UberFlow: A GPU-Based Particle Engine

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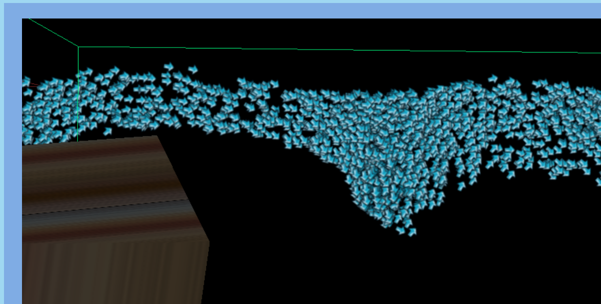
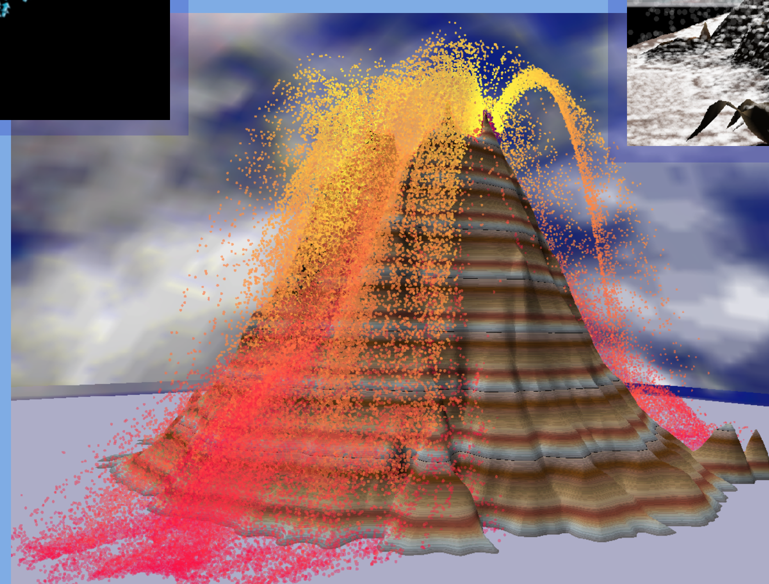
computer graphics & visualization

Motivation

Want to create, modify and render large geometric models





Important example:

Particle system

Motivation

Major bottleneck

- Transfer of geometry to graphics card

Process on GPU if transfer is to be avoided

- Need to avoid intermediate read-back also

Requires dedicated GPU implementations

→ Perform geometry handling for rendering on the GPU

Bus transfer

- Send geometry for every frame
  - because simulation or visualization is time-dependent
  - the user changed some parameter
- Render performance: 12.6 mega points/sec

- Make the geometry reside on the GPU
  - need to create/manipulate/remove vertices without read-back
- Render performance: 114.5 mega points/sec

ATI Radeon 9800Pro, AGP 8x, **`GL_POINTS`** with individual color

Motivation

Previous work

- GPU used for large variety of applications
  - local / global illumination [Purcell2003]
  - volume rendering [Kniss2002]
  - image-based rendering [Li2003]
  - numerical simulation [Krüger2003]
- GPU can outperform CPU for both compute-bound and memory-bound applications

→ Geometry handling on GPU potentially faster

GPU Geometry Processing

Simple copy-existing-code-to-shader solutions will not be efficient

Need to re-invent algorithms, because

- different processing model (stream)
- different key features (memory bandwidth)
- different instruction set (no binary ops)

GPU Geometry Processing

Need shader access to vertex data

- OpenGL SuperBuffer
  - Memory access in fragment shader
  - Directly attach to compliant OpenGL object
- VertexShader 3.0
  - Memory access in vertex shader
  - Use as displacement map
- Both offer similar functionality

