USING GPUS FOR COLLISION DETECTION

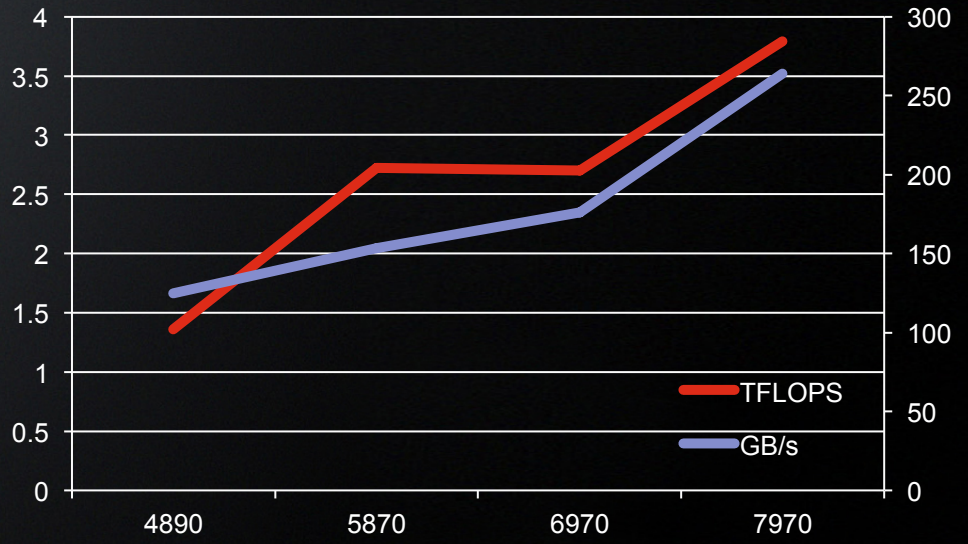
AMD
Takahiro Harada

GPUS

GPU RAW PERFORMANCE

- High memory bandwidth
- High TFLOPS

- Radeon HD 7970
  - 32x4 SIMD engines
  - 64 wide SIMD
  - 3.79 TFLOPS
  - 264 GB/s



RAW PERFORMANCE IS HIGH, BUT

- GPU performs good only if used correctly
  - Divergence
  - ALU op / Memory op ratio
  - etc

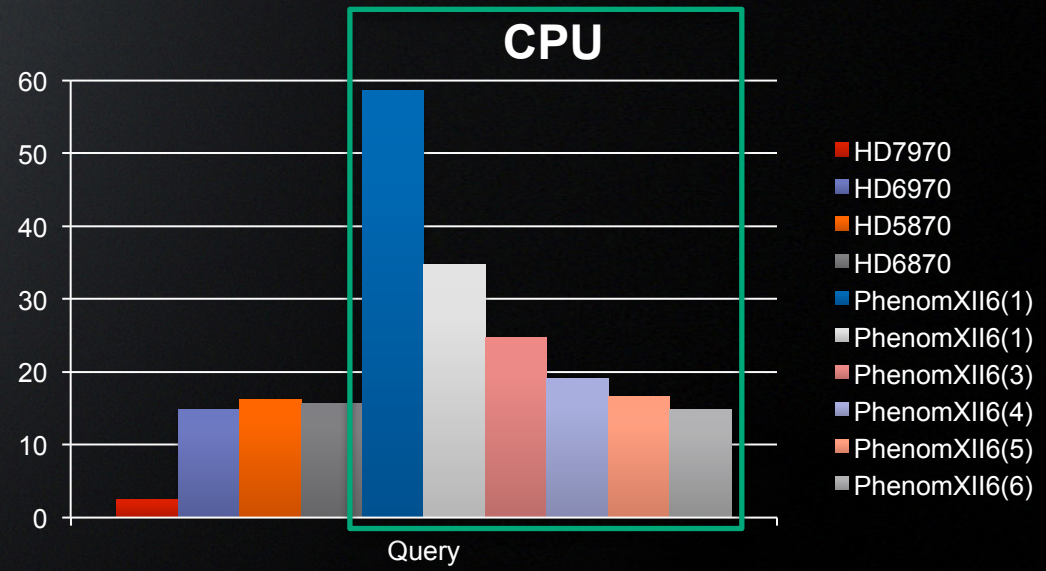
- Some algorithm requires operation GPUs are not good at

EX) HASH GRID (LINKED LIST)

- Low ALU op / Mem op ratio
- Spatial query using hash grid

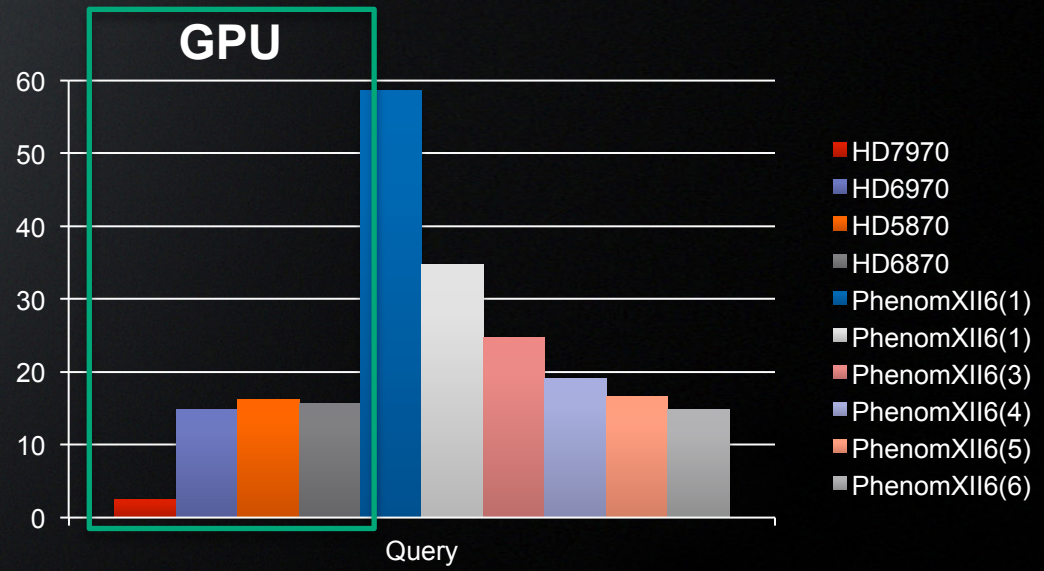
```
do
{
  write( node );
  node = node->next;
}while( node )
```

- CPUs is better for this



EX) HASH GRID (LINKED LIST)

- Low ALU op / Mem op ratio
- Spatial query using hash grid
  - while()
  - {
    - Fetch element
    - Copy
  - }
- CPUs is better for this



REASON OF PERFORMANCE JUMP

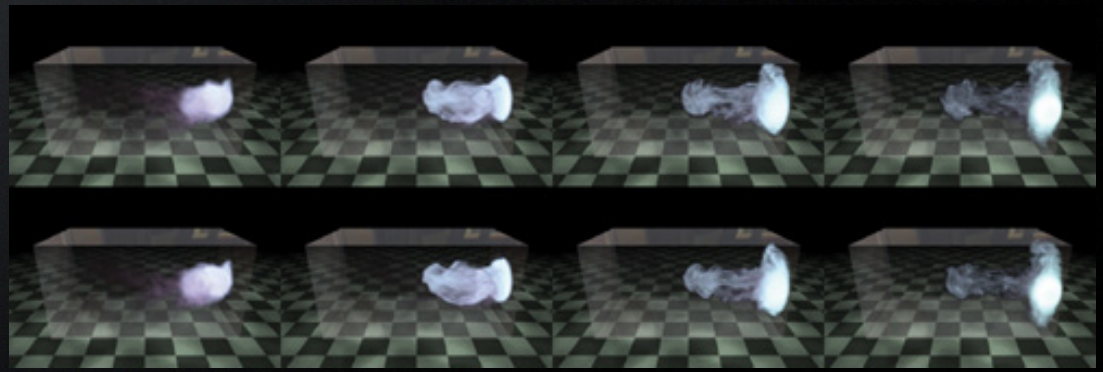
- Key architectural changes
  - No VLIW
  - Improved memory system

GPU COLLISION DETECTION

COLLISION DETECTION WAS HARD FOR GPUS

- Old GPUs were not as flexible as today's GPUs
  - Fixed function
  - Programmable shader (Vertex shader, pixel shader)

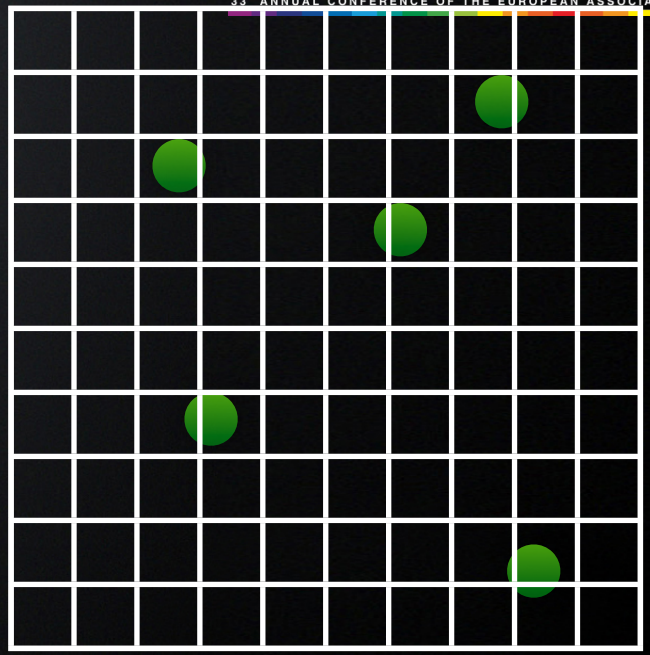
- Grid based fluid simulation
- Cloth simulation



Crane et al., Real-Time Simulation and Rendering of 3D Fluids, GPU Gems3 (2007)

UNIFORM GRID

- Simplest but useful data structure
- Pre Compute Language
  - Vertex shader, pixel shader
  - Vertex texture fetch -> Random write
  - Depth test, blending etc -> Atomics
- Now it is very easy
  - Random write and atomics are supported



```
struct Cell
{
  u32 m_counter;
  u32 m_data[N ];
}
```

