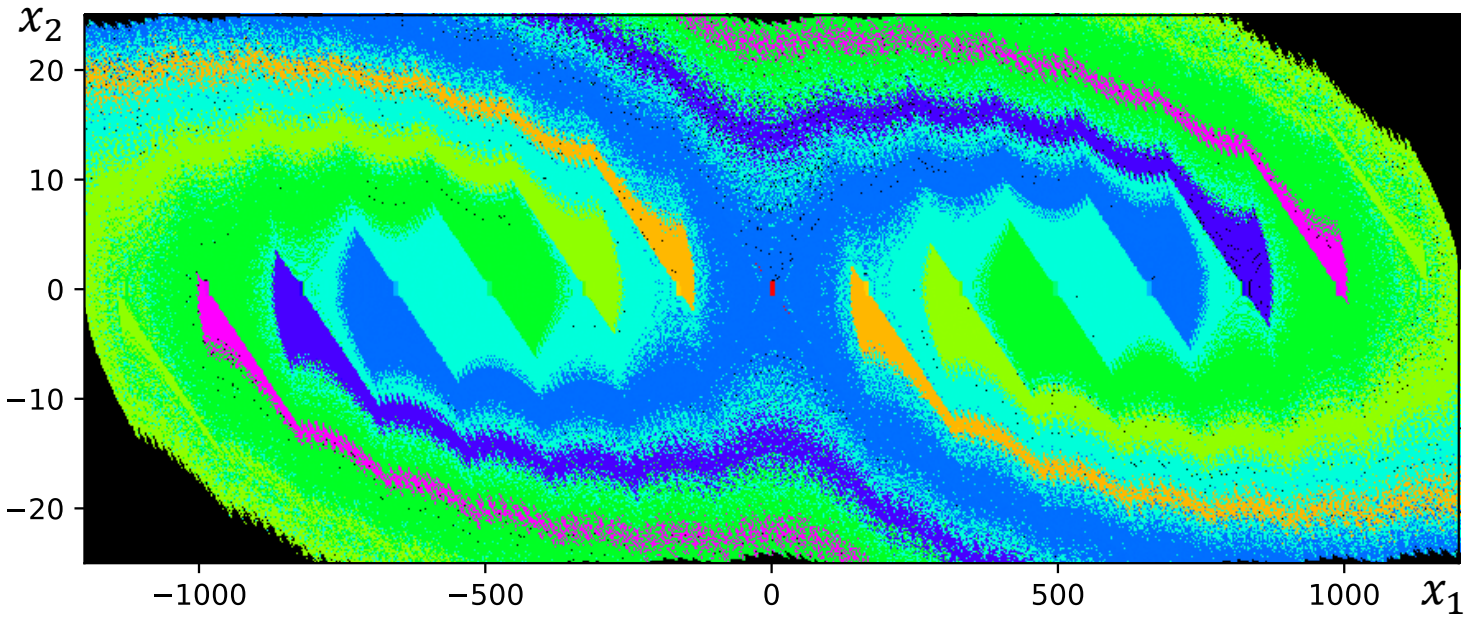
- Micro-chaos map
  - State-feedback: $u[k] = \mathrm{trunc}(-\mathbf{K}\,\mathbf{x}[k])$
  - State equation: $\mathbf{x}[k+1] = \mathbf{A}\,\mathbf{x}[k] + \mathbf{B}\,u[k]$
- SCM on a 1920×1080 cell state-space:

Parameters:

$$\mathbf{A} = \begin{bmatrix} 1{,}00304 & 1{,}00101 \\ 0{,}00609 & 1{,}00304 \end{bmatrix};$$

