

# Molecular Dynamics - Assignment 5

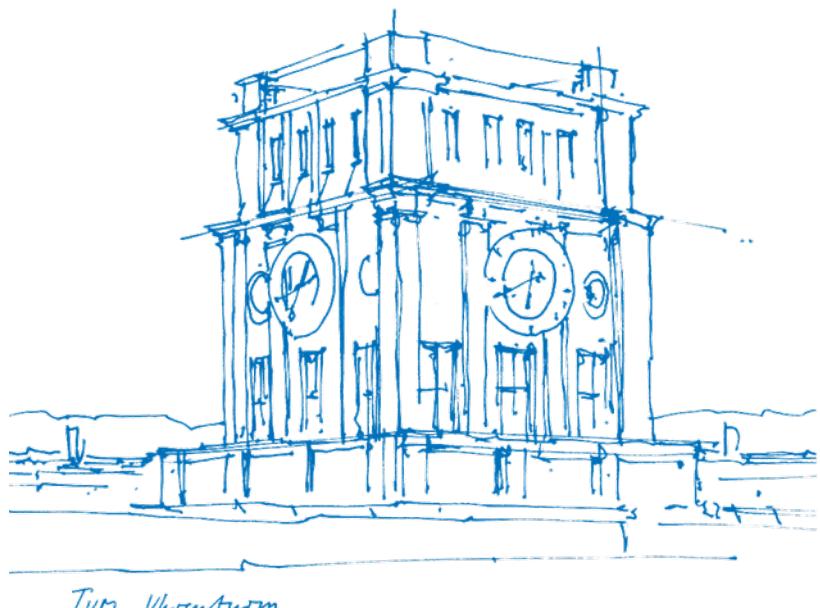
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# Implementation of Membranes

- Membrane is wrapper class around 2d-vector of Particle IDs
- Actual Particles still get stored in ParticleContainer

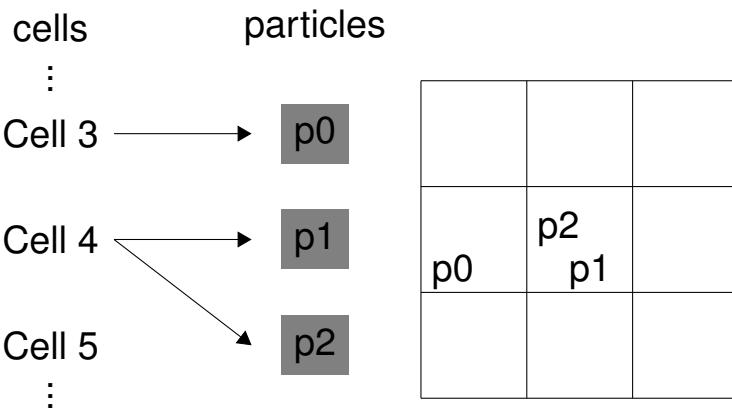
# Implementation of immovable Particles

- Set mass of particle to -inf
- refactor code to ignore those particles wherever needed (e.g. Thermostat)

# Preparation for Multithreading- Refactoring the Particle Container

Our current implementation of the Cell Data structure (as displayed in Assignment 3):

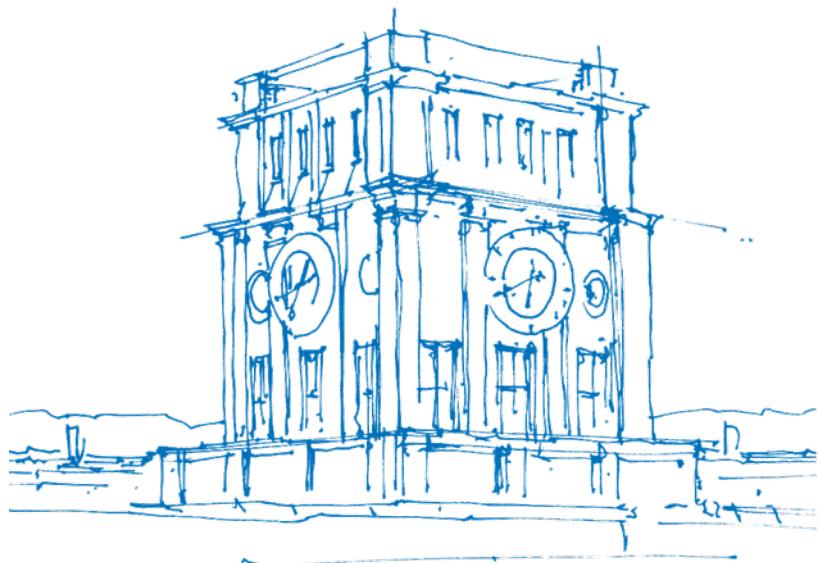
- Particles get stored in one giant vector
- Each Cell keeps references to their particles
- No sorting or copying takes place



Our changes to avoid false sharing:

- Sort particle according to cell index of their respective cell
- Add size of one cacheline between each cell as padding

# The Multithreading Odyssey



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# Defining Terminology

Terms necessary to talk about our multithreading approaches efficiently.

- **Task:** A Task is a pair of cells that should interact with each other. Tasks get represented by pairs of cell indices.
- **Task Model:** The task model defines the data structure that these tasks are stored in.
- **Distribution Strategy:** Many task models require splitting up bundles of tasks into buckets. The distribution strategy defines the strategy used for this splitting process.