UNIFORM GRID

- Simplest but useful data structure
- Pre Compute Language
  - Vertex shader, pixel shader
  - Vertex texture fetch -> Random write
  - Depth test, blending etc -> Atomics
- Now it is very easy
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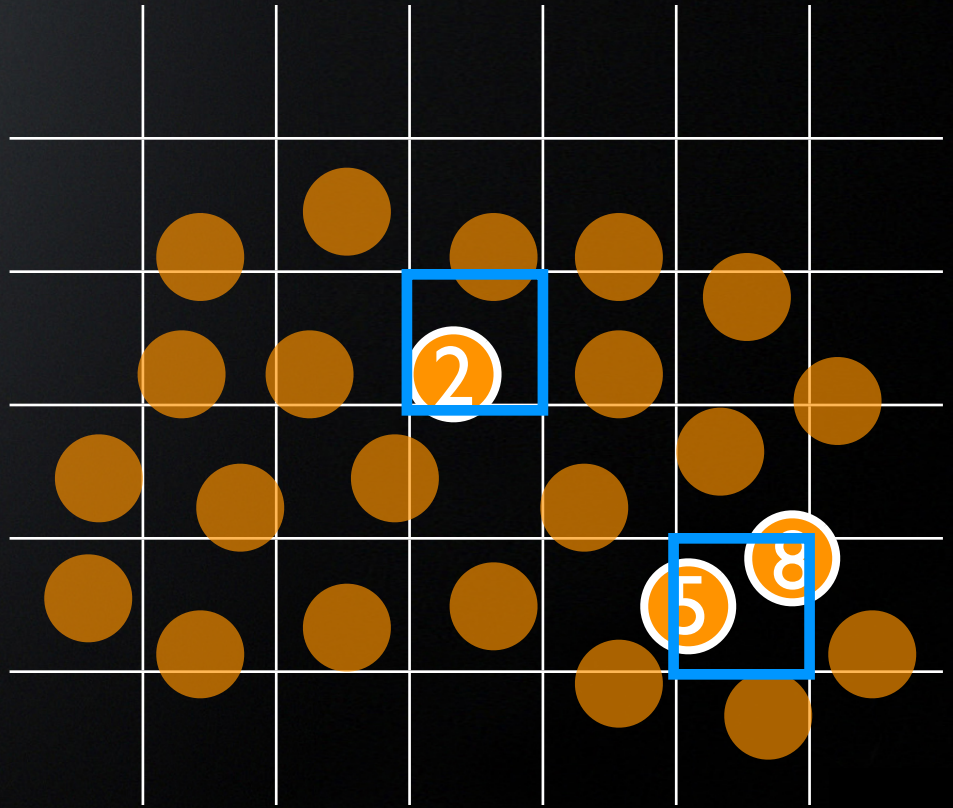
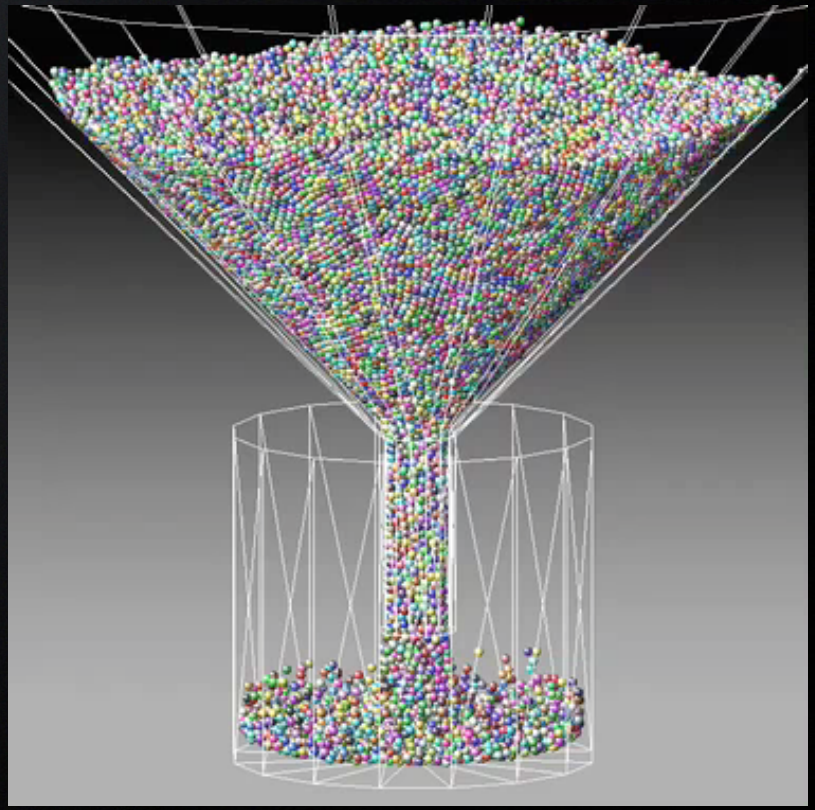


WITH UNIFORM GRID

- Often used for particle-based simulation
- Other steps are embarrassingly parallel

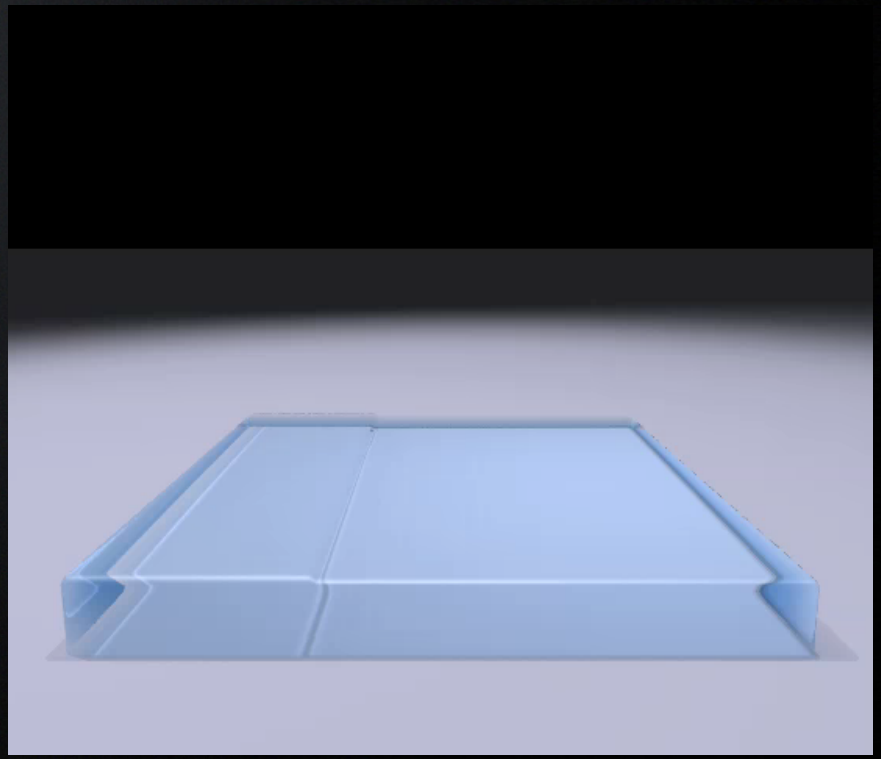
- Distinct Element Method (DEM)

- Particles can be extended to…



SMOOTHED PARTICLE HYDRODYNAMICS

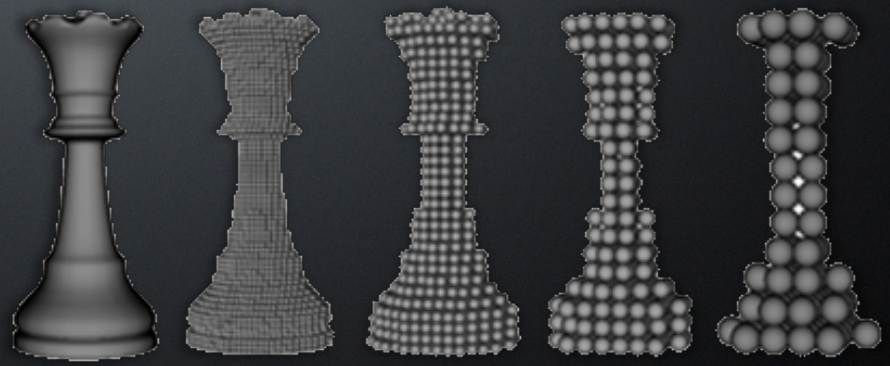
- Fluid simulation
- Solving the Navier-Stokes equation on particles

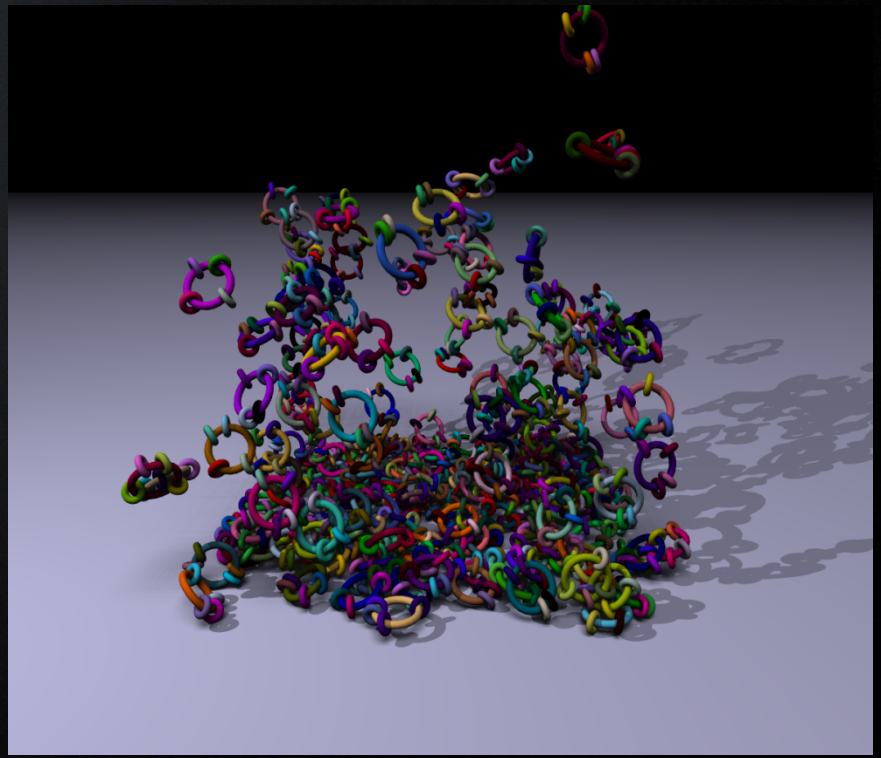


Harada et al., Smoothed Particle Hydrodynamics on GPUs, CGI (2007)

RIGID BODY SIMULATION

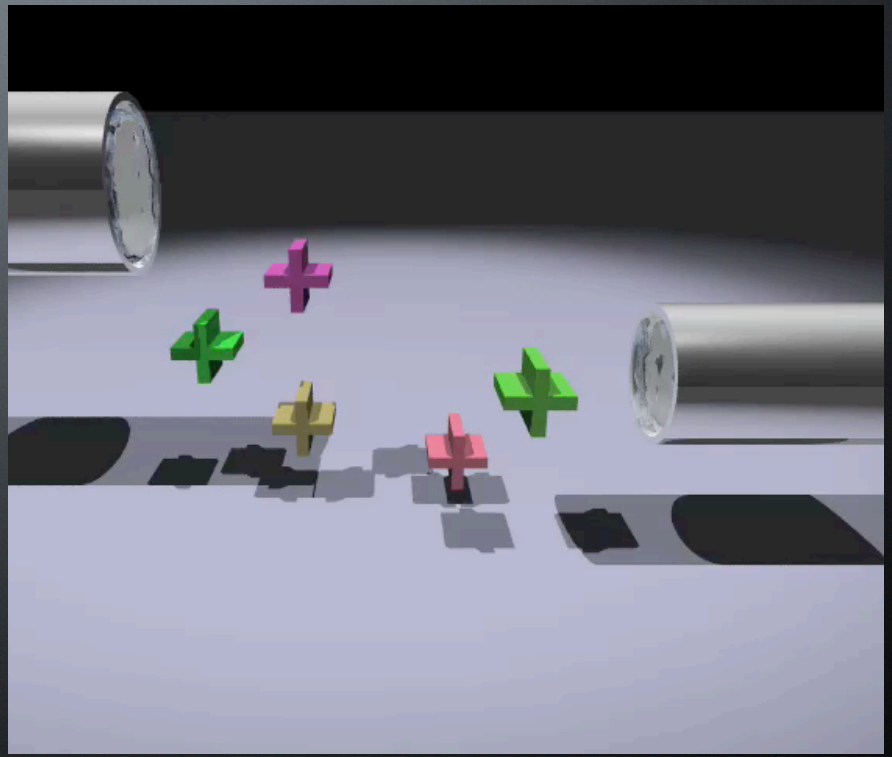
- Represent a rigid body with a set of particles
- Rigid body collision = Particle collision