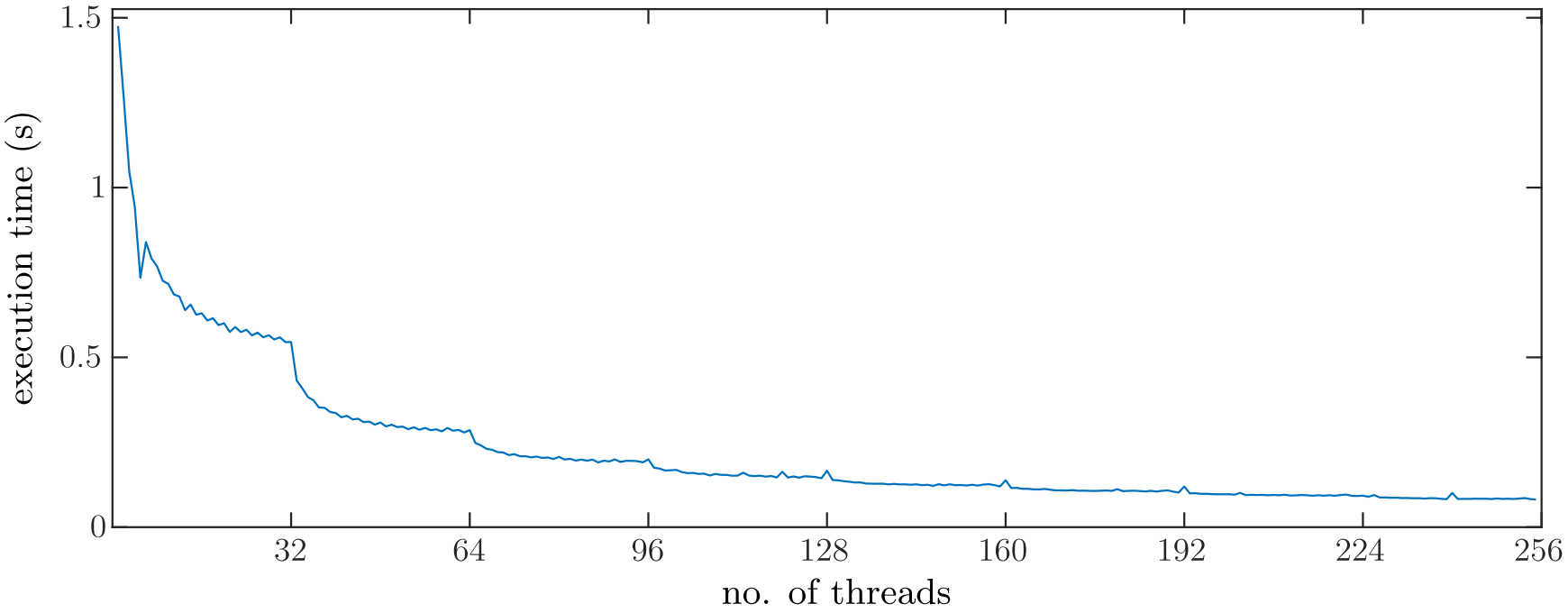
$$\mathbf{B} = \begin{bmatrix} 0{,}50025 \\ 1{,}00101 \end{bmatrix};$$