# Distribution Strategy

- Splitting tasks into even-ish packages is necessary functionality
- This problem is np-complete

Approaches we looked at:

1. Round Robin: Assume that every Cell-Interaction has the same weight and distribute them via Round Robin
2. Greedy distribution: give the next job to the package that has the least work so far
3. Round Robin Threshold: Give Cell Interactions into one package until the number of interactions surpasses a threshold value (e.g.  $10^4$  interactions); continue in Round Robin fashion

# Approach 1- 1D task model

- Store all tasks in one giant „task pool“ (e.g. a vector)
- Schedule freely
- Requires reduction
- Just one fork and join needed

6	7	8
3	4	5
0	1	2

```
tasks = {(0,1), (1,2), ... ,  
         (0,3), (3,6), ... ,  
         (0,4), (1,5), ... ,  
         (3,1), (4,2), ... }
```

## Approach 2- Thread oriented 2D task model

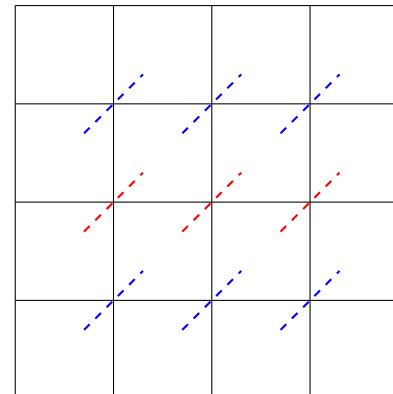
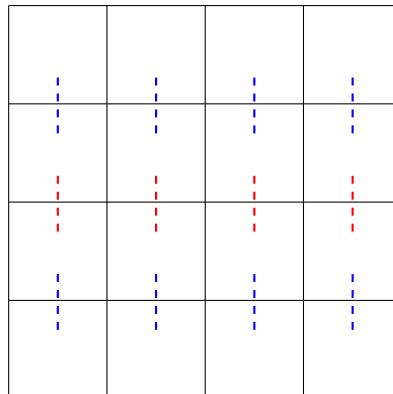
- Split up giant „task pool“ into num\_threads jobs
- Use distribution strategy and information unavailable to scheduler (computing cost of each cell interaction) to distribute workload evenly
- Give one job to each thread
- Requires reduction
- Just one fork and join needed

6	7	8
3	4	5
0	1	2

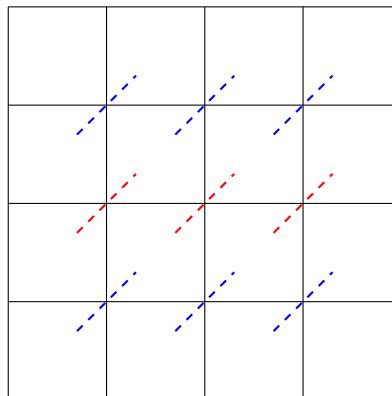
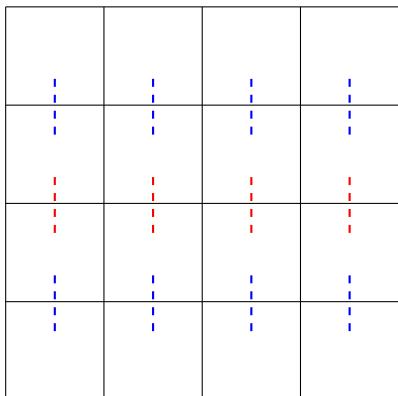
```
tasks = {{(0,1), (0,3), (3,6) ...},  
         {(1,2), (0,4), ...}}  
        ...  
    }
```

## Approach 3- Color oriented 2D task model

- You need 13 „lines“ in the Cell-Algorithm to cover all neighbouring cell-interactions
- Idea: split up every line into 2 sets of edges to get 26 sets of edges that can be fully parallelized
- Fork and join 26 times
- No reduction required; no race condition in any of the 26 iterations possible
- Forks and joins needed



## Approach 3- Color oriented 2D task model



```
tasks = {{vertical blue tasks},  
         {vertial red tasks},  
         {diagonal blue tasks},  
         {diagonal red tasks},  
         {other diagonal blue tasks},  
         ...  
};
```

## Approach 4- 3D task model

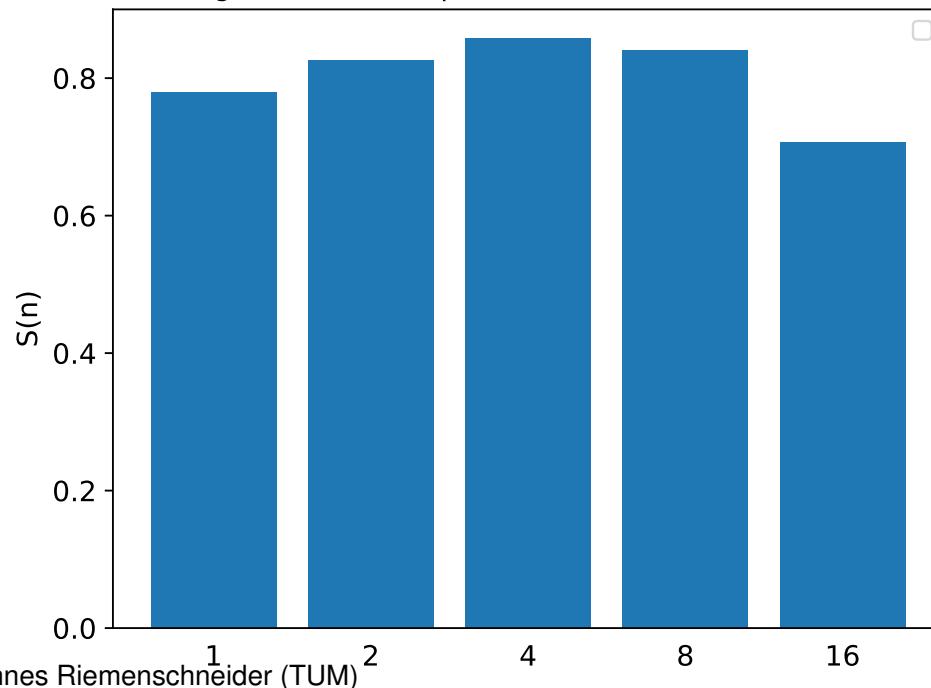
- Combination of thread oriented and color oriented 2D approaches
- Split up tasks into 26 fully parallelizable blocks
- Split those blocks into num\_threads jobs; use a distribution strategy to balance workload
- No reduction required
- Forks and joins needed