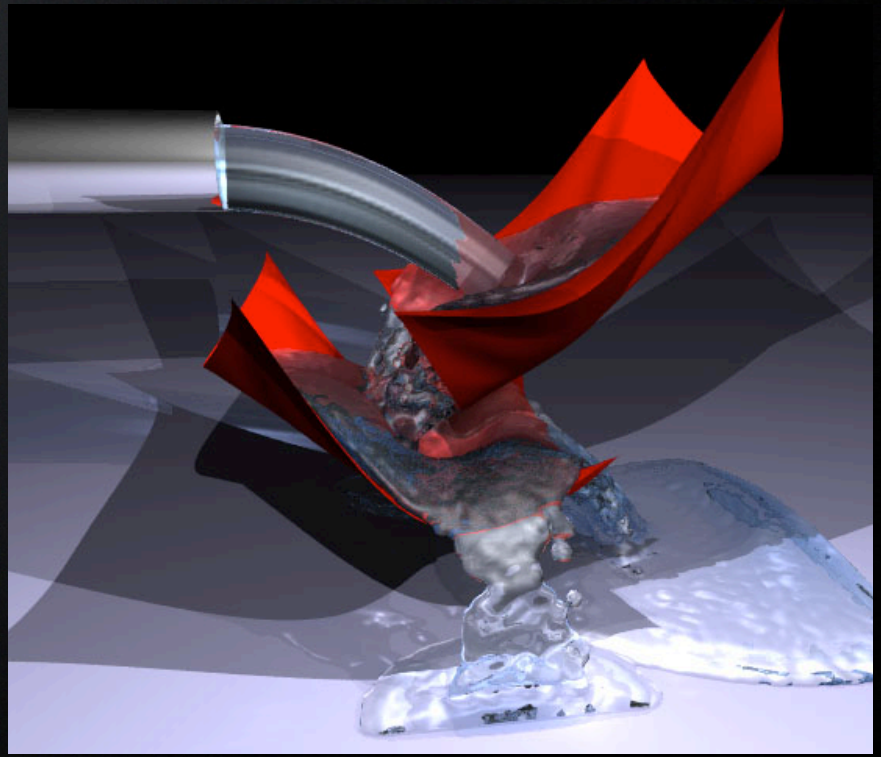
Harada et al., Real-time Rigid Body Simulation on GPUs, GPU Gems3 (2007)

COUPLING RIGID BODIES + FLUID



CLOTH COLLISION DETECTION

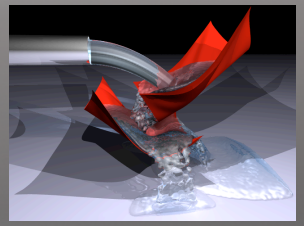
- Particle v.s. triangle mesh collision
- Dual uniform grid
  - 1st grid: particles
  - 2nd grid: triangles

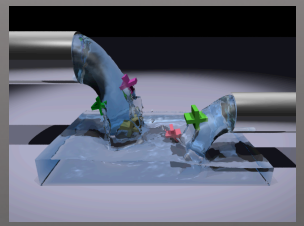


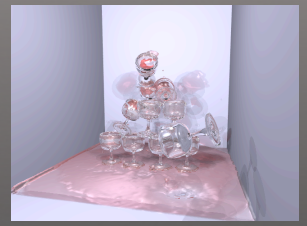
Harada et al., Real-time Fluid Simulation Coupled with Cloth, TPCG (2007)

SEVERAL PHYSICS PROBLEMS WERE SOLVED

Coupling

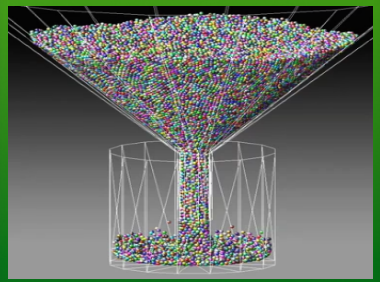




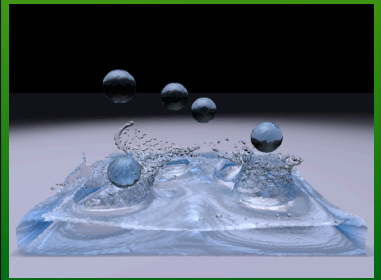


Cloth

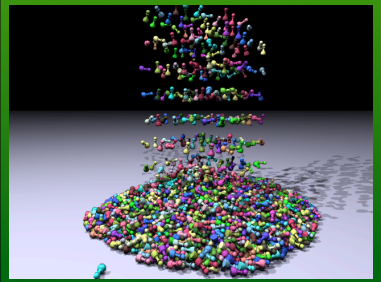
Granular Materials



Fluids



Rigid Bodies



Particle Simulations

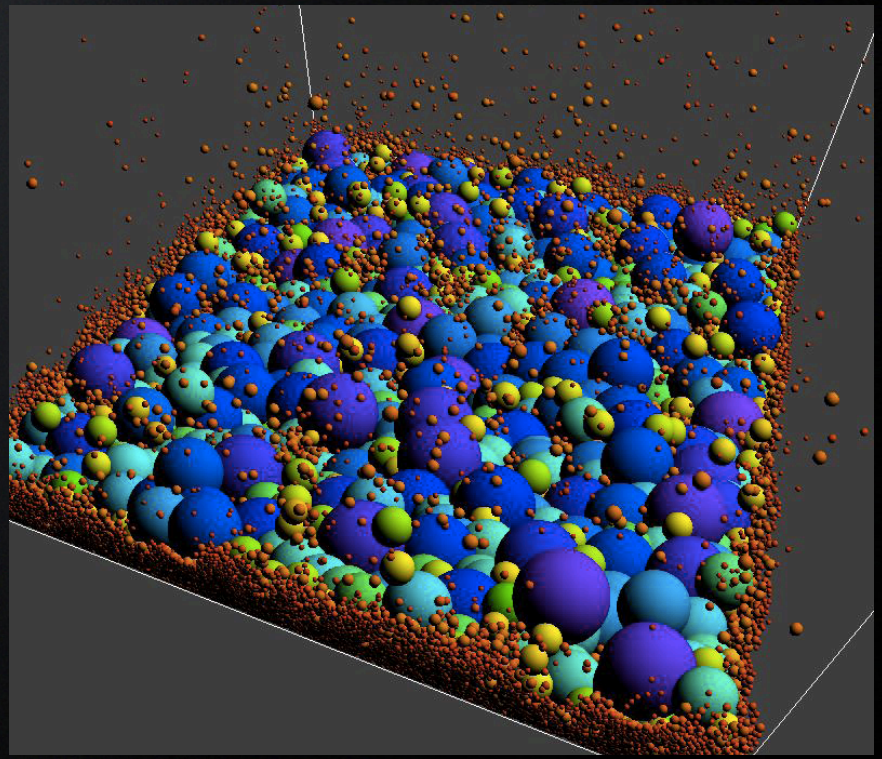
PROBLEM SOLVED??

- Not yet

- Uniform grid is not a perfect solution
- More complicated collision detection is necessary
  - E.g., rigid body simulation
  - Broad-phase collision detection
  - Narrow-phase collision detection

BROAD-PHASE COLLISION DETECTION

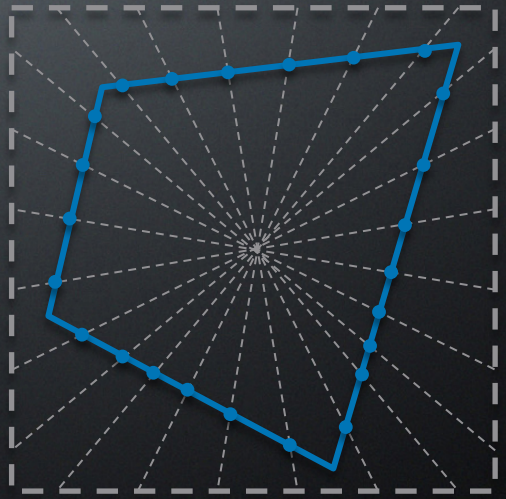
- Sweep & prune
  - Sort end points
  - Sweep sorted list
- Optimizations
  - Split sweep of a large object
  - Workspace subdivision
  - Cell subdivision

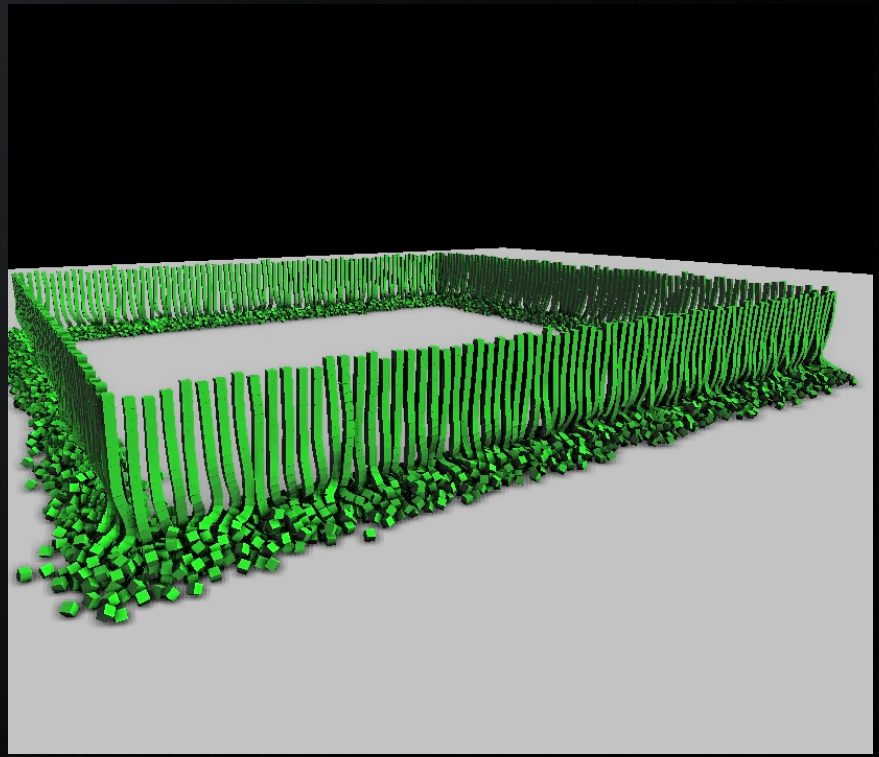


Liu et al., Real-time Collision Culling of a Million Bodies on Graphics Processing Units, TOG(2010)

NARROW-PHASE COLLISION DETECTION

- Variety of work
  - So many shape combinations -> divergence
- Unified shape representation
- Each collision computation is parallelizable



