

Implementing Wave Particles for Real-time Water Waves with Object Interaction

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Outline



SIGGRAPH2007

- **Introduction to Wave Particles**
- Wave Particle Iteration
- Rendering the Height Field
- Wave Generation
- Forces on Objects
- The Overall System