$$\mathbf{K} = [0{,}007 \quad 0{,}020]$$



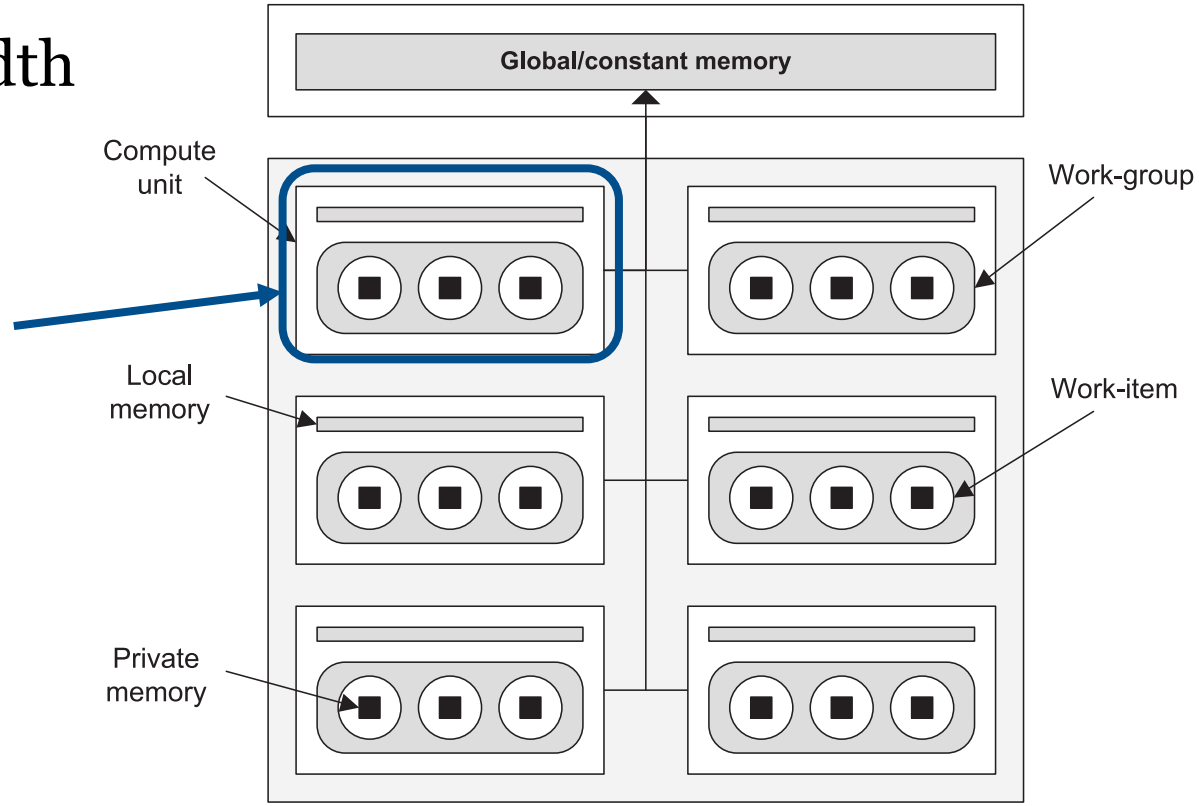
Results

- GPU: NVIDIA RTX 3050 Ti
- Scalability:

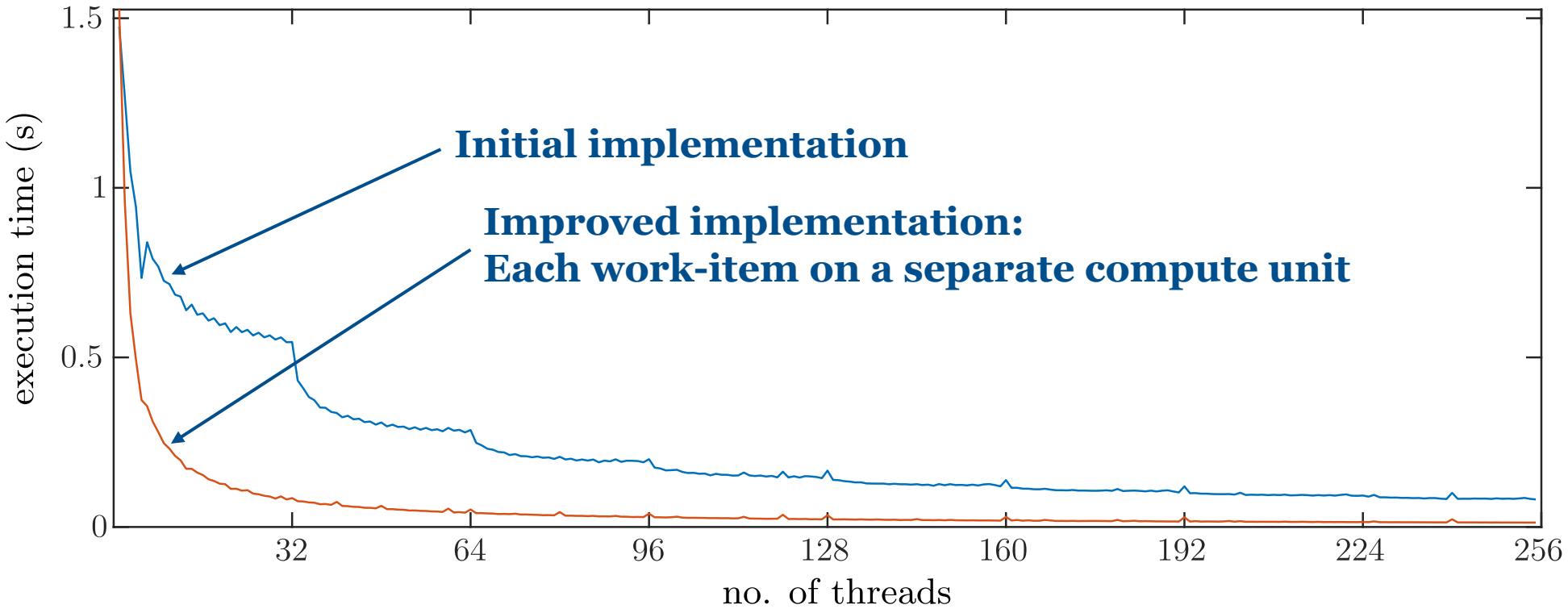


Further challenges

- Memory access
  - Global memory: limited bandwidth
  - Random access
- Thread divergence
  - Same WG, same Compute Unit
  - Shared program counter
  - Threads block each other at branches
  - Experiment: assign each Work-item to a separate Compute Unit

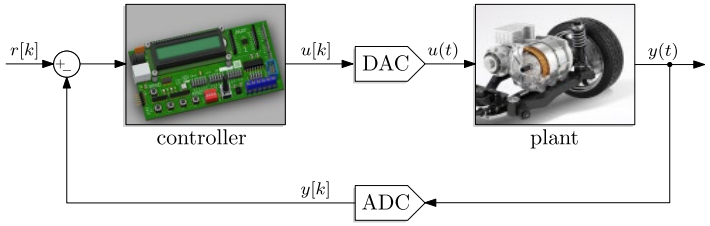


Results

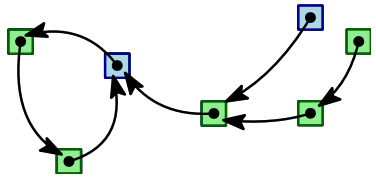

1.5
1
0.5
0
execution time (s)
32
64
96
128
160
192
224
256
no. of threads
Initial implementation
Improved implementation:
Each work-item on a separate compute unit

Conclusions

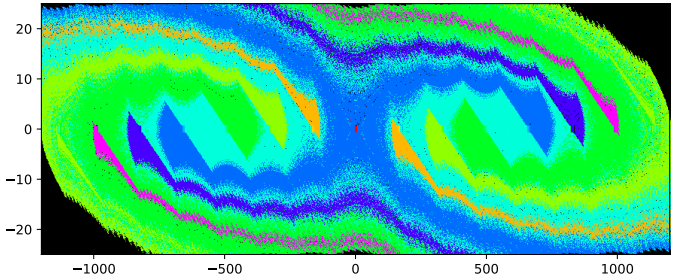
- HPC methods for analysis of mechatronic systems
- Goal: global dynamical analysis
- Parallelization of the Simple Cell Mapping (SCM) algorithm
- GPU implementation
- Test results on the micro-chaos map



Mechatronic system



GPU implementation of the SCM algorithm



Testing on the micro-chaos map

Thank you for your attention!

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