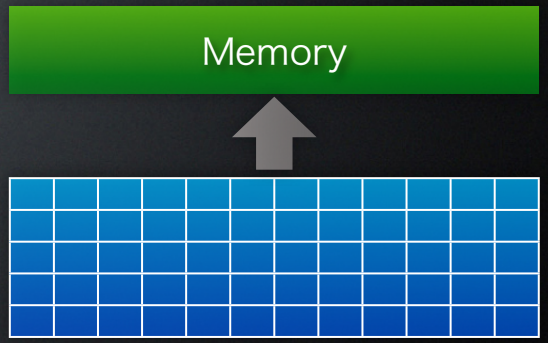


MULTIPLE GPU COLLISION DETECTION

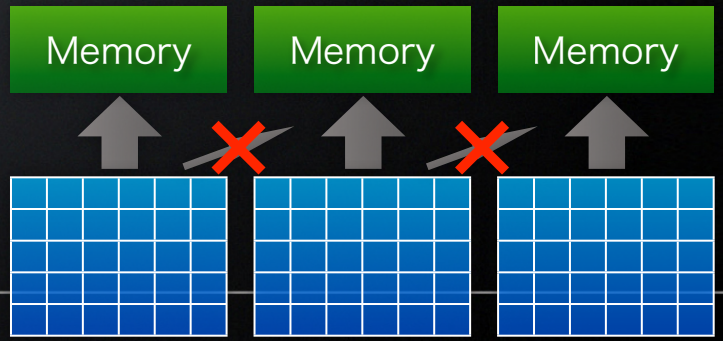
MULTIPLE GPU PROGRAMMING

Parallelization using Multiple GPUs

- Two levels of parallelization
- 1GPU



- Multiple GPUs

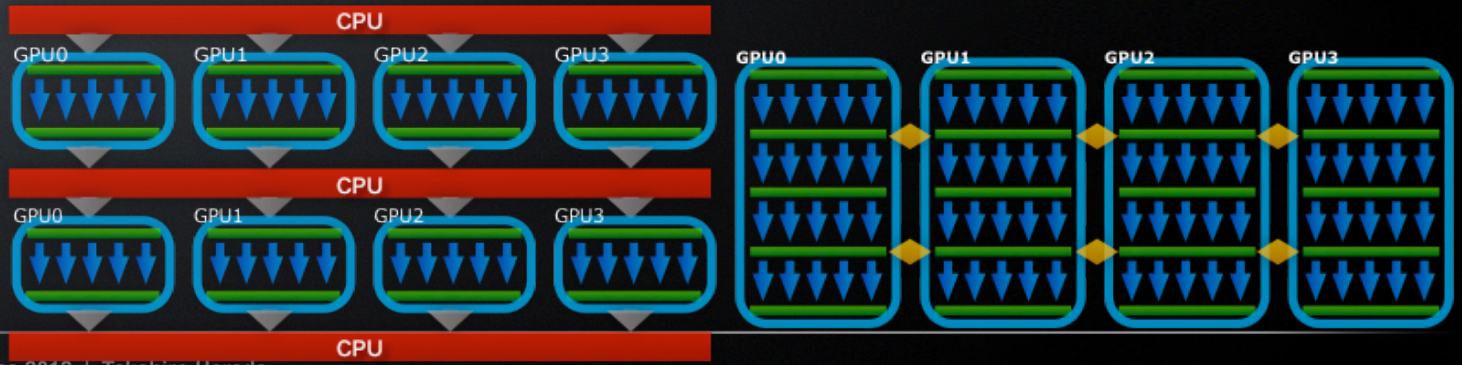


Programming Model for Multiple GPUs

- Have to choose a programming model for particle methods
  1. Server-client model
  2. Peer-to-peer model

1. Server-client model
- Data is managed by the CPU, working as a server
- Overhead of parallelization can be big
- The process of CPU is serialized
- GPUs have to be idle while CPU is processing

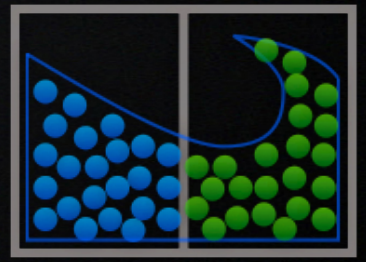
2. Peer-to-peer model
- No processor manages the entire data
- Each GPU manages its own data
- Small overhead of parallelization
- No sequential process, completely parallel



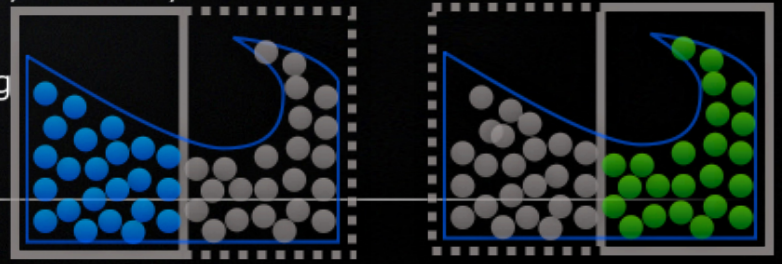
PARTICLE SIMULATION ON MULTIPLE GPUS

Decomposition of Simulation

- Peer-to-peer model is employed
  - Each GPU manages its own data
  - No processor manages all the data
- Computation domain is decomposed into subdomains
- A processor is responsible for a subdomain
  - Compute particles in its subdomain

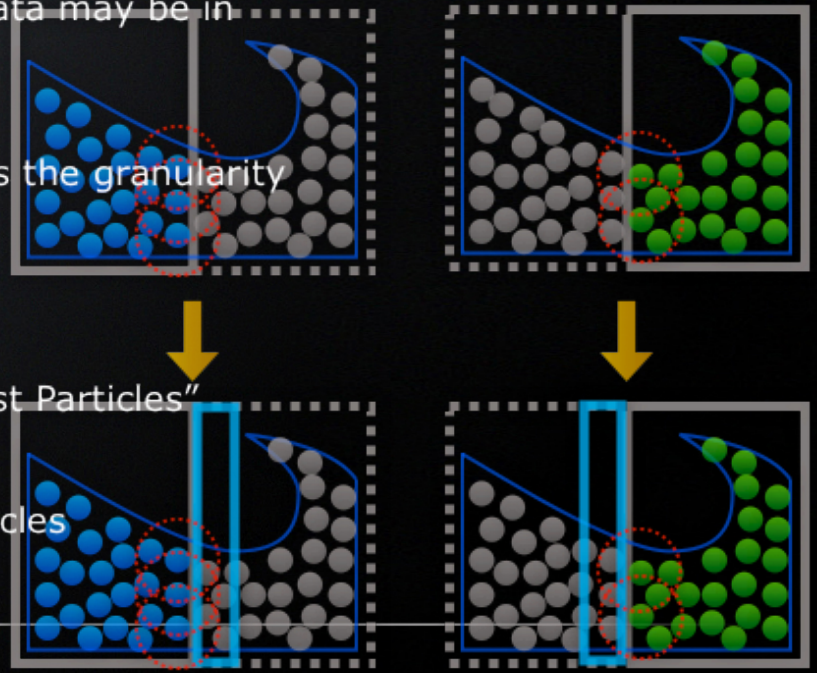


- Grid-based
  - Domain decomposition is natural choice because elements in a subdomain does not change
- Particle-based
  - Have to assign particles to GPUs dynamically because they move
- Overhead of parallelization can be big



Decomposition of Simulation

- Computation of particle values requires neighboring values
  - Inside of subdomain: all the data is in the memory of its own
  - Boundary of subdomain : Some data may be in the memory of others
- Have to read data in other GPUs
- Communicating when required makes the granularity of transfer smaller and inefficient



- Introduced "Ghost Region" and "Ghost Particles"
  - Each GPU
    - Not update value of ghost particles
    - Just refer the data

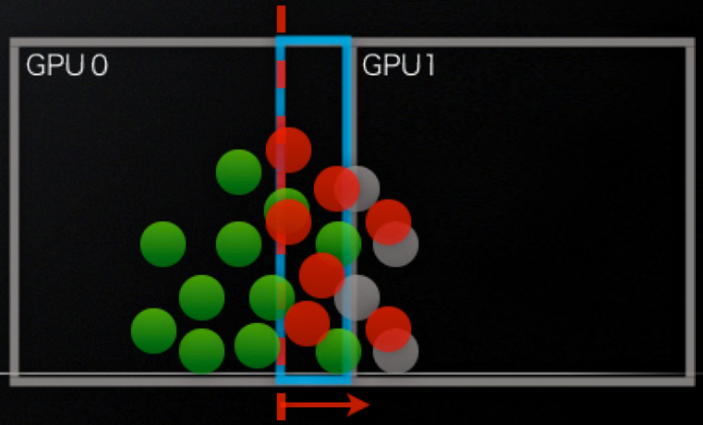
Data Management

- Not all the data have to be sent
- Data required for the computation has to be sent

- Two kinds of particles have to be sent to adjacent GPU
  1. Escaped particles : Particles get out from adjacent subdomain (adjacent GPU will be responsible for these particles in the next time step)
  2. Ghost particles in the ghost region

Data Transfer

- After computation (advection etc.)
- Particles have to sent to adjacent GPU
  - Escaped particles
  - Ghost particles
- How to choose them?
  1. Scan particles and set flag to particles in the region
     - Need a lot of additional computations
- Overhead can be big



Data Transfer

- Where were these particles at time t?
  - Using the Courant condition (particle does not move more than their diameter in a time step)
- Escaped particles were in the blue area
- Ghost particles were in the red area

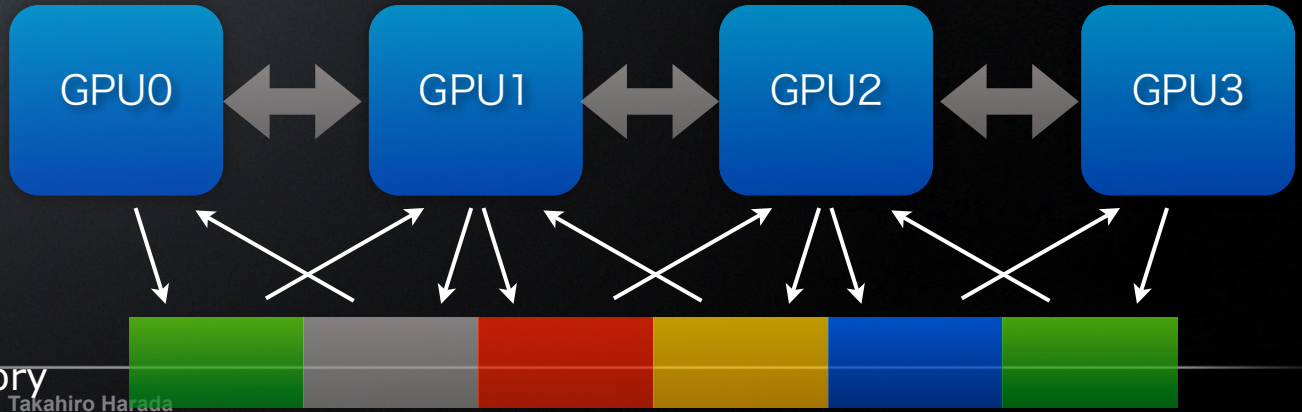
- Particles have to be sent is the particles in the red area
- Grid constructed in the previous step can be used for selection
  - The Sliced Grid

Slided Data Structure for Particle-based Simulations on GPUs, Harada et al. , GRAPHITE, 55-62(2007)
ShaderX 7, To Appear