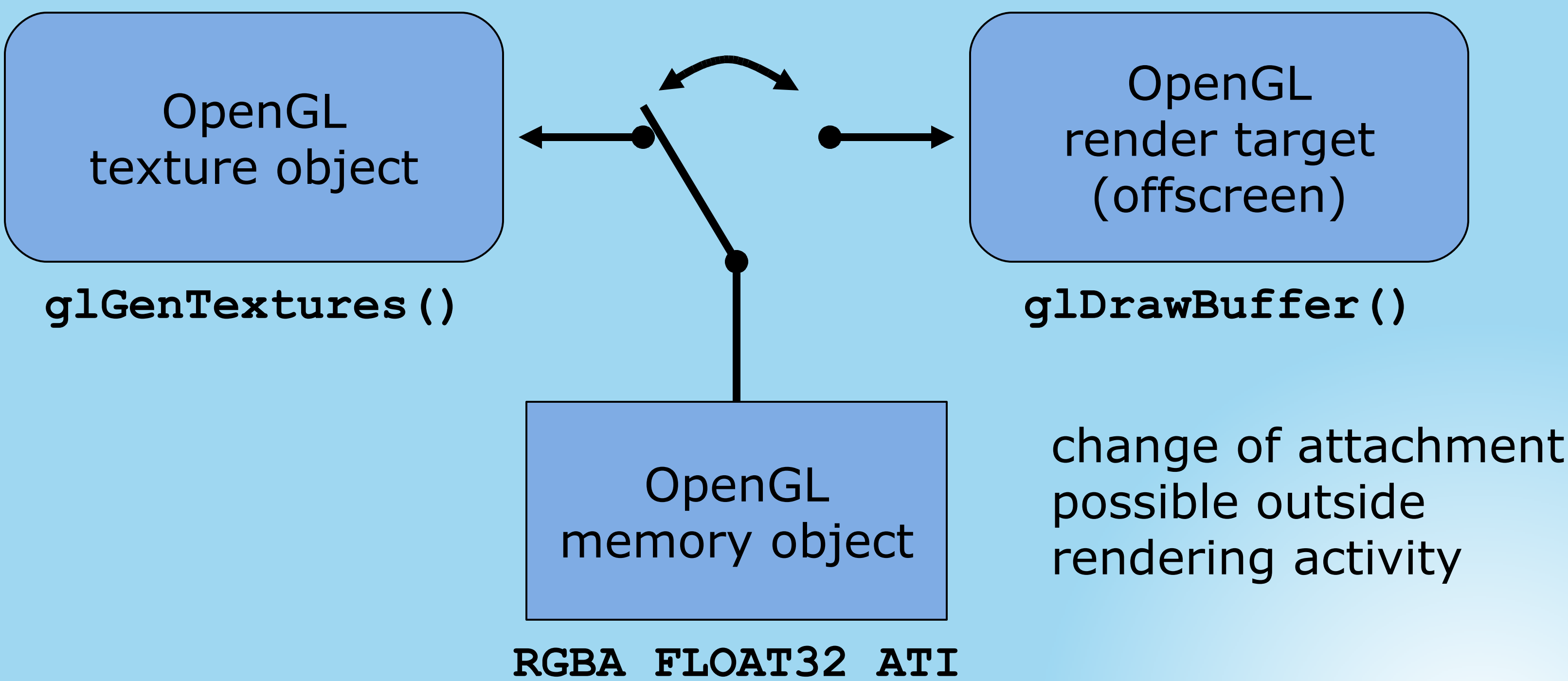
OpenGL SuperBuffer

Separate semantic of data from it's storage

- Allocate buffer with a specified size and data layout
- Create OpenGL objects
  - Colors: texture, color array, render target
  - Vectors: vertex array, texcoord array
- If data layout is compatible with semantic, the buffer can be attached to / detached from the object
  - Zero-copy operation in GPU memory
  - Render-to-vertex array possible by using floating-point textures and render targets

OpenGL SuperBuffer

- Example: floating point array that can be read and written (not at the same time)



