Speculative Atomics

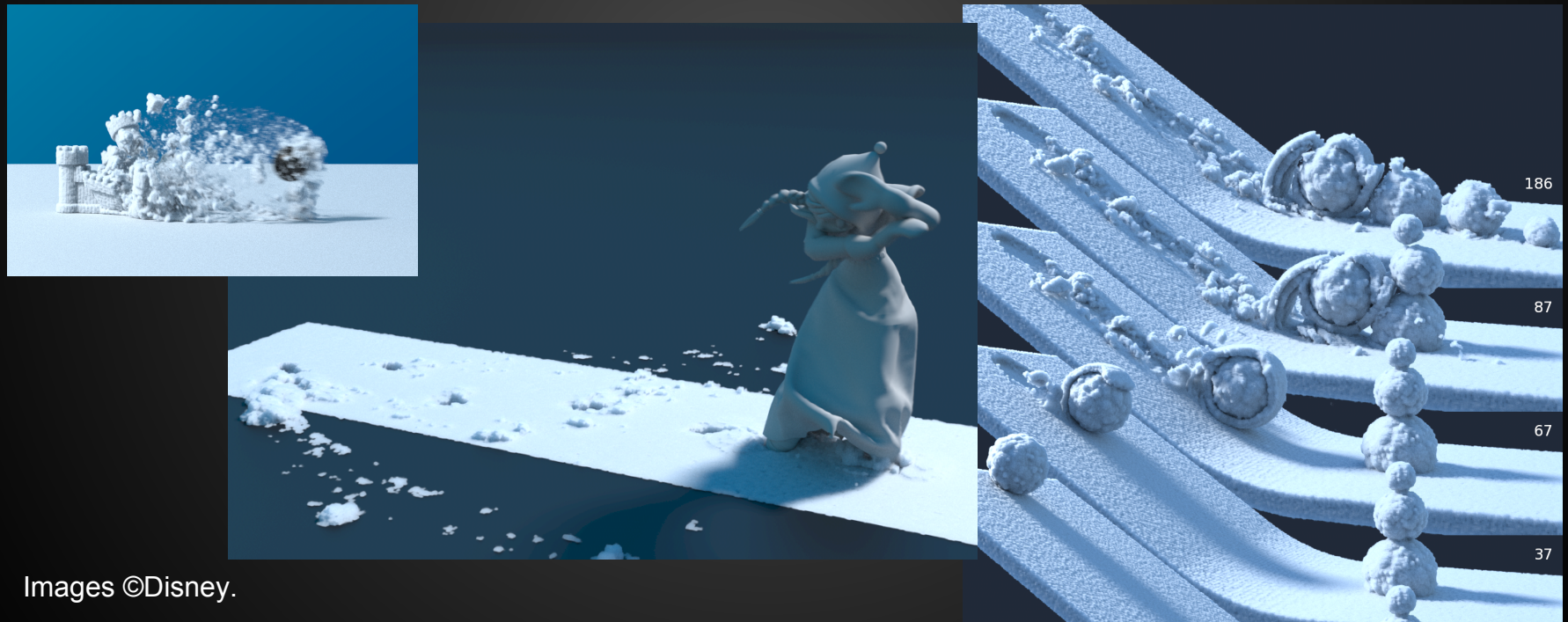
Case-study of the GPU Optimization of the Material Point Method for Graphics

Gergely Klar

UCLA Computer Graphics & Vision Laboratory

Motivation

A. Stomakhin, C. Schroeder, L. Chai, J. Teran, A. Selle, *A Material Point Method for Snow Simulation*, ACM Transactions on Graphics (SIGGRAPH 2013), 32(4), pp. 102:1-102:10, 2013.



Images ©Disney.

MPM Simulations

- Amazing new effects
- Extremely computationally demanding
  - millions of particles
  - 200 million cell grids
  - up to 30 minutes per frame

MPM Simulations

- Amazing new effects
- Extremely computationally demanding
  - millions of particles
  - 200 million cell grids
  - up to 30 minutes per frame

GPU to the rescue!