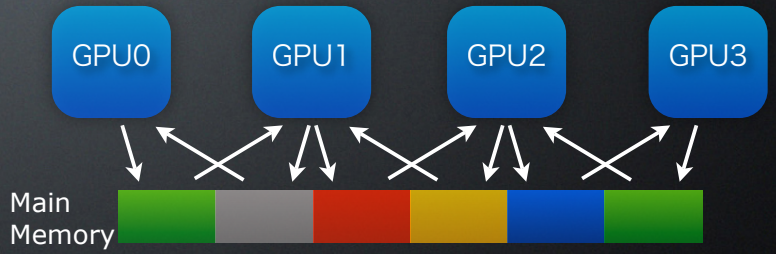
Data Transfer between GPUs

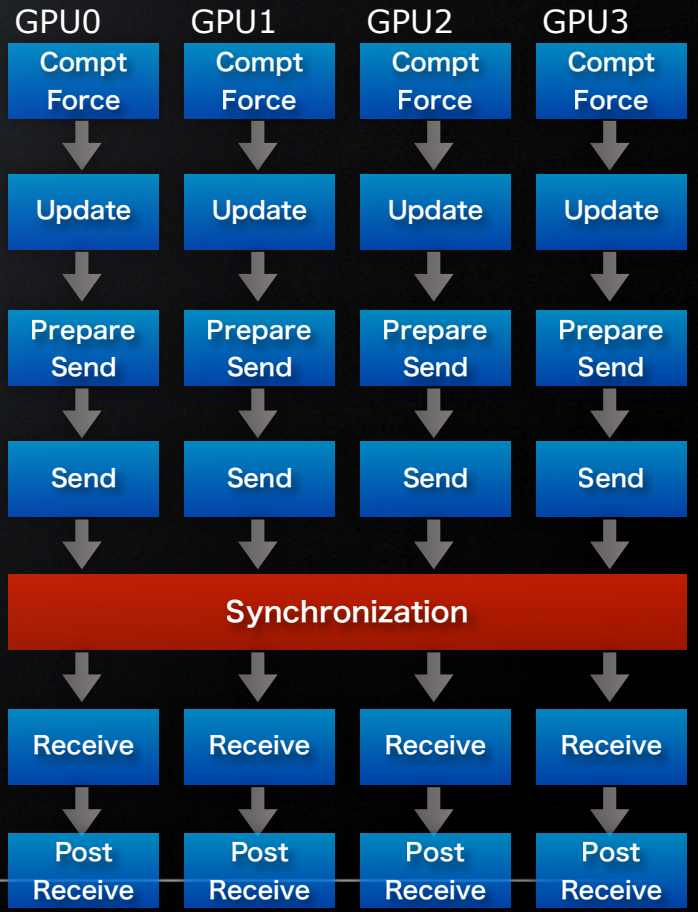
- No direct data transfer is provided on current hardwares

- Transfer via main memory
  - The buffers equal to the number of connectors are allocated
  - Each GPU writes data to the defined location at the same time
  - Each GPU read data of the defined location at the same time



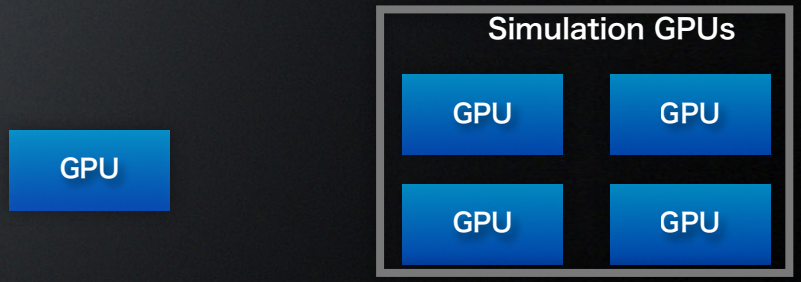
Computation of 1 Time Step



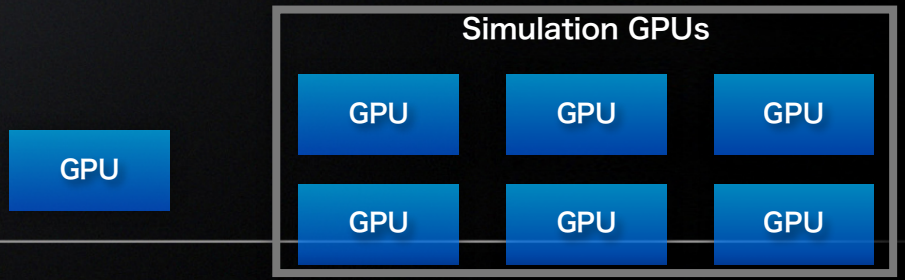


Environment

- 4GPU server (Simulation) + 1GPU (Rendering)
  - 1M particles

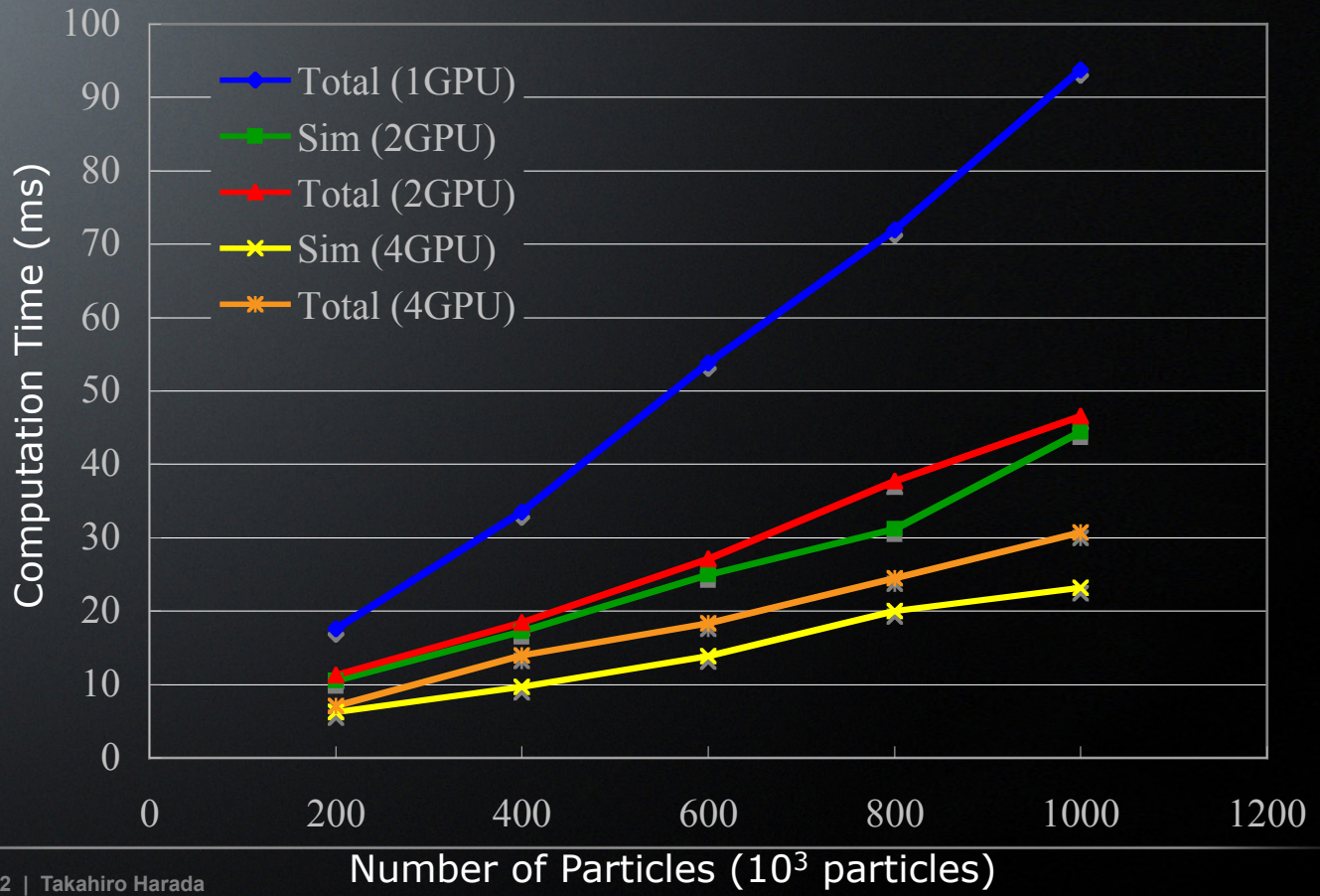


- 6GPU server boxes (Simulation) + 1GPU (Rendering) @ GDC2008
  - 3M particles



Harada et al., Massive Particles: Particle-based Simulations on Multiple GPUs, SIG Talk(2008)

Results


Computation Time (ms)
100
90
80
70
60
50
40
30
20
10
0
Total (1GPU)
Sim (2GPU)
Total (2GPU)
Sim (4GPU)
Total (4GPU)
0
200
400
600
800
1000
1200
Number of Particles (10^3 particles)

PROBLEM SOLVED??

- Not yet

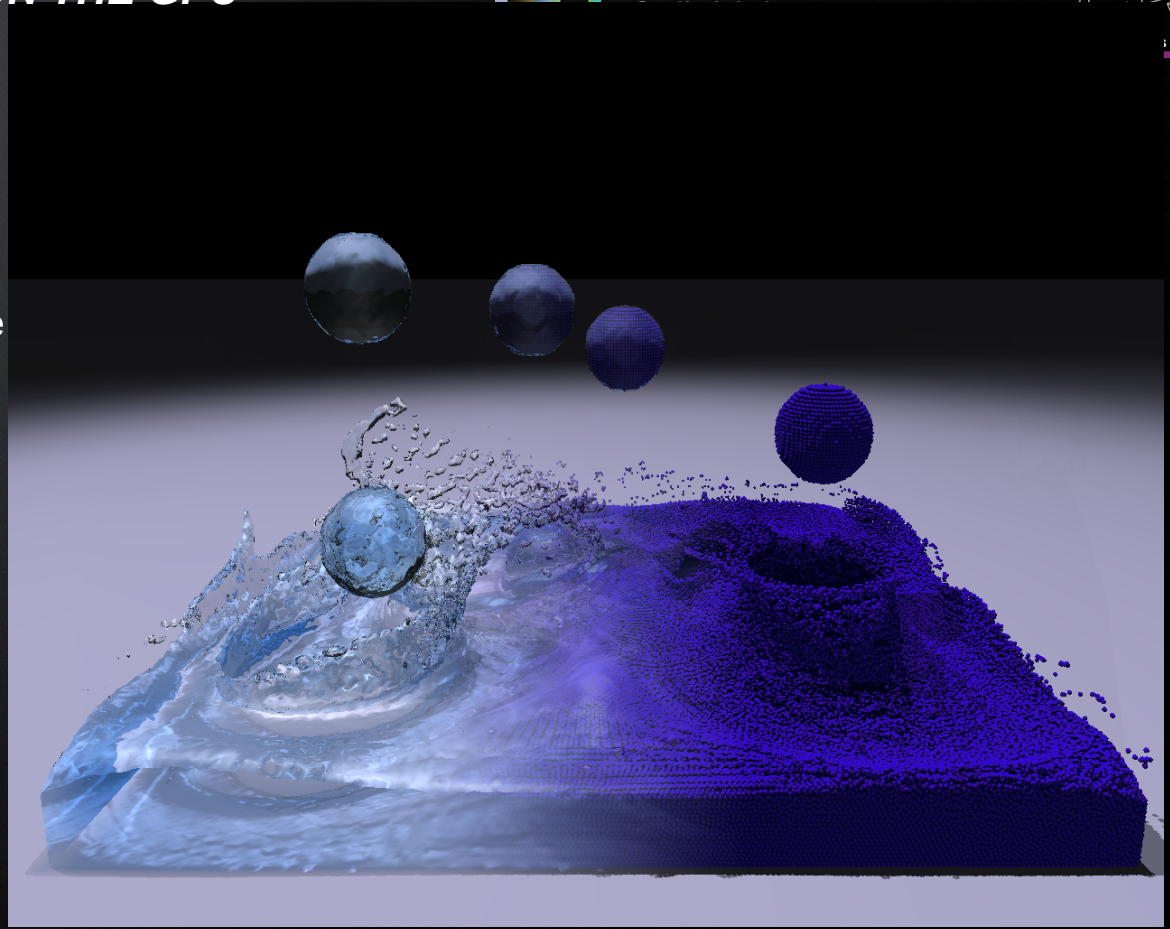
- Most of the problems had identical object size
  - e.g., Particles

- The reason is because of GPU architecture
  - Not designed to solve non-uniform problem