GPU Particle Engine

cool demo

Overview

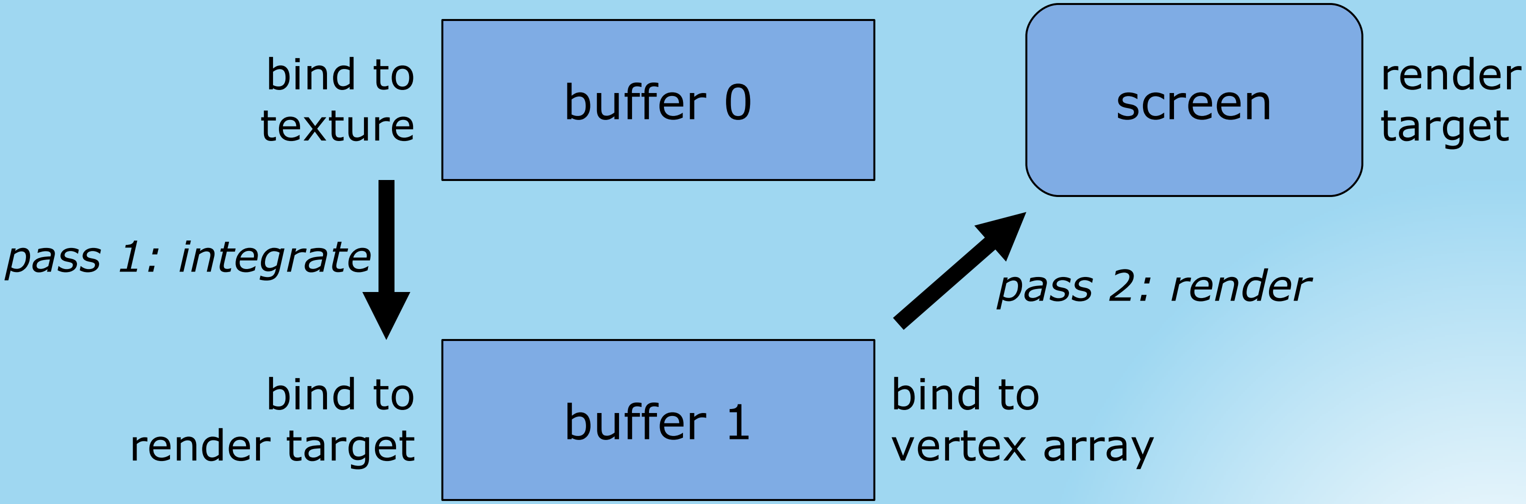
GPU particle engine features

- Particle advection
  - Motion according to external forces and 3D force field
- Sorting
  - Depth-test and transparent rendering
  - Spatial relations for collision detection
- Rendering
  - Individually colored points
  - Point sprites

Particle Advection

Simple two-pass method using two vertex arrays in double-buffer mode

- Render quad covering entire buffer
- Apply forces in fragment shader



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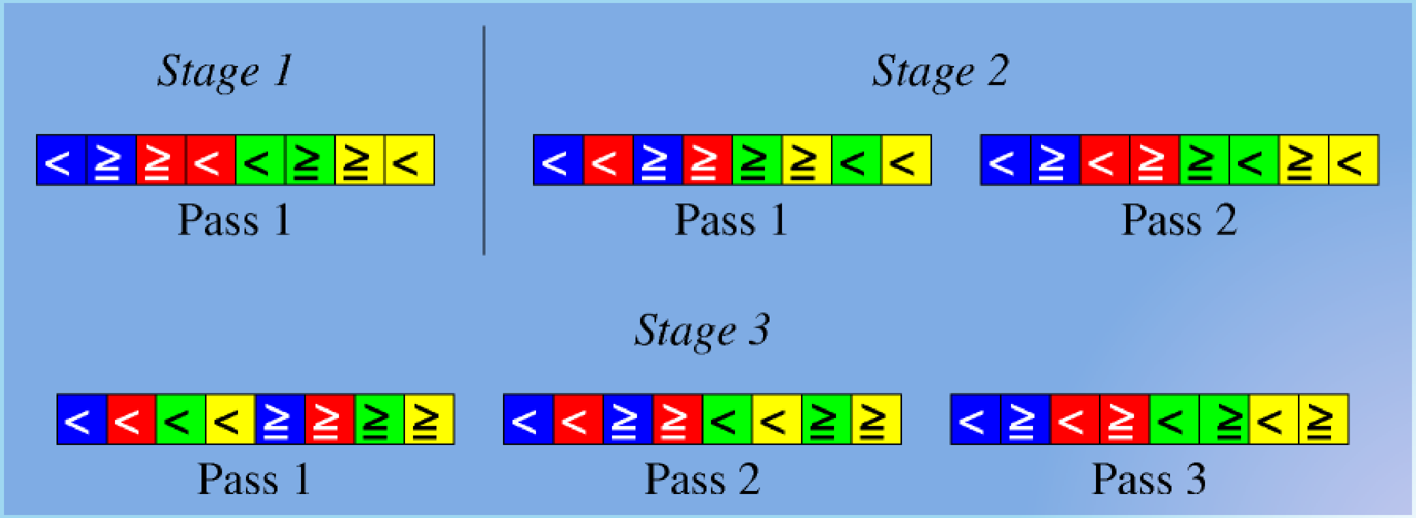
Sorting