# Approach Comparison

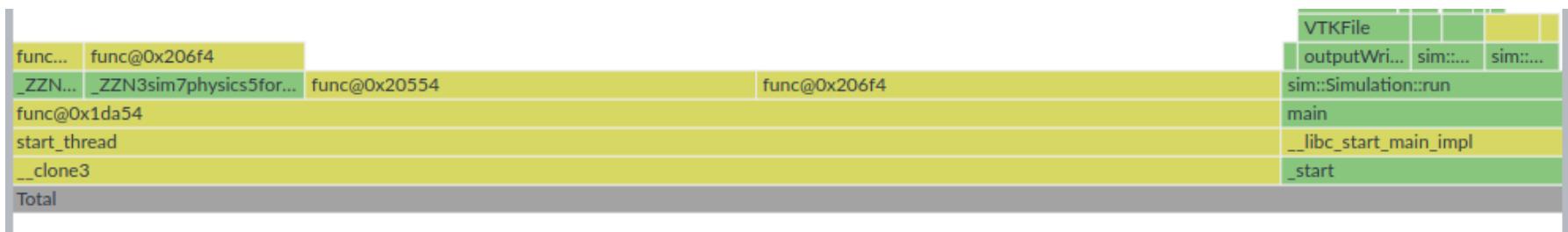
1D Tasks	2D thread tasks		2D colored tasks		3D tasks	
	Greedy	Round Robin			Greedy	Round Robin
Simplest approach	+ Potentially better scheduling than 1D tasks		+ Limit for parallelization corresponds to problem given theoretical limit		+ Potential to get the best out of both „2D worlds“	
+ Just one fork and join needed – Reduction needed	+ Just one fork and join needed – Reduction needed		– 26 forks and joins needed + No reduction needed		– 26 forks and joins needed + No reduction needed	

# Speedup of the 3D task model

SpeedUp of the 3D-Task approach with greedy distribution  
and no padding between cells  
Single-Threaded implementation used as reference



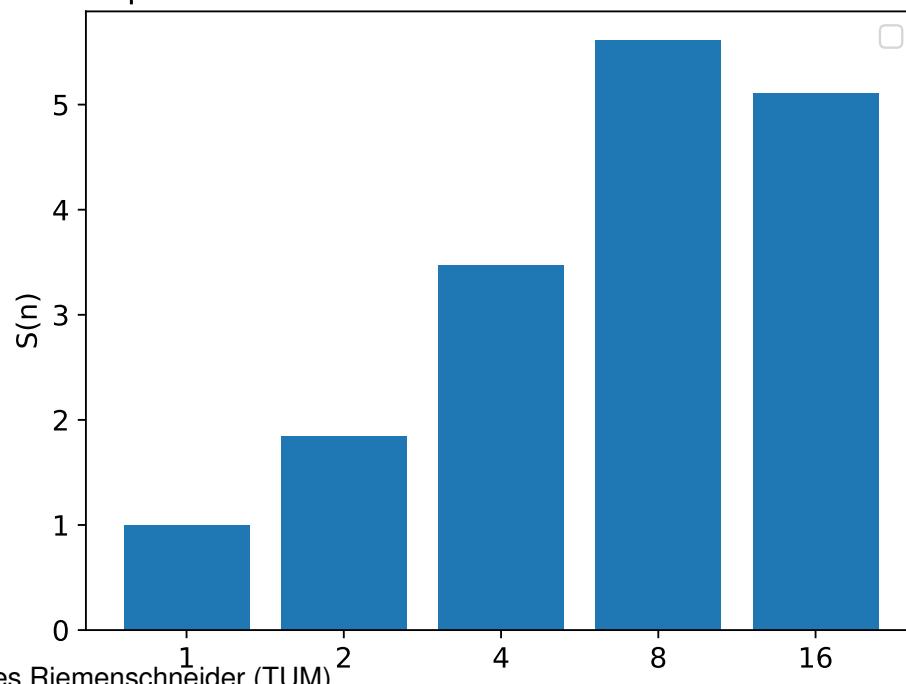
# What happened?



- As you can see we only use a fraction of our time actually computing forces
- The majority of time is spent with OMP overhead
- Our conclusion: dividing the workload by  $num\_threads \cdot 26$  doesn't leave enough tasks in each job

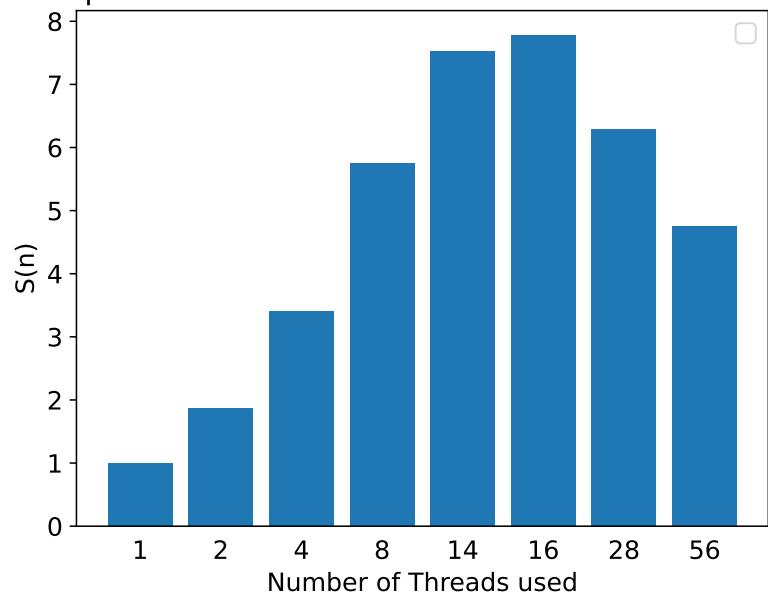
# Speedup of the 1D approach

SpeedUp of the 1D-Task approach with no padding between cell  
OMP-implementation executed with one Thread is reference