MPM Overview

1. Particles-to-grid
2. Grid operations
3. Particles-from-grid
4. Particle operation

Parallelizing steps

1. Particles-to-grid
2. Grid operations
3. Particles-from-grid
4. Particle operations

Parallelizing steps

1. Particles-to-grid
2. Grid operations
3. Particles-from-grid

✓ 4. Particle operations --- trivial

Parallelizing steps

1. Particles-to-grid
2. Grid operations
3. ✓ Particles-from-grid --- trivial
4. ✓ Particle operations --- trivial

Parallelizing steps

1. Particles-to-grid
✓ 2. Grid operations --- case by case
✓ 3. Particles-from-grid --- trivial
✓ 4. Particle operations --- trivial

Parallelizing steps

✘ 1. Particles-to-grid --- challenge

✓ 2. Grid operations --- case by case

✓ 3. Particles-from-grid --- trivial

✓ 4. Particle operations --- trivial

What's wrong with *particles-to-grid?*

It is a classical *scatter* operation

- up to 10 particles per cell initially
- 5^3 support (region of influence) per particle

⇒ Many race conditions, if processed particle-by-particle

How to do super fast *scatter?*

1. Use atomics operations!
2. Protect coalesced access!
3. Disperse the particles!

Why not *gather?*

Classical work around:

Turn *scatter* it into *gather*!

Problems:

- No constraint on particle count per cell
- Overhead
- **Need to do it in every step!**

Why not *gather?*

Classical work around:

Turn *scatter* it into *gather*!

Problems:

- No constraint on particle count per cell
- Overhead
- **Need to do it in every step!**

Let’s use atomics!

(and I mean *atomic instructions*)

Pro: Don’t need to worry about race conditions

Con: Can get very slow

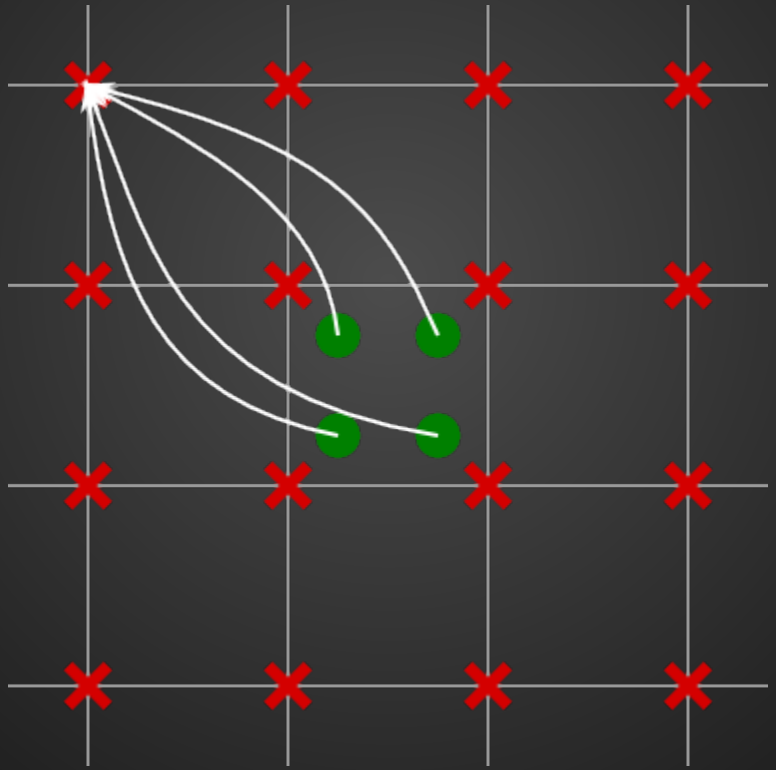
Speculative atomics

Guaranteeing no race conditions is expensive.