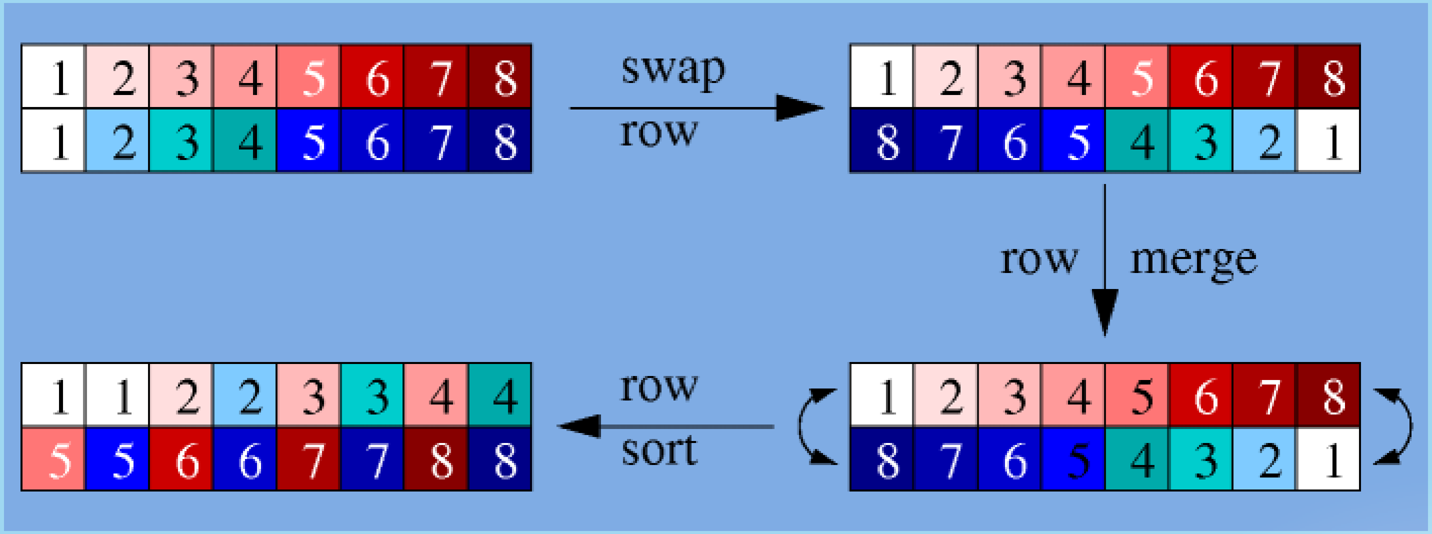
Required for correct transparency and collision detection

- Bitonic merge sort (sorting network) [Batcher1968]
- Sorting n items needs (log n) stages
- Overall number of passes $\frac{1}{2}(\log^2 n + \log n)$