HETEROGENEOUS COLLISION DETECTION

PARTICLE BASED SIMULATION ON THE GPU

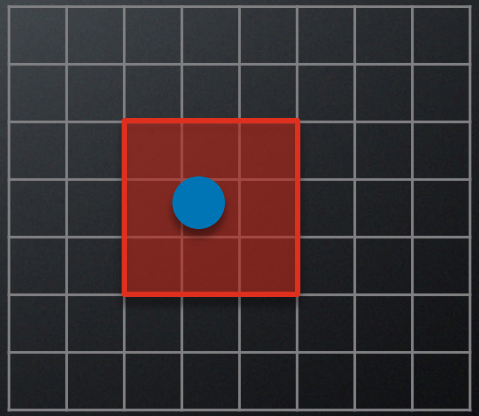
- Large number of particles
- Particles with identical size
  - Work granularity is almost the same
  - Good for the wide SIMD architecture

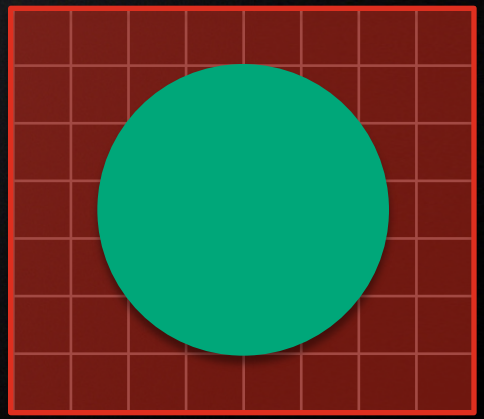


Harada et al. 2007

MIXED PARTICLE SIMULATION

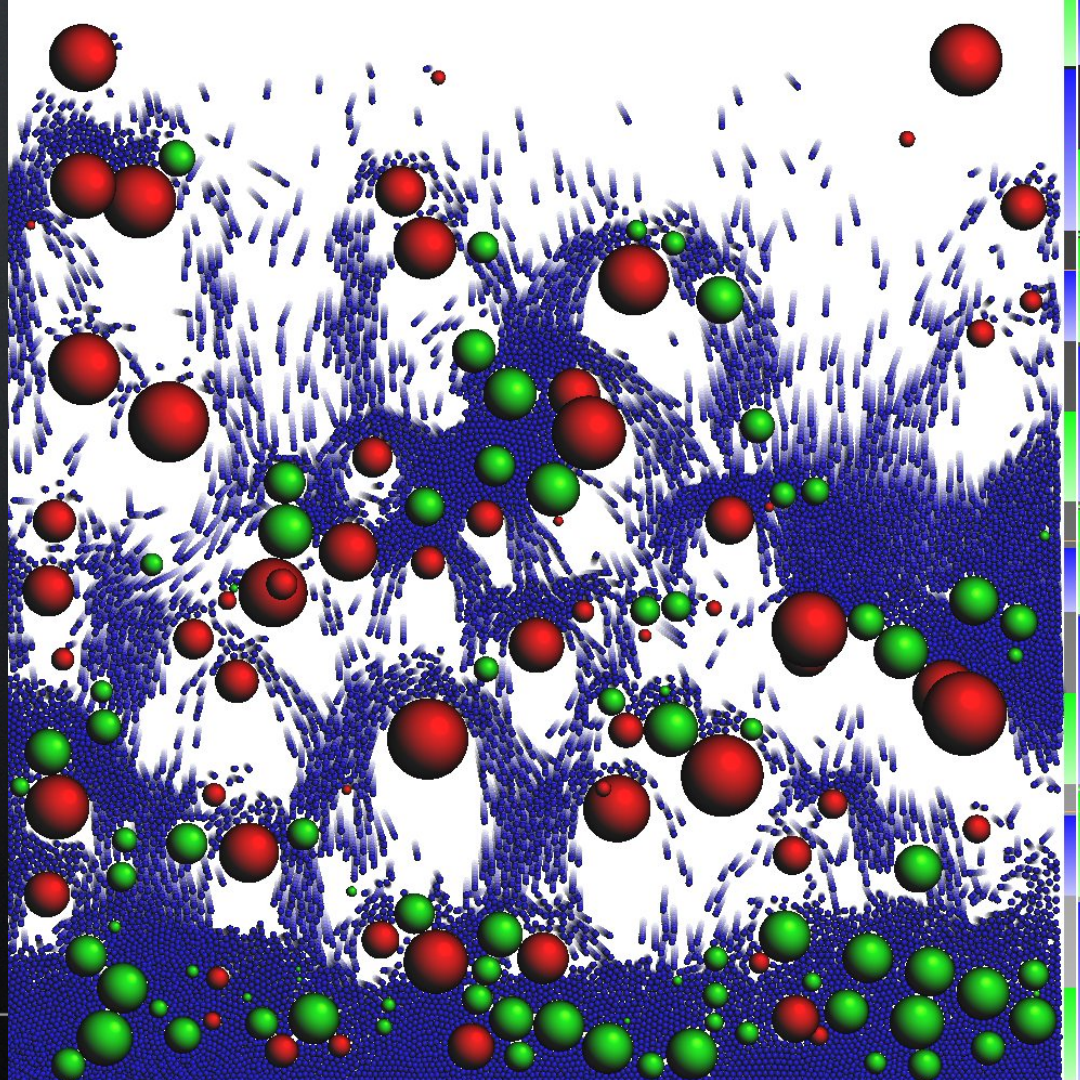
- Not only small particles
- Difficulty for GPUs
  - Large particles interact with small particles
  - Large-large collision





CHALLENGE

- Non uniform work granularity
  - Small-small(SS) collision
    - Uniform, GPU
  - Large-large(LL) collision
    - Non Uniform, CPU
  - Large-small(LS) collision
    - Non Uniform, CPU



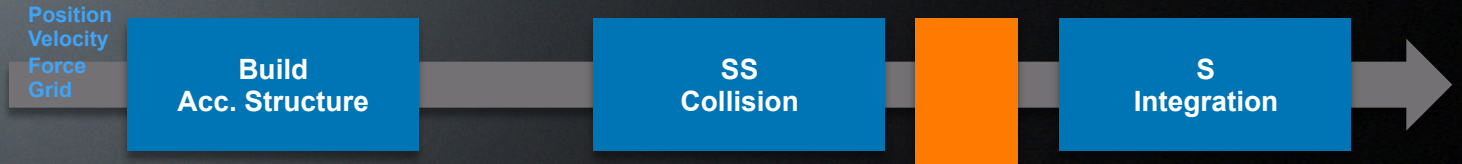
FUSION ARCHITECTURE

- CPU and GPU are:
  - On the same die
  - Much closer
  - Efficient data sharing
- CPU and GPU are good at different works
  - CPU: serial computation, conditional branch
  - GPU: parallel computation
- Able to dispatch works to:
  - Serial work with varying granularity → CPU
  - Parallel work with the uniform granularity → GPU