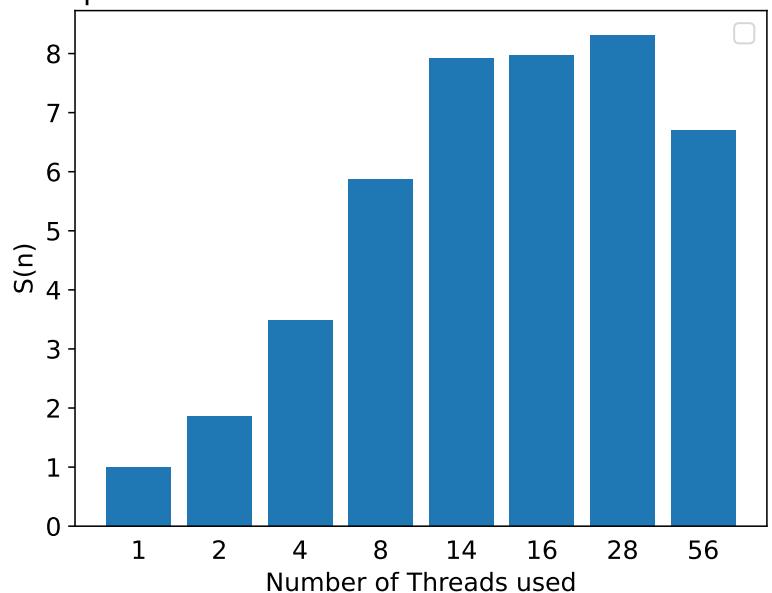


# Speedups of the 2D approaches

SpeedUp of the 2D task model with greedy distribution  
OMP-implementation executed with one Thread is reference

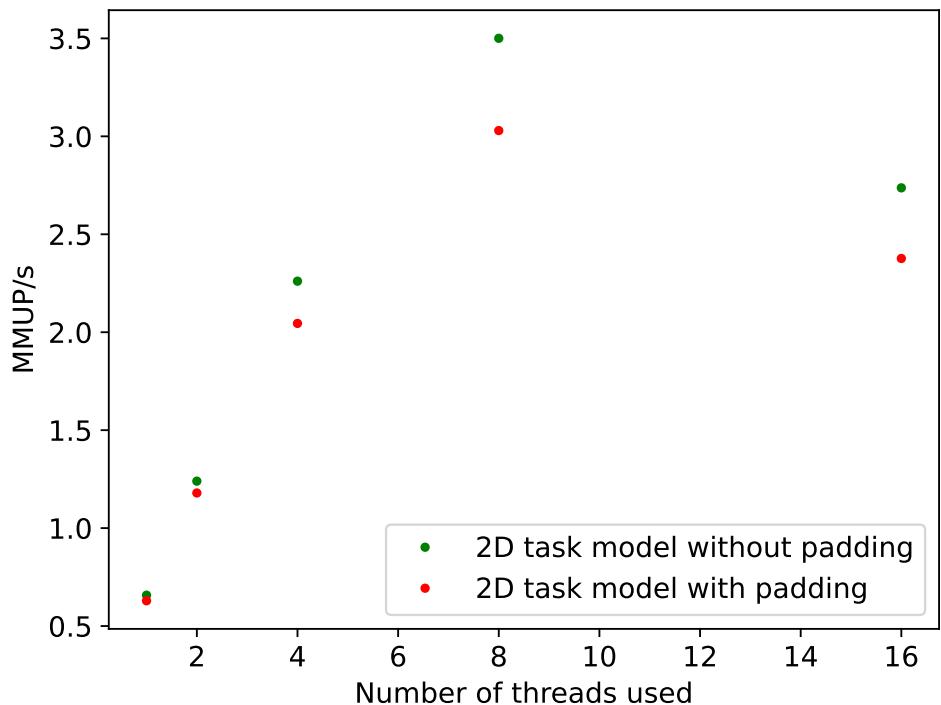


SpeedUp of the 2D color oriented approach  
OMP-implementation executed with one Thread is reference



# The price of padding

- As you can see padding adds a measurable overhead
- Even in cases where we expected false sharing to occur disabling padding gave a performance boost