Sorting a 2D field

- Merge rows to get a completely sorted field

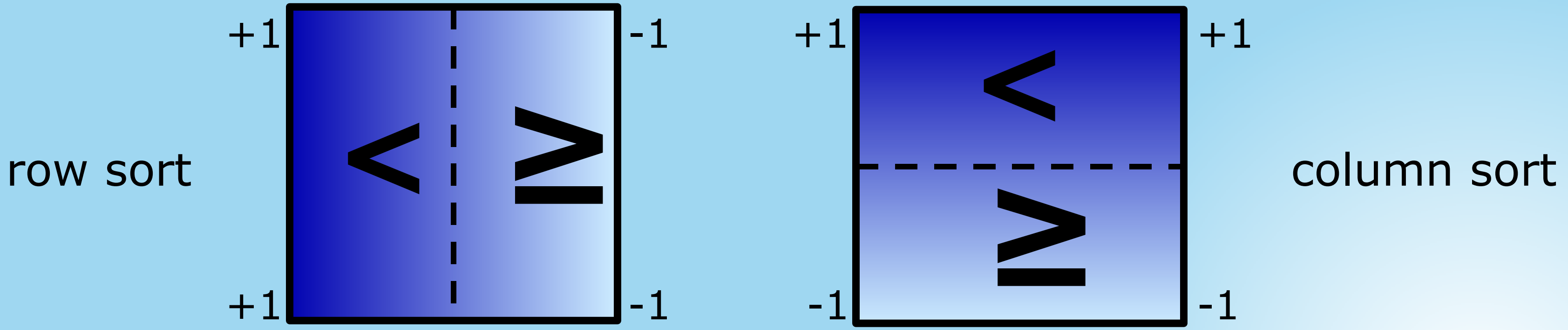


- Implement in fragment shader [Purcell2003]
  - A lot of arithmetic necessary
  - Binary operations not available in shader

Fast sorting

Make use of all GPU resources

- Calculate constant and linear varying values in vertex shader and let raster engine interpolate
- Render quad size according to compare distance
- Modify compare operation and distance by multiplying with interpolated value



Fast sorting

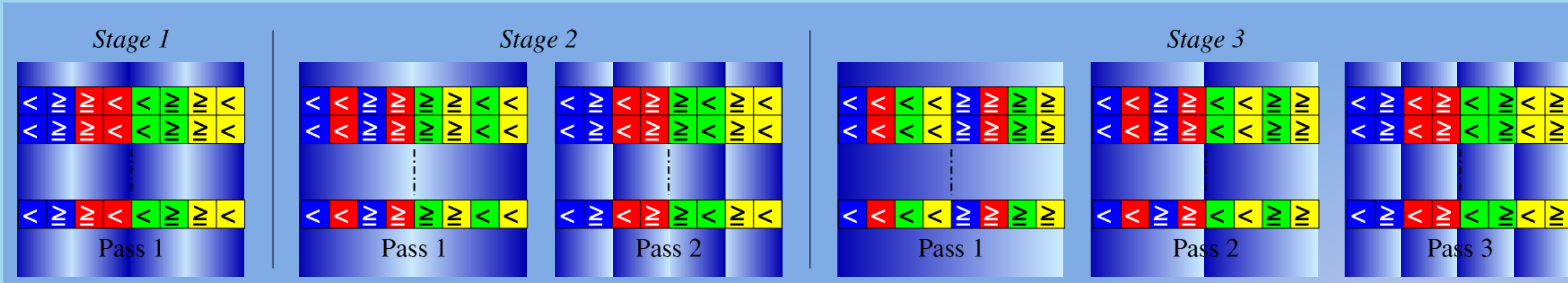
- Perform mass operations (texture fetches) in fragment shader

  t0 = fragment position
  t1 = parameters from vertex shader (interpolated)

```
OP1 = TEX[t0]
sign = (t1.x < 0) ? -1 : 1
OP2 = TEX[t0.x + sign*dx, t0.y]
return (OP1 * t1.y < OP2 * t1.y) ? OP1 : OP2
```

Fast sorting

- Final optimization: sort [index, key] pairs
  - pack 2 pairs into one fragment
  - lowest sorting pass runs internal in fragment shader
- Generate keys according to distance to viewer or use cell identifier of space partitioning scheme



initial pass | collapse into single pass | third pass | collapse into single pass

Fast sorting

- Same approach for column sort, just rotate the quads
- Benefits for full sort of n items
  - 2*log(n) less passes (because of collapse and packing)
  - n/2 fragments processed each pass (because of packing)
  - workload balanced between vertex and fragment units (because of rendering quads and interpolation)