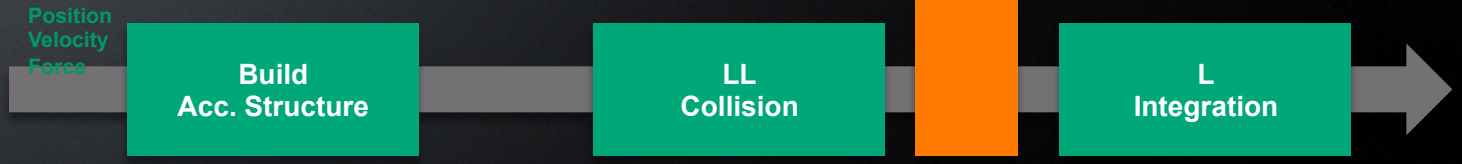
METHOD

TWO SIMULATIONS

- Small particles

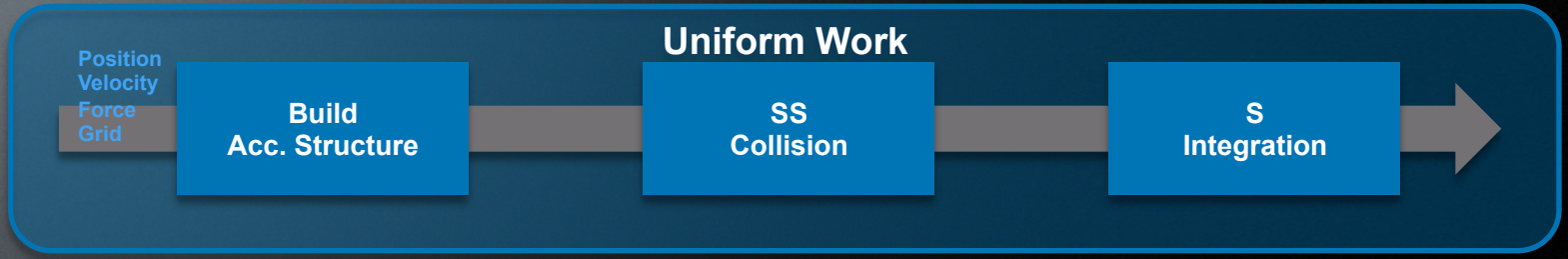


- Large particles

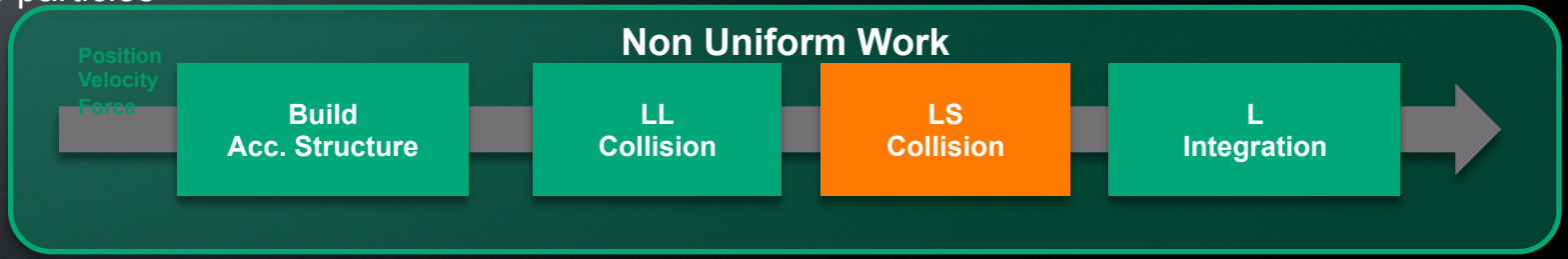


CLASSIFY BY WORK GRANULARITY

- Small particles

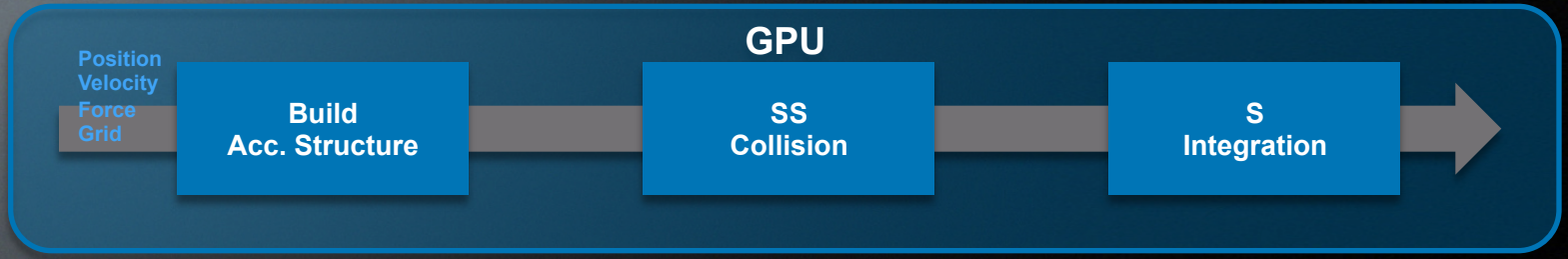


- Large particles

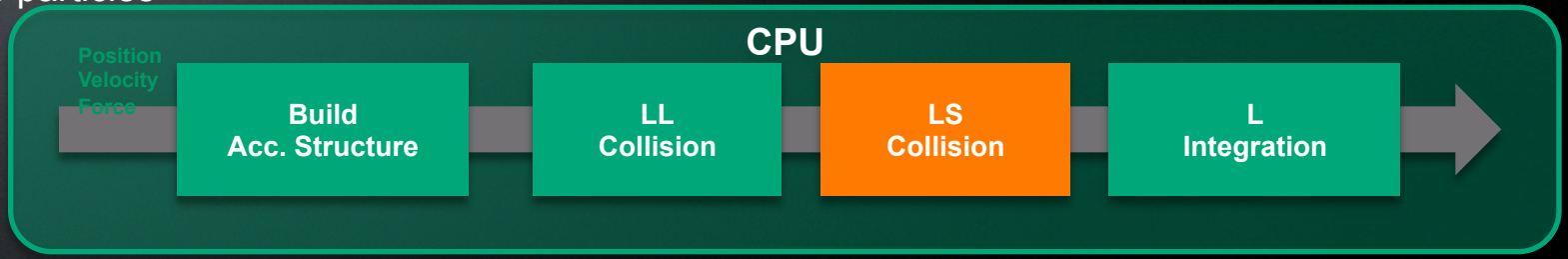


CLASSIFY BY WORK GRANULARITY, ASSIGN PROCESSOR

- Small particles

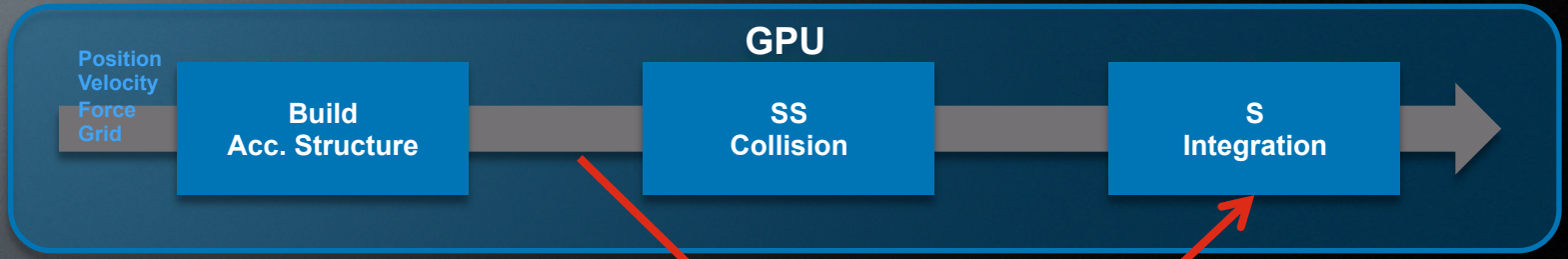


- Large particles

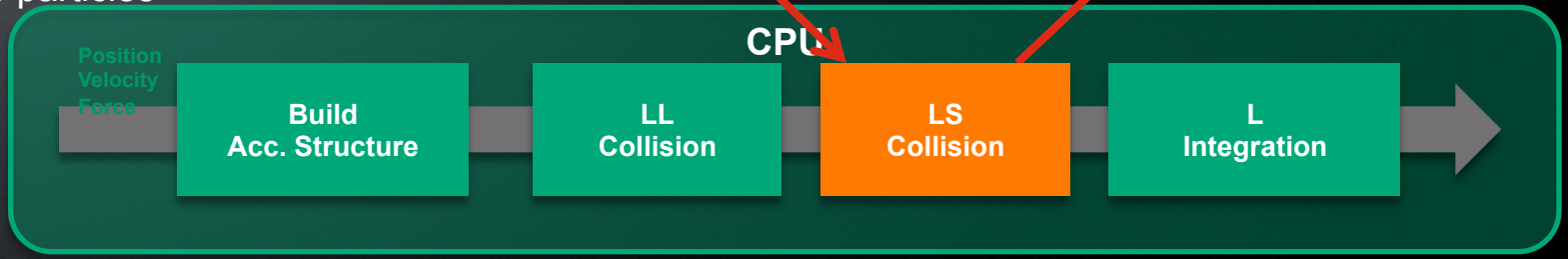


DATA SHARING

- Small particles



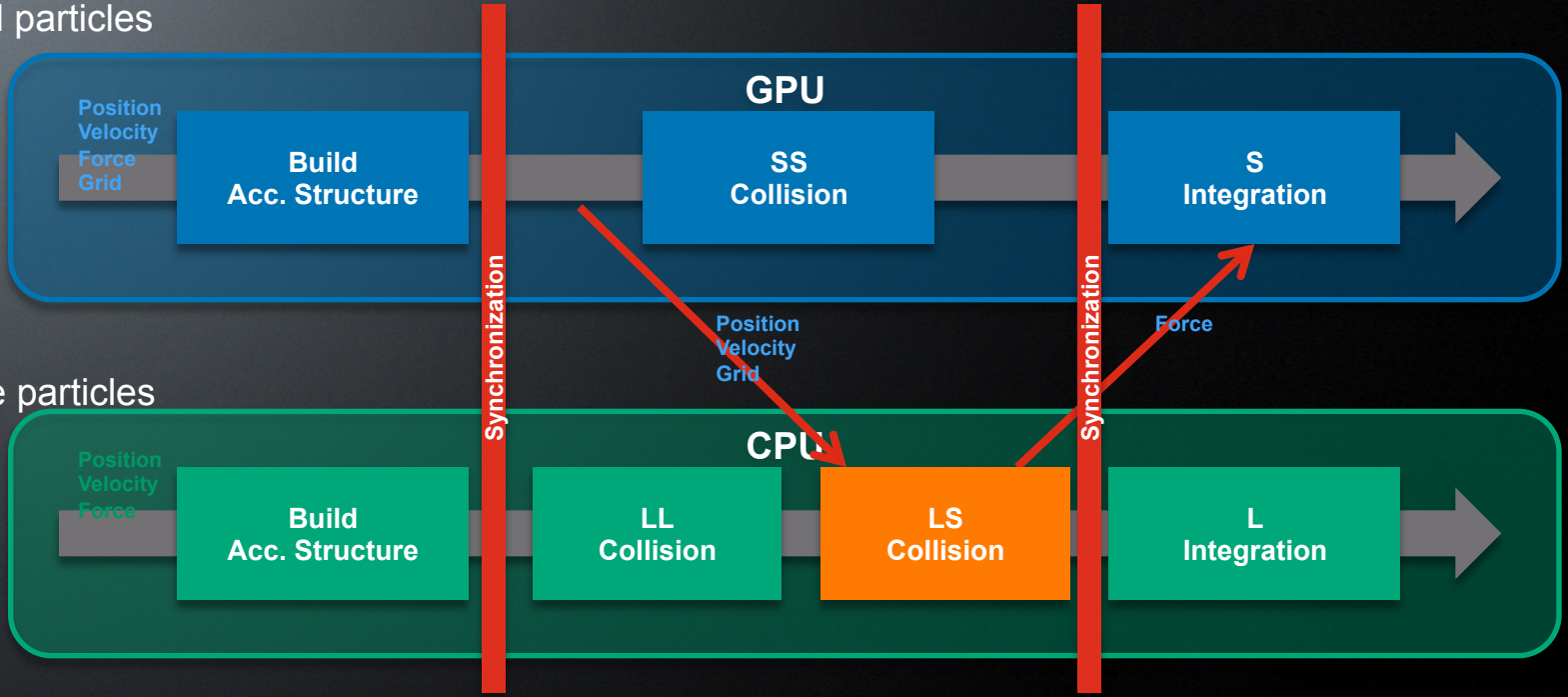
- Large particles



- Grid, small particle data has to be shared with the CPU for LS collision
  - Allocated as zero copy buffer

SYNCHRONIZATION

- Small particles

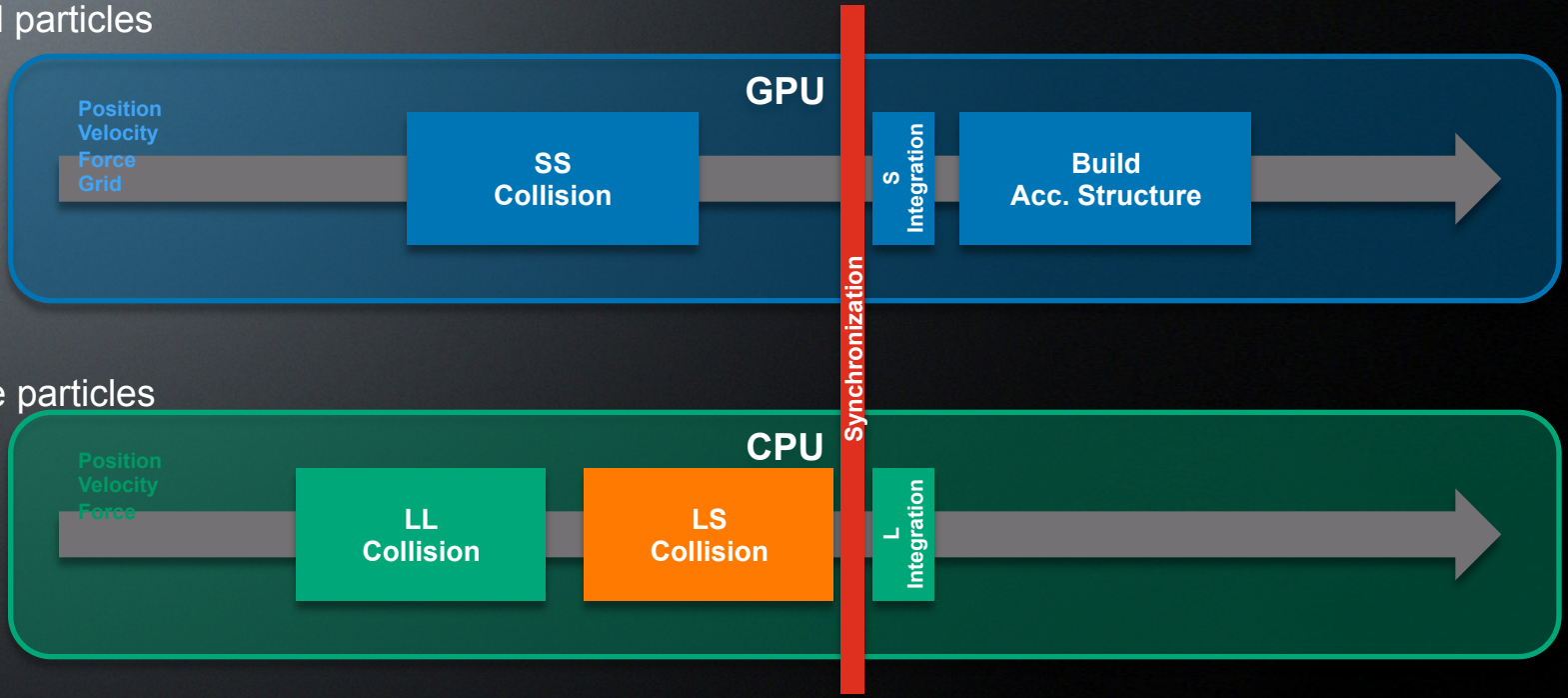


- Large particles

- Grid, small particle data has to be shared with the CPU for LS collision
  - Allocated as zero copy buffer