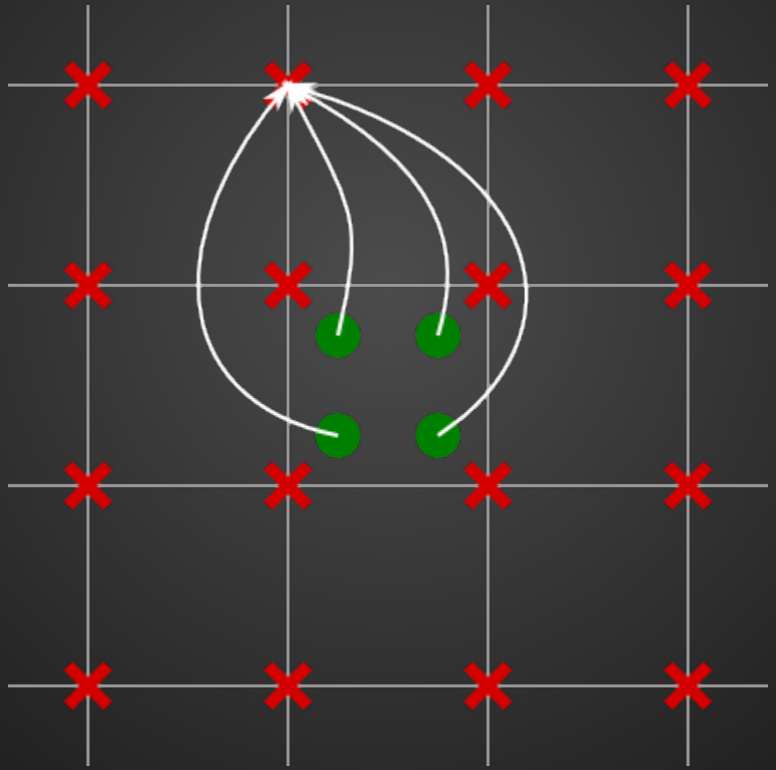
Atomic instructions are getting better, minimal overhead when there's no need to block

Idea: Don't try to eliminate all race conditions, but reduce their likelihood and use atomic instructions