→ Speedup factor of 10 compared to previous solutions

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Fast sorting

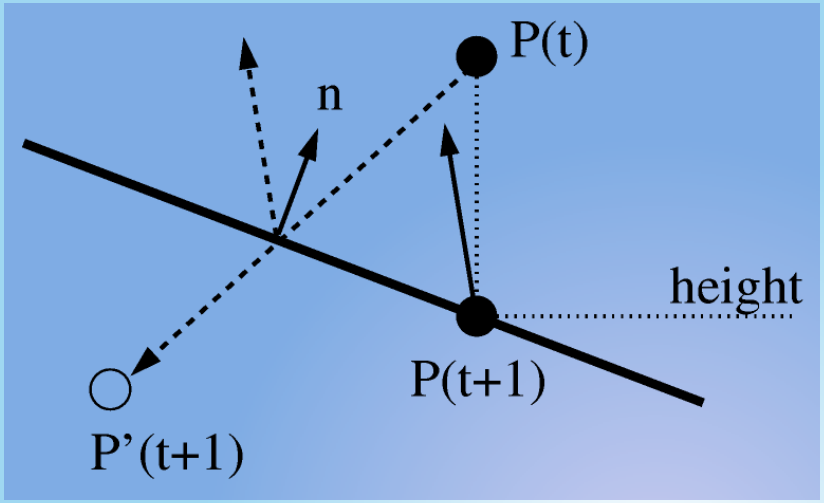
– Performance: full sort

n	*sorts/sec*	*mega items/sec*	*mega frag/sec*	
128^2	175.0	2.8	130	ATI Radeon 9800Pro
256^2	43.6	2.8	171	
512^2	9.3	2.4	186	
1024^2	1.94	2.0	193	
128^2	238.0	3.9	177	ATI Radeon X800 XT
256^2	110.0	7.2	433	
512^2	24.4	6.4	489	
1024^2	4.85	5.1	483	

Particle – Scene Collision

Additional buffers for state-full particles

- Store velocity per particle (Euler integration)
- Keep last two positions (Verlet integration)
- Simple: Collision with height-field stored as 2D texture
  - RGB = [x,y,z] surface normal
  - A = [w] height
  - Compute reflection vector
  - Force particle to field height

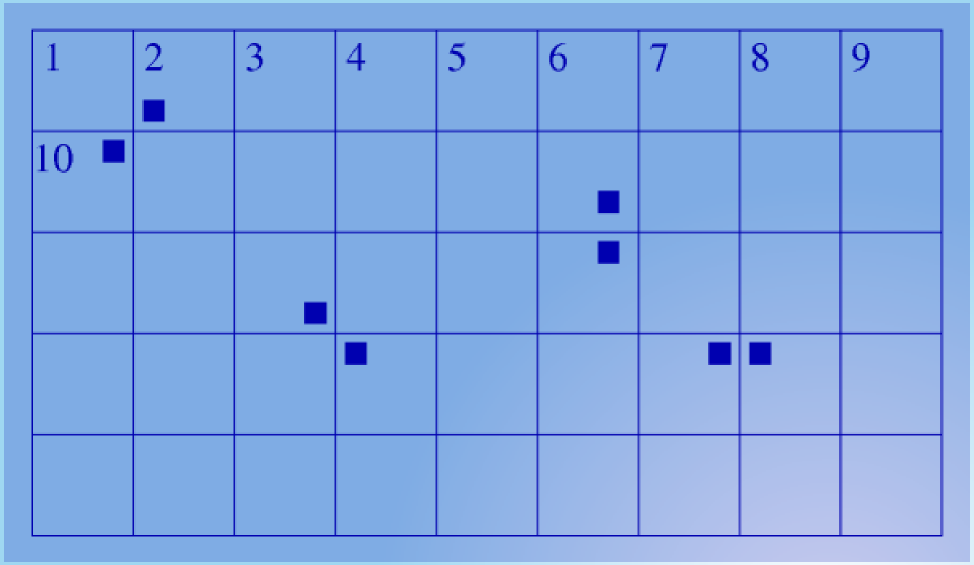


Particle – Particle Collision

Essential for natural behavior

- Full search is $O(n^2)$, not practicable
- Approximate solution by considering only neighbors
- Sort particles into spatial structure
  - Staggered grid misses only few combinations