VISUALIZING WORKLOADS

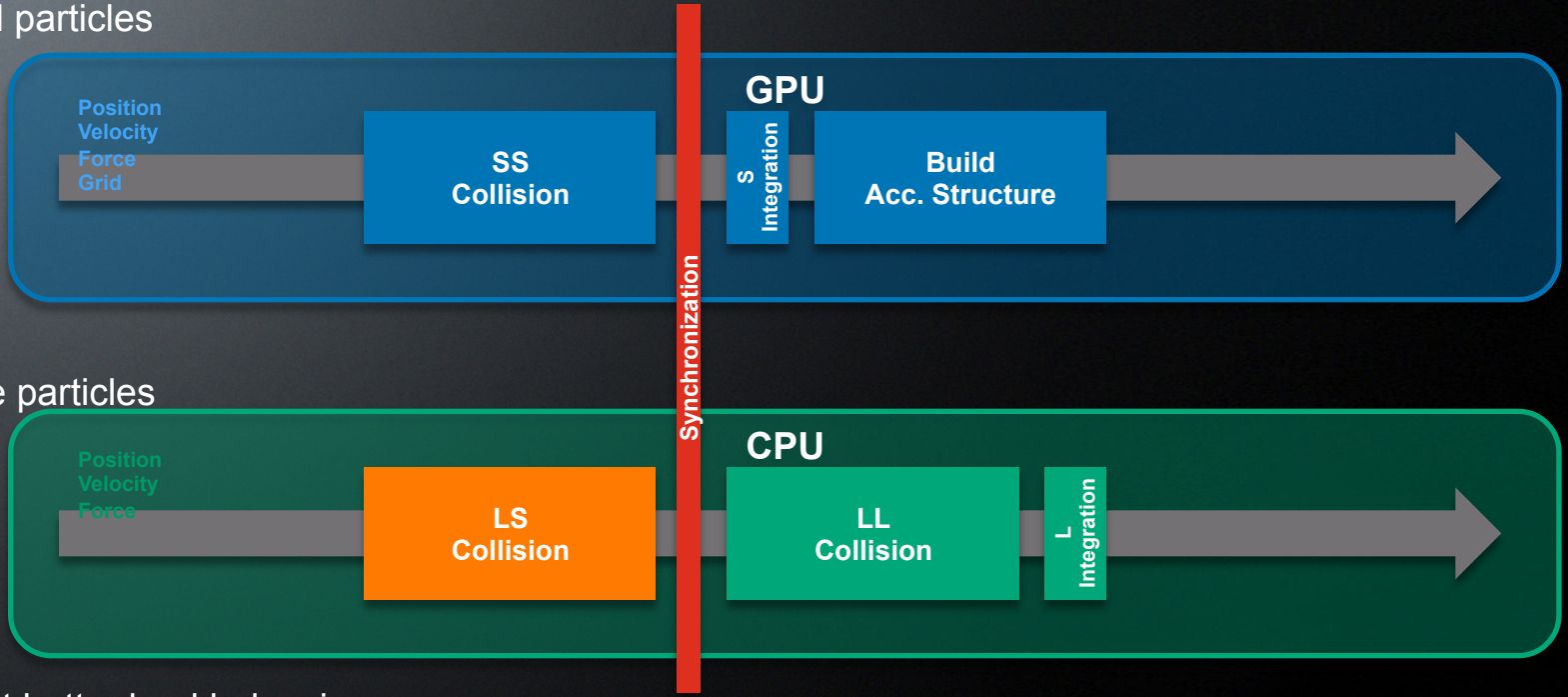
- Small particles



- Large particles
- Grid construction can be moved at the end of the pipeline
  - Unbalanced workload

LOAD BALANCING

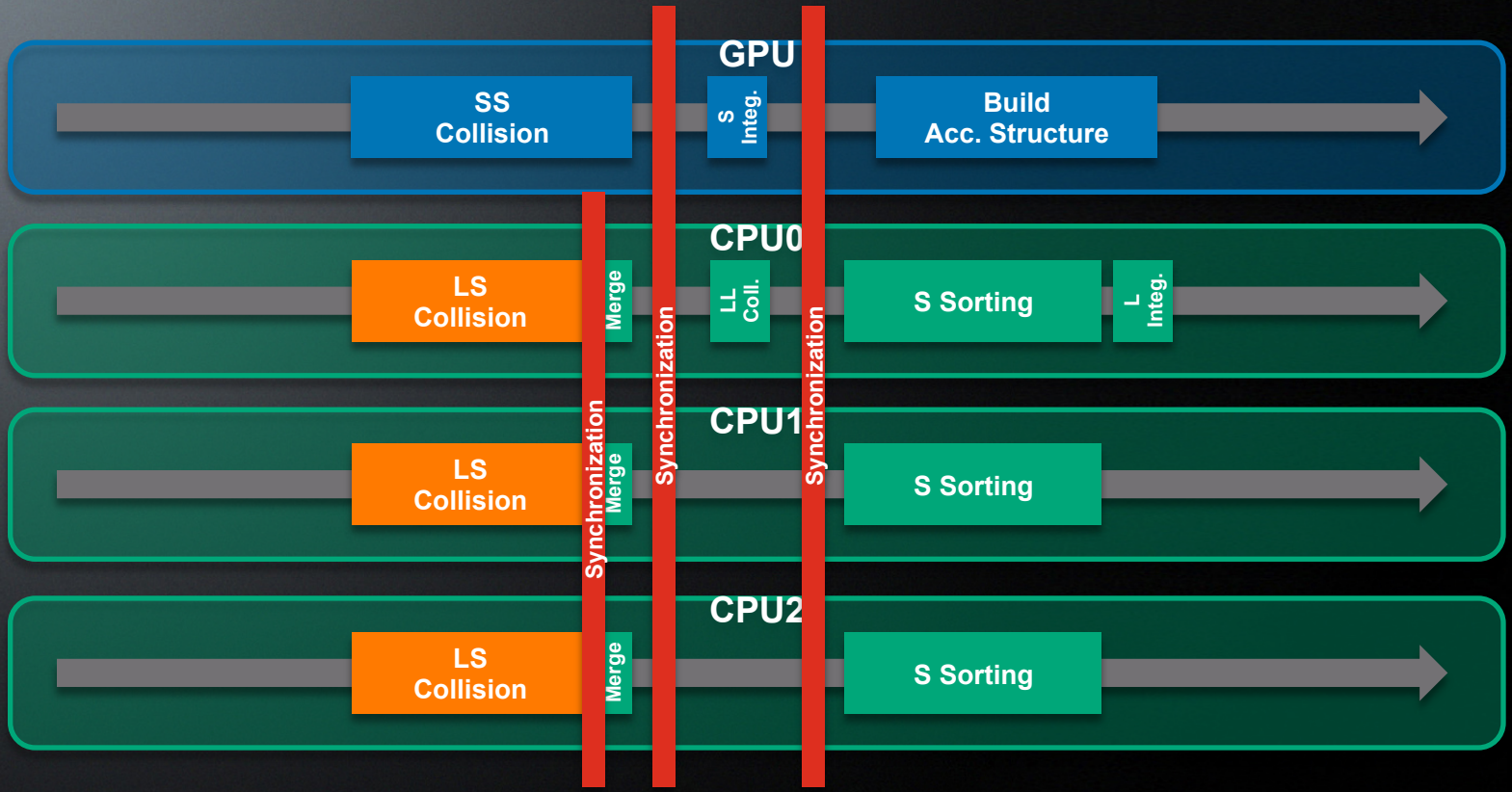
- Small particles



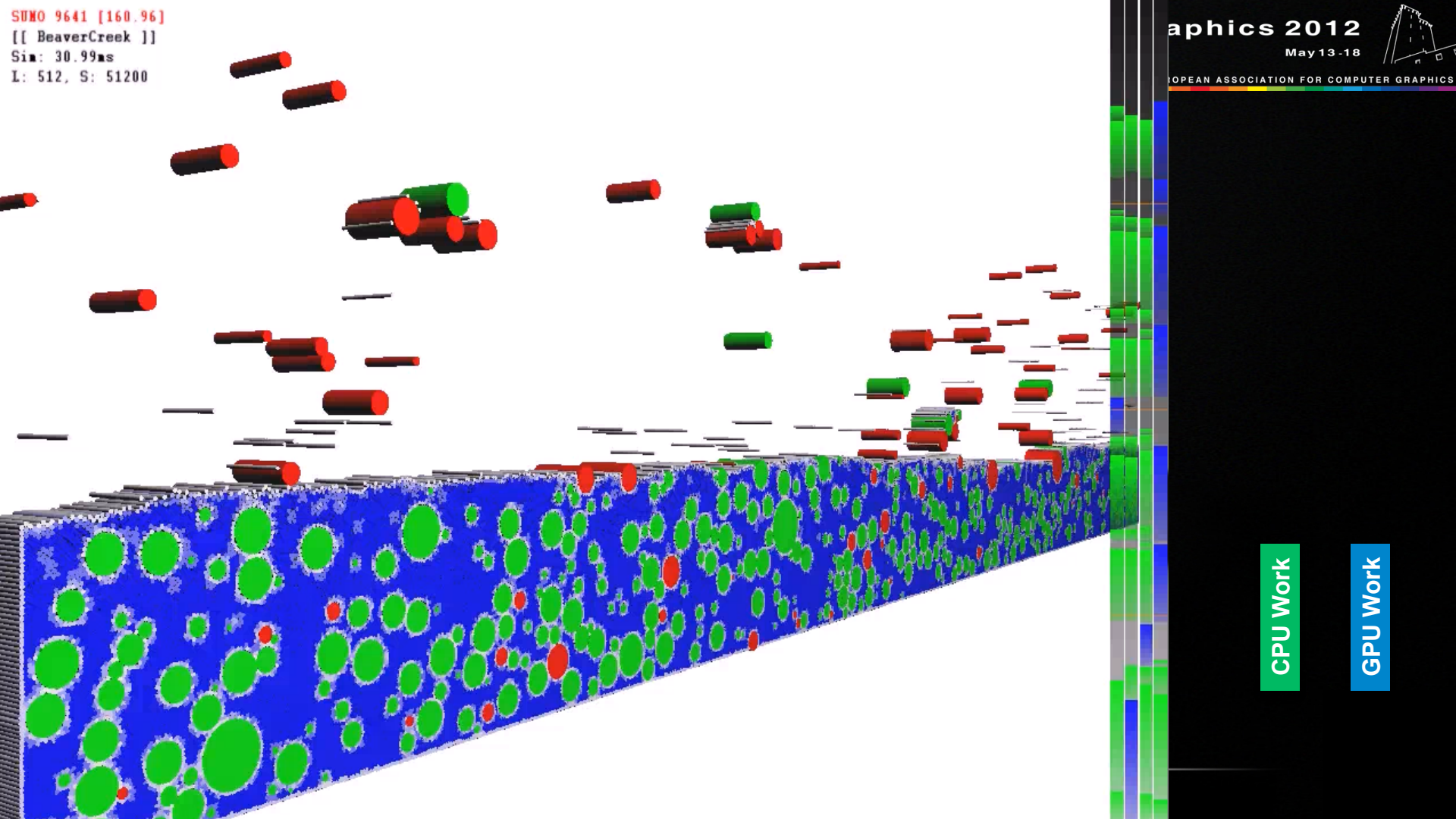
- Large particles
- To get better load balancing
  - The sync is for passing the force buffer filled by the CPU to the GPU
  - Move the LL collision after the sync

MULTI THREADING (4 THREADS)

OPTIMIZATION2: IMPROVING SMALL-SMALL COLLISION



Harada, Heterogeneous Particle-Based Simulation, SIG ASIA Talk(2011)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[[BeaverCreek]]
Sim: 30.99ms
L: 512, S: 51200
aphics 2012
May 13-18
OPEAN ASSOCIATION FOR COMPUTER GRAPHICS
CPU Work
GPU Work

QUESTIONS?