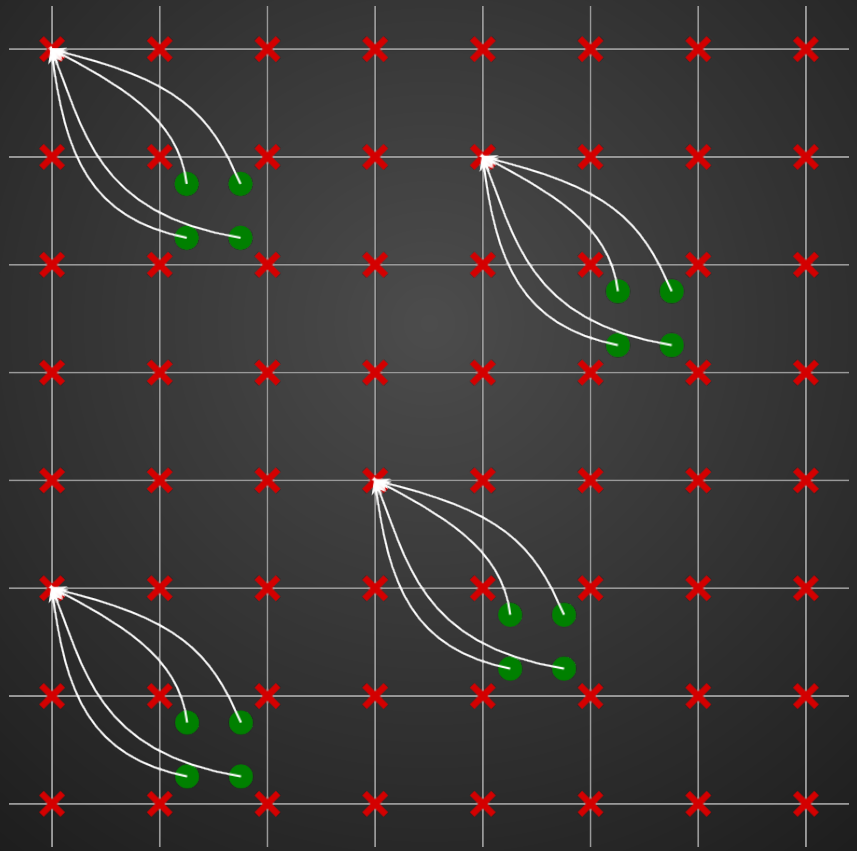
Bad case



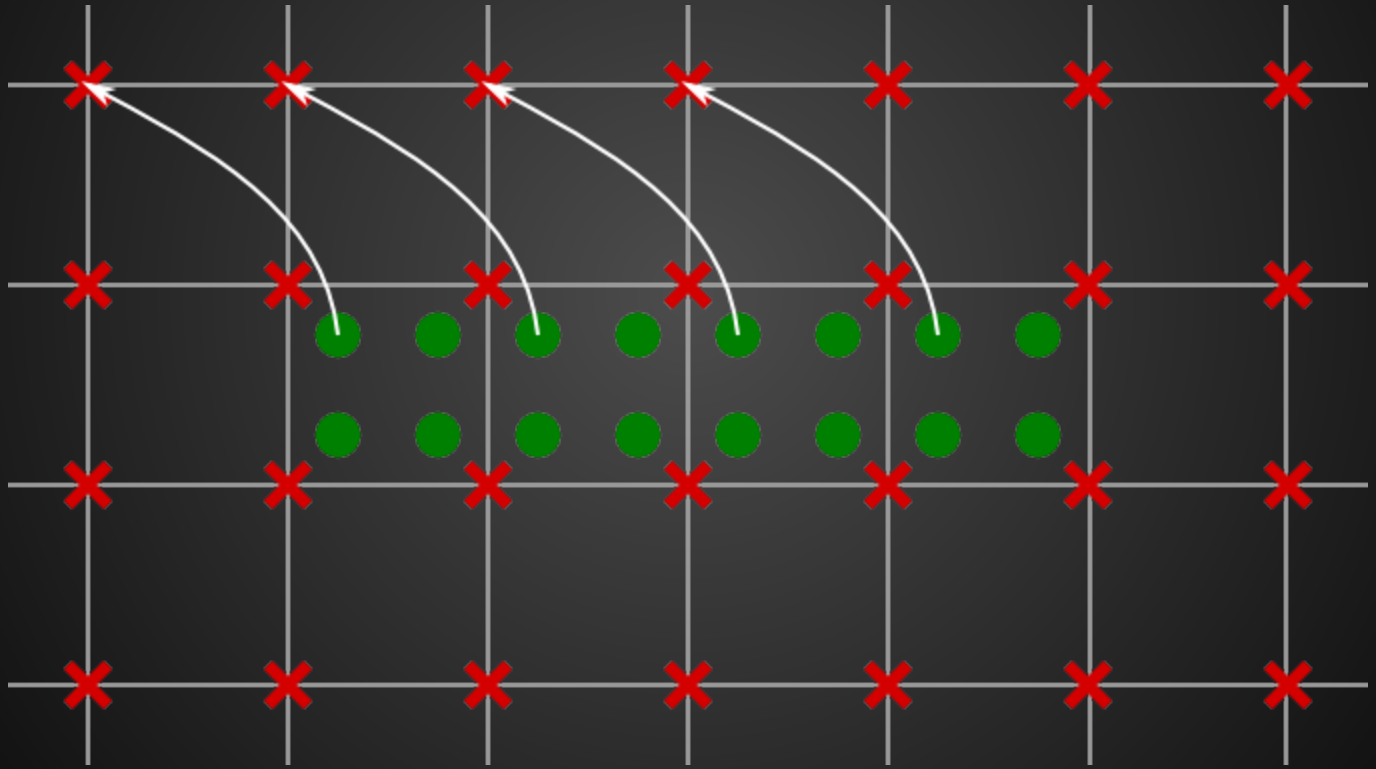
Bad case



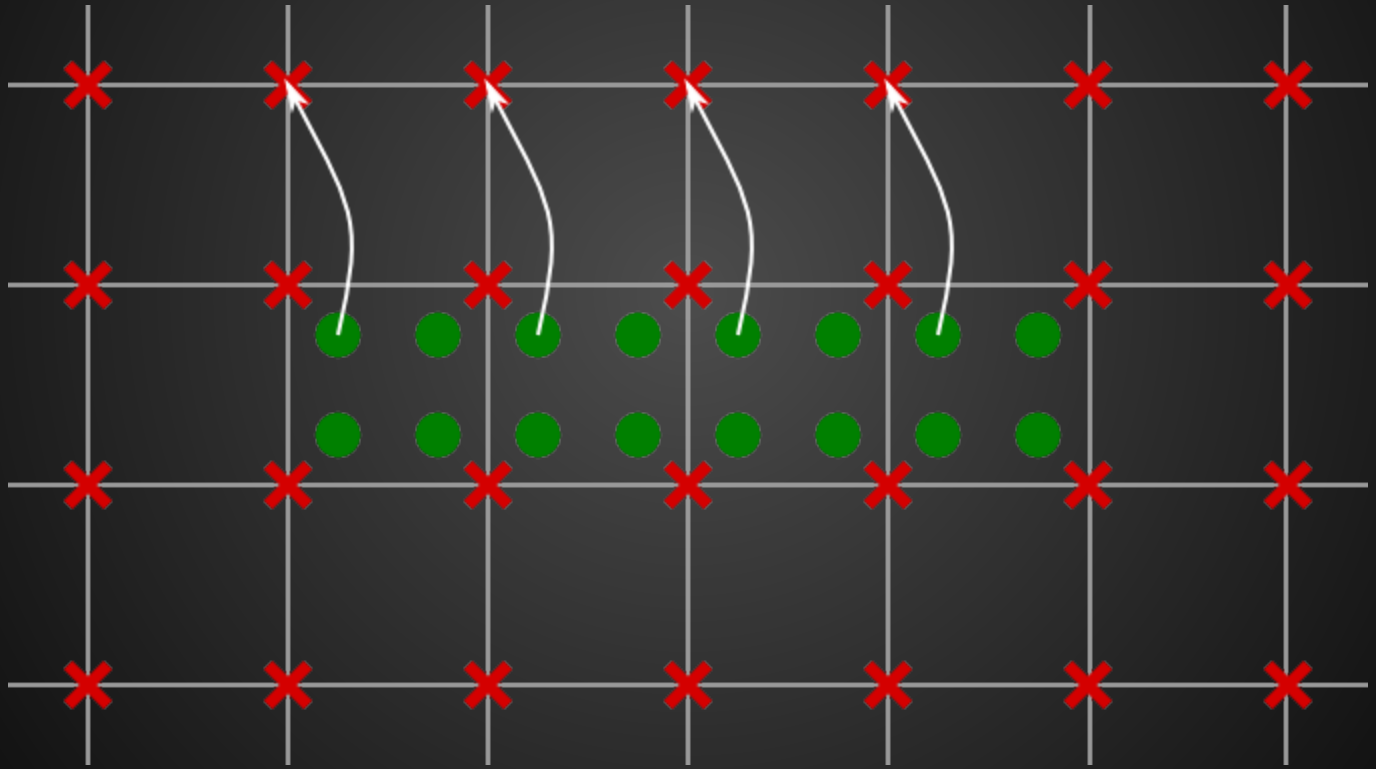
Worst case



Best case



Best case



How to get the best case all the time?

Concurrent threads need to process particles that

- are from different cells
- are consecutive in memory
- access consecutive grid cells

Bad idea: Indirect indexing

```
processParticle(p[particleIndexShuffler(threadIdx)])
```

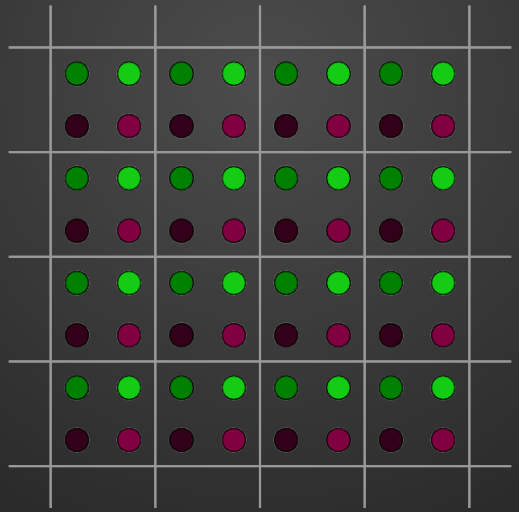
Problem: particles processed in parallel are spread out in memory → can not use coalesced memory access → poor performance

Solution: need to physically shuffle particles

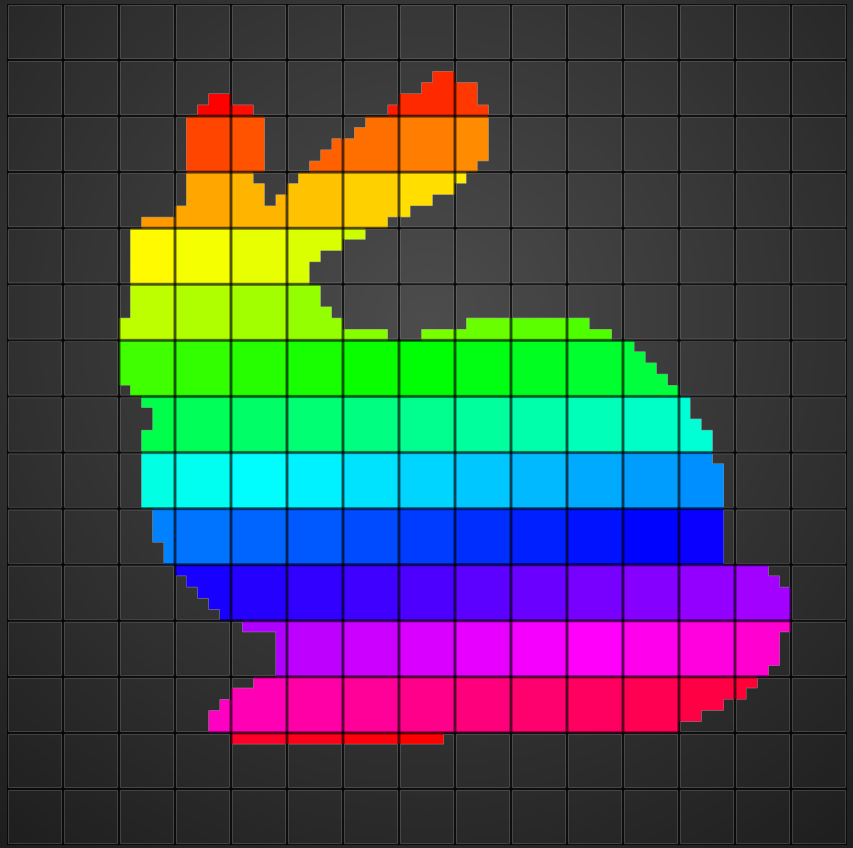
Blocked layout

Particles in memory

Particles in space



Blocked layout in action



Blocked layout

1. Assign cell ID to each particle by the grid cell it is in. cell IDs define groups.
2. Sort particle IDs by cell IDs
3. Rearrange particles by picking the 1st from each group, then the 2nd, etc.

Blocked layout Pseudocode 1/2

```
kernelComputeCellID // per particle
   cellX = floor(x[pID]/dx)
   cellY = floor(y[pID]/dx)
   cellZ = floor(z[pID]/dx)
   cellID[pID] = cellX+
      cellY*GRID_WIDTH+
      cellZ*GRID_WIDTH*GRID_HEIGHT
```

Blocked layout Pseudocode 2/2

```
sequence(pIDs)
sort_by_key(cellIDs, pIDs)
exclusive_scan_by_key(cellIDs, constant(1),
newIDs)
sort_by_key(newIDs,
   permutation(zip(<all particle data>),
      pIDs))
```

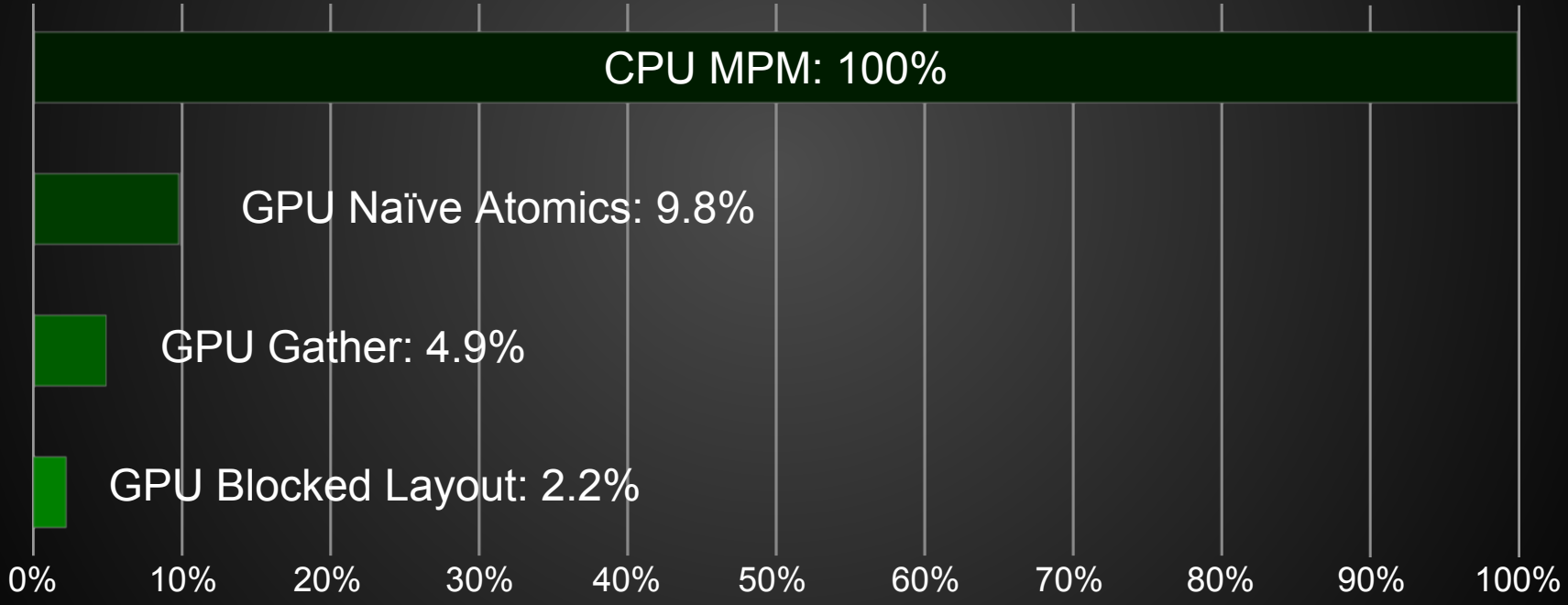
Re-blocking

No need to rearrange the particles in every step, but

- Goal of MPM is to simulate deformations and fracturing
- Particles can move around a lot
- Monitor *scatter* performance, re-block if drops below threshold

Results

Relative speeds compared to the CPU implementation



Results

Relative speed-ups compared to other methods

	CPU	GPU Naïve	GPU Gather	**GPU B. Layout**
CPU	1x	10.20x	20.41x	**45.45x**
GPU Naïve		1x	2.00x	**4.45x**
GPU Gather			1x	**2.23x**
GPU B. Layout				1x

Summary

- Speculative Atomics:
  - The overhead of unnecessary atomic instructions is lower than the overhead of complicated gather transforms
- Blocked layout:
  - Special arrangement of particles to minimize the number of race conditions
- Not just for MPM:
  - Can be adopted to other particles-and-grids simulations as well

Takeaway

1. Don’t be afraid to use atomic operations!
2. Use coalesced access at all costs!
3. Spread out the particles (but not too far)!

Questions?

Thank you!