single grid



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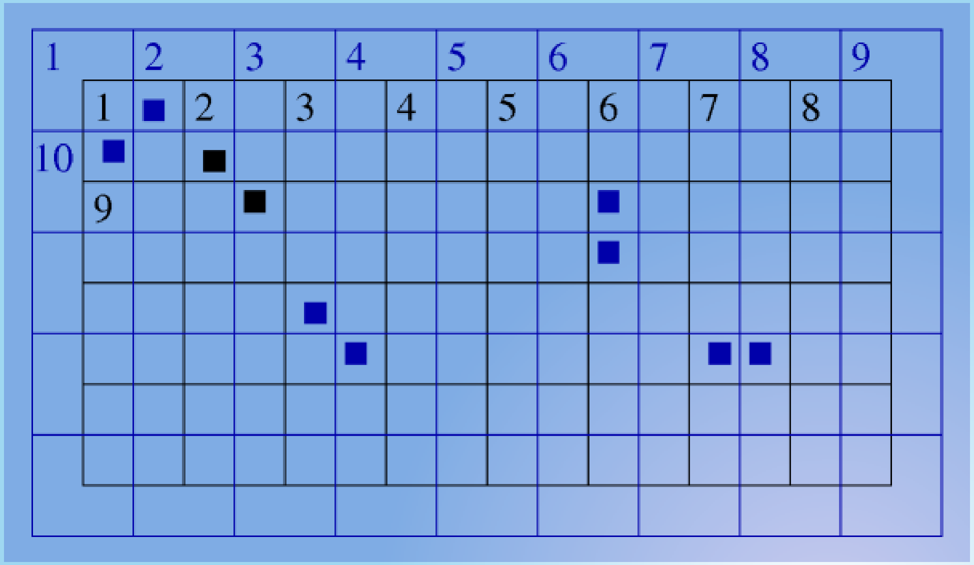
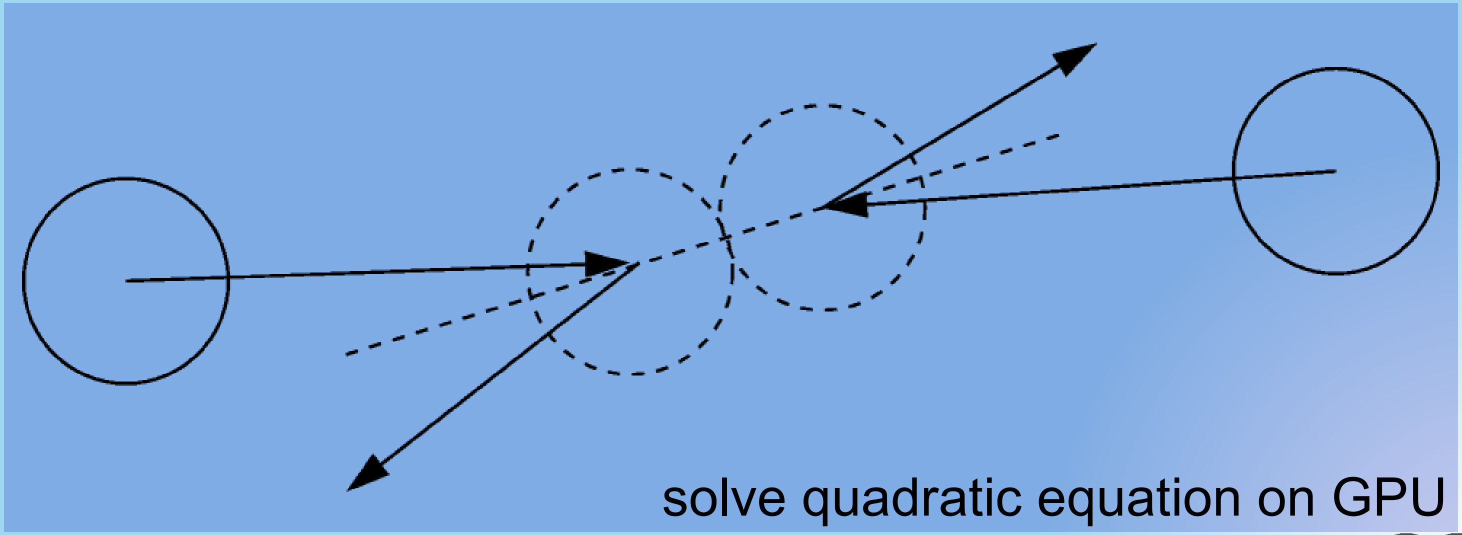
staggered grid



Particle – Particle Collision

- Check m neighbors to the left/right
- Collision resolution with first collider (time sequential)
- Only if velocity is not excessively larger than integration step size



GPU Particle Engine

more cool demos

GPU Particle Engine

Acknowledgements

- ATI Research for providing hardware
- Jens Krüger for insight on shader programming

http://wwwcg.in.tum.de/GPU