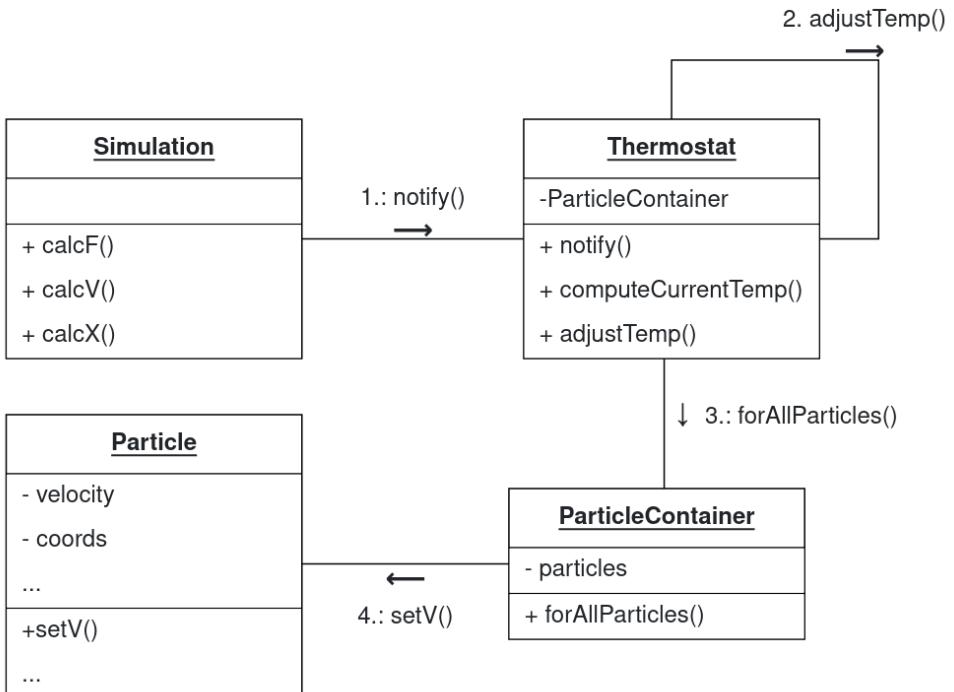


# Comparing distribution strategies

# Why does our Speedup reach a plateau?

# NanoFlow

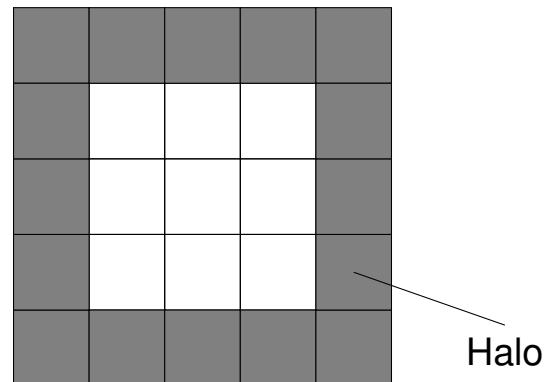
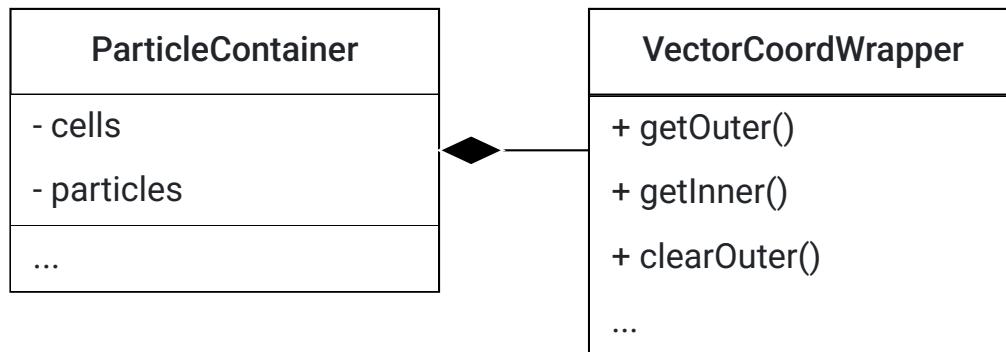
# Thermostat



# Adapting ParticleContainer for periodic bounds

Idea:

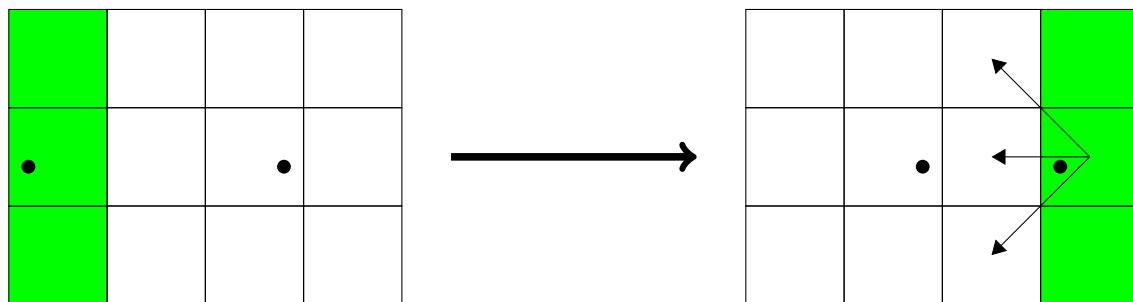
- Provide virtual cells around the actual domain for anyone who needs it
- Existence of additional cells is invisible with old interface



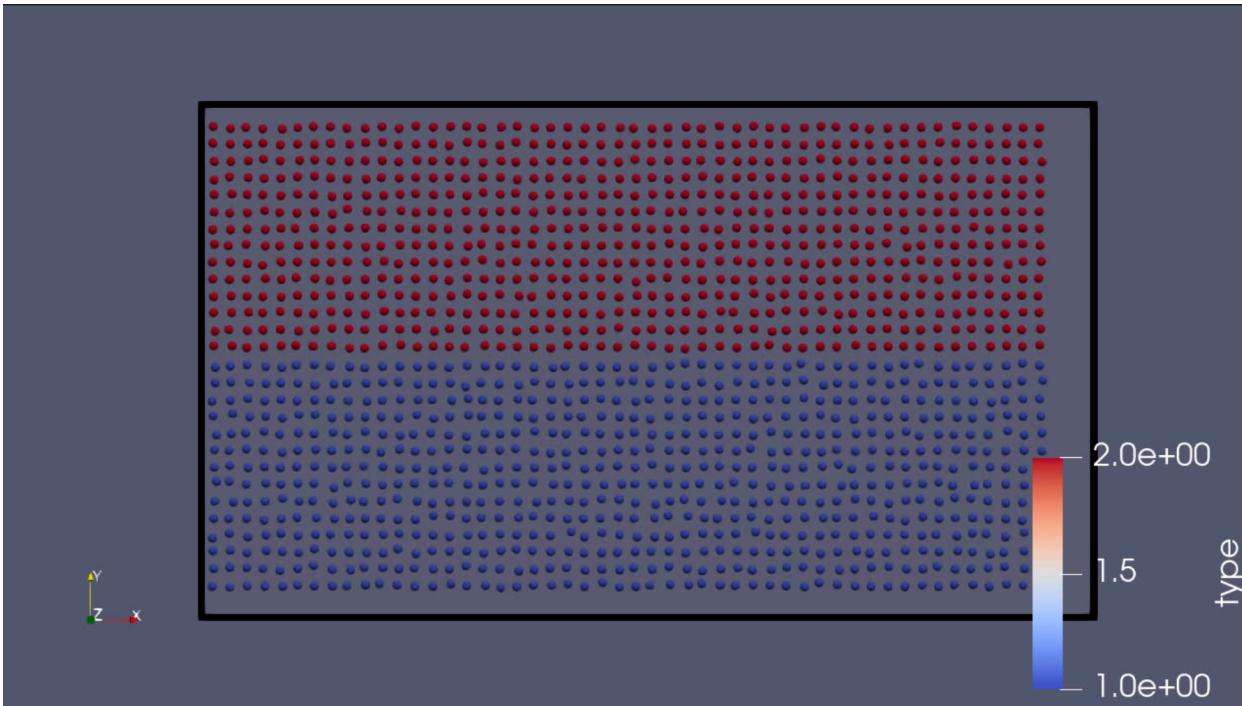
# Boundary conditions

Idea:

1. Temporarily move all particles next to Boundary of the other side
2. Let Neighbouring cells interact

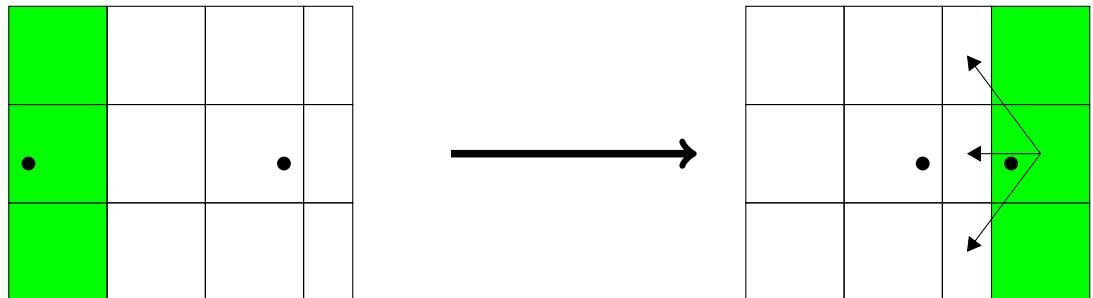


# The result



# The problem

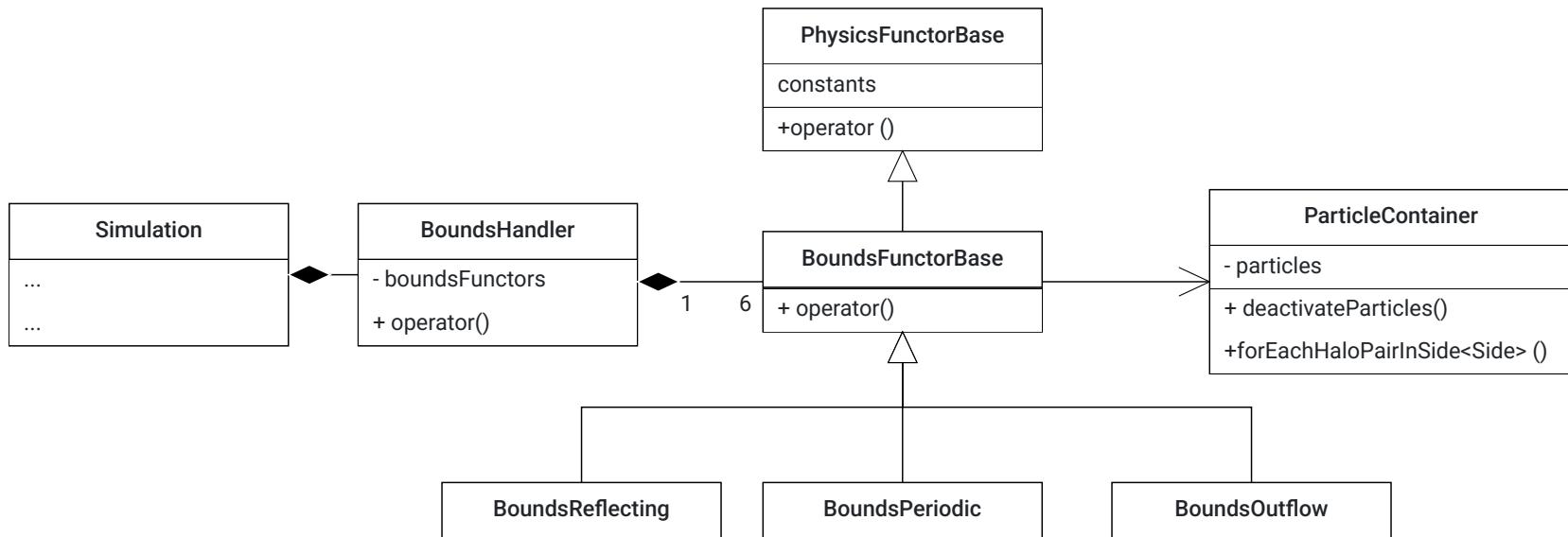
1. Outer boxes may not have the expected sidelengths
2. Interacting with neighbouring cells  $\Rightarrow$  Catching everything in  $r_{cutoff}$



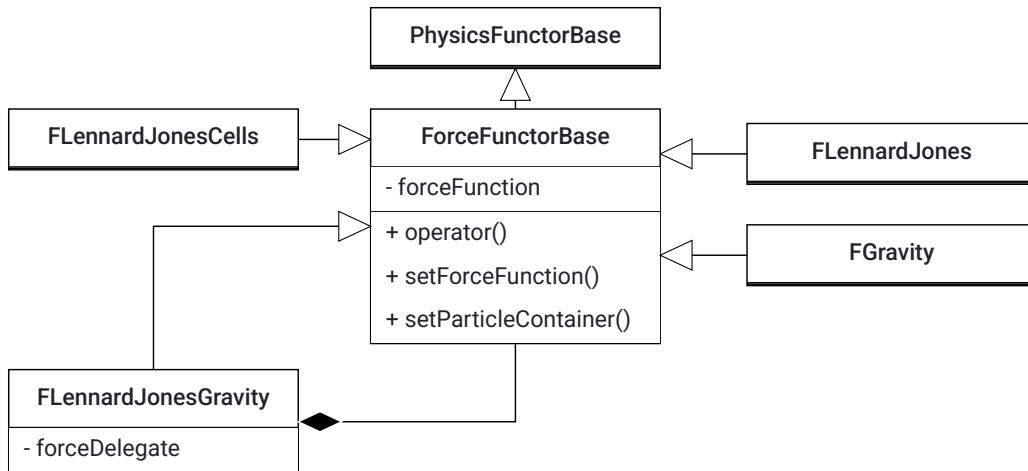
$\Rightarrow$  Interact with one more „Cellblock“ in that direction

# Adding Periodic bounds

This slide should look very familiar to Assignment 3



# Adding Gravitational Force



```
FLennardJonesGravity :: operator ()(){
    forceDelegate->operator ();
    particleContainer.forAllParticles ([]( auto& p){
        p.force[1] += p.m * gGrav;
    });
}
```

# Optimizations 1

As mentioned in Assignment 3 our ParticleContainer does not contain Particle-structs anymore. Keeping the old interface lead to the following method:

```
void ParticleContainer::forAllParticles(void(*function)(Particle &)) {  
    for (unsigned long index: activeParticles) {  
        Particle p;  
        loadParticle(p, index);  
        function(p);  
        storeParticle(p, index);  
    }  
}
```

⇒ rewriting old code where this method got used was a major improvement

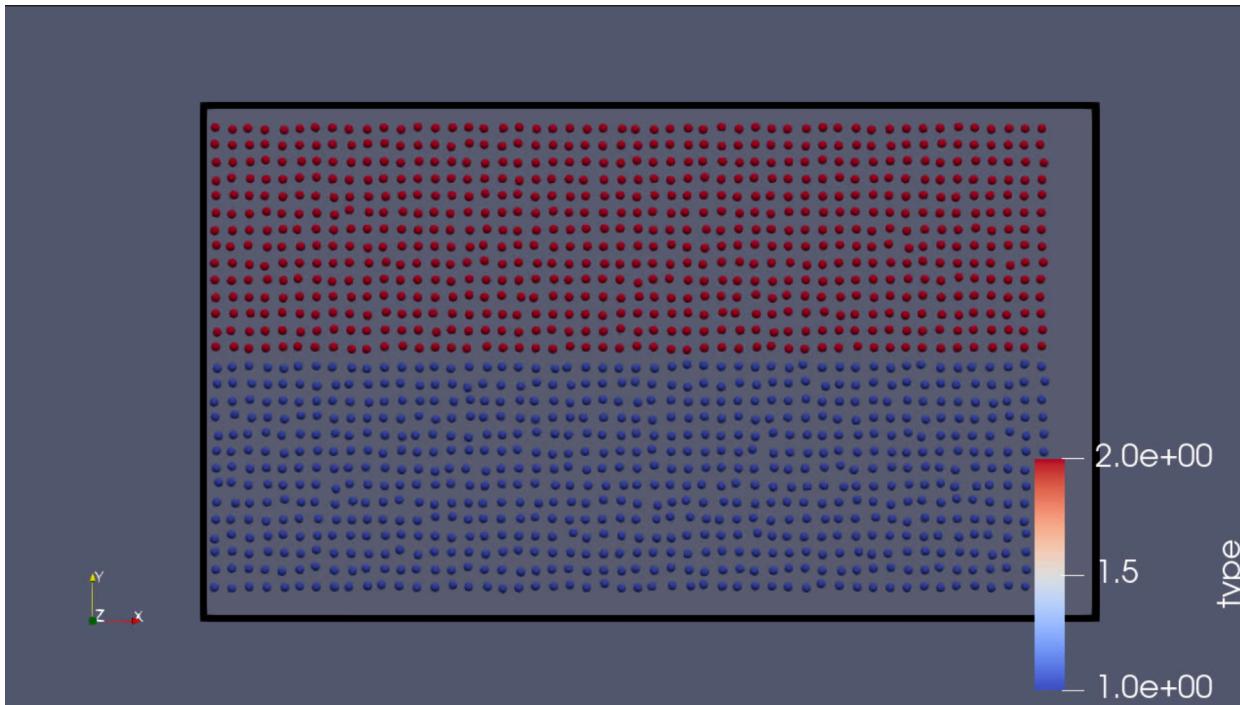
# Optimizations 2

sim::Simulation::runBenchmark	100.0%	0s	MolSim	sim::Simulati...	0x63282
▼ sim::physics::force::FLennardJonesCells::operator()	88.2%	0s	MolSim	sim::physics::...	0x143b94
▼ ParticleContainer::forAllDistinctCellNeighbours<sim::physics::force::FL	81.6%	0.024s	MolSim	ParticleCont...	0x143dd6
► sim::physics::force::FLennardJonesCells::operator()(void)::(lambda(s	80.9%	0.640s	MolSim	sim::physics::...	0x143a00
► ParticleContainer::VectorCoordWrapper::operator[]	0.4%	0.012s	MolSim	ParticleCont...	0x76be6

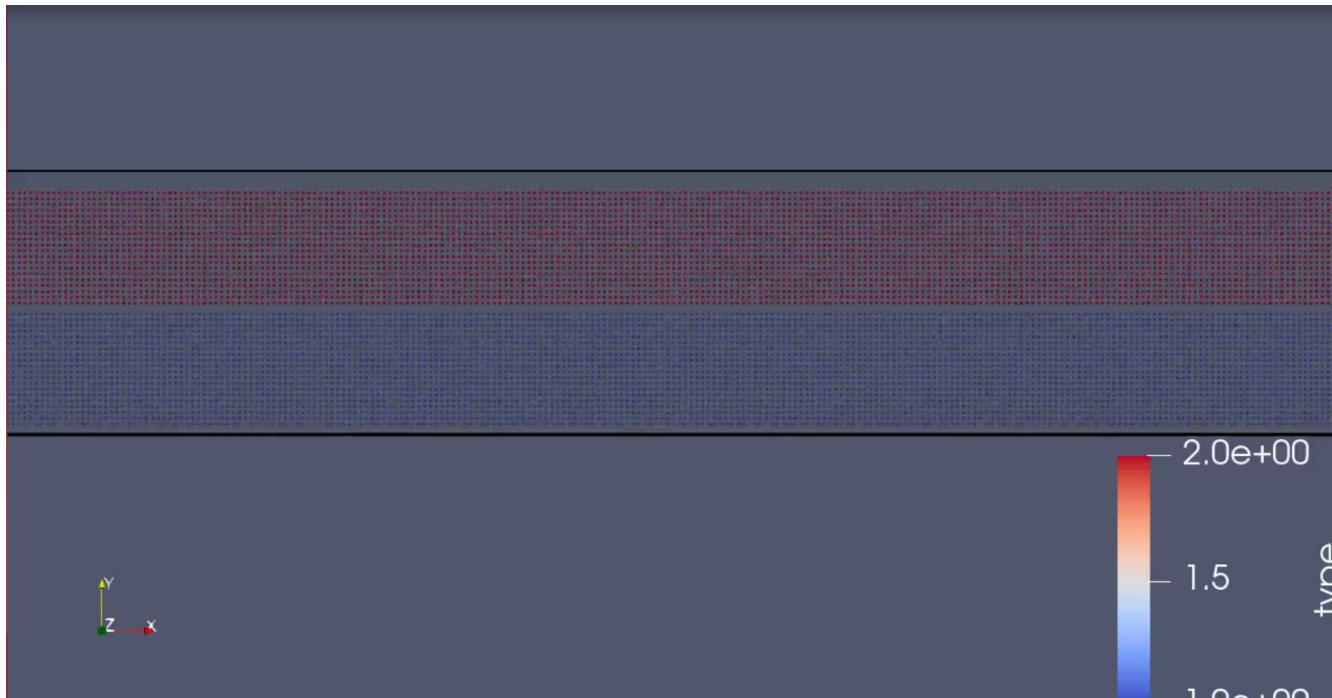
- Force calculation takes a significant portion of CPU time
- Force between two particles in Force-Functors got represented as lambda expression

⇒ Represent force as static function instead

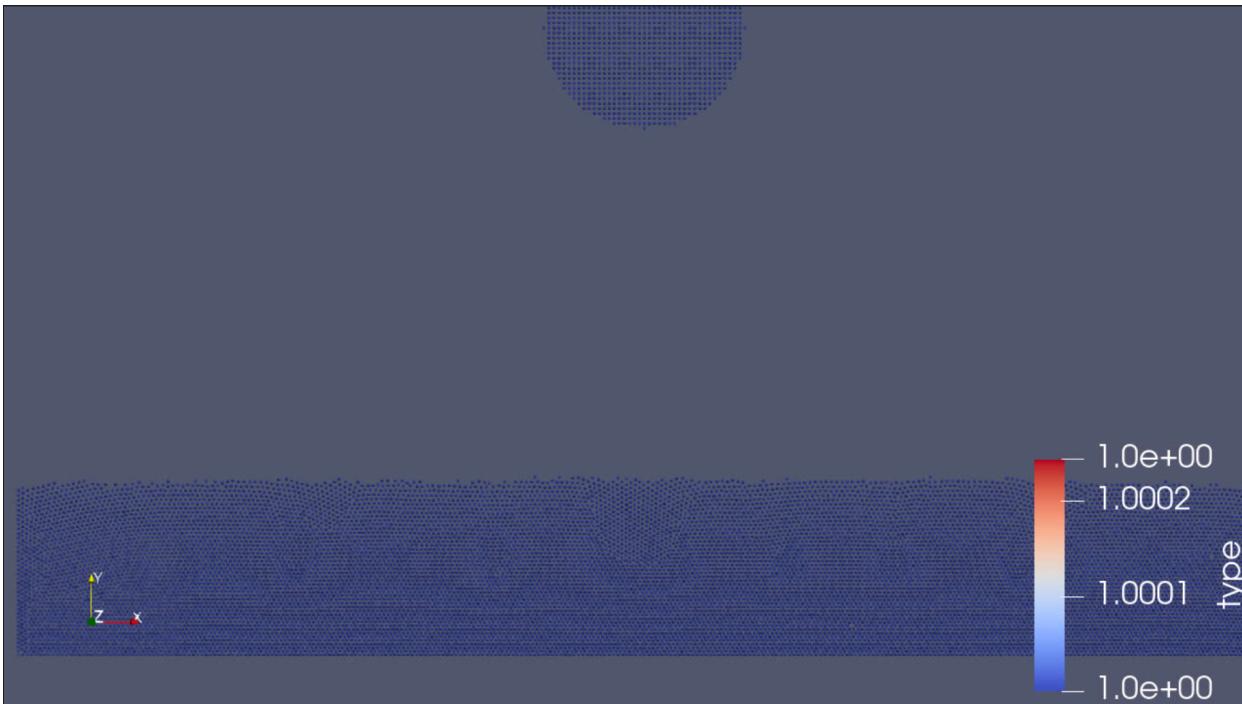
# Small Rayleigh-Taylor instability



# Rayleigh-Taylor instability



# Falling drop



# Serial Benchmarks

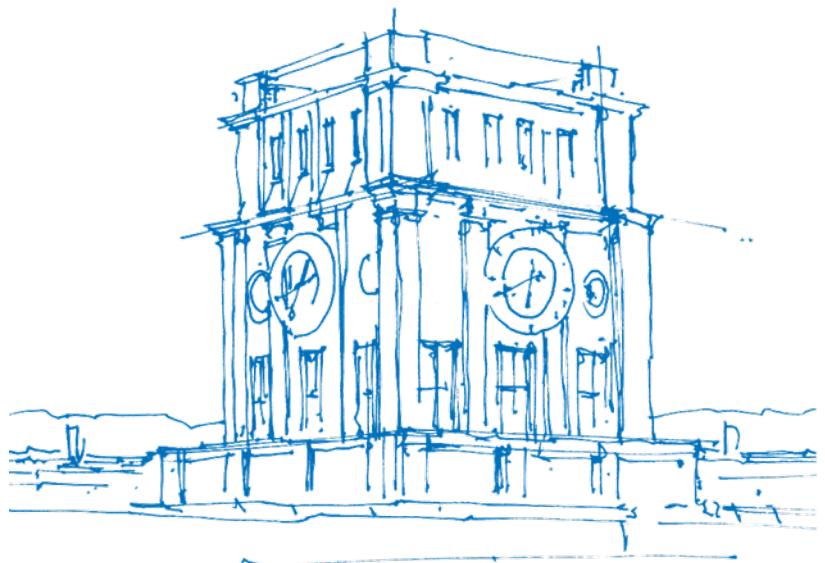
- As already mentioned building with the Intel compiler didn't work even with major time investments
- The option „-slow“ lets the code run in the pre-optimized state

Options	MMU/s Cluster	MMU/s Local
-slow -O2	0.0087	$\geq 1/6 \cdot 0.036 \wedge \leq 1/2 \cdot 0.036$
-O2	0.0087	0.036
-O0	0.0087	0.036

Since these measurements are so close together and significantly smaller than our local measurements, we assume that something went wrong on the cluster.

# Roadblocks

- Compiling and running jobs on the cluster turned out to be a nightmare
- Intel compiler broke us trying to unbreak him
- Searching for bugs that may or may not be there (bouncy particles in Rayleigh-Taylor)
- Searching for bugs that definitely are there (see Boundary conditions)
- Large time investments in order to get tools to run



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# Recreating Profiling

1. `mkdir build`
2. `cmake ..`
3. `make ProfileMolSim` or `make CXX_FLAGS+=Dslow -std=c++20"ProfileMolSim`
4. `./ProfileMolSim ../input/[file_you_want_to_profile]`
5. `gprof ProfileMolSim gmon.out > profile-data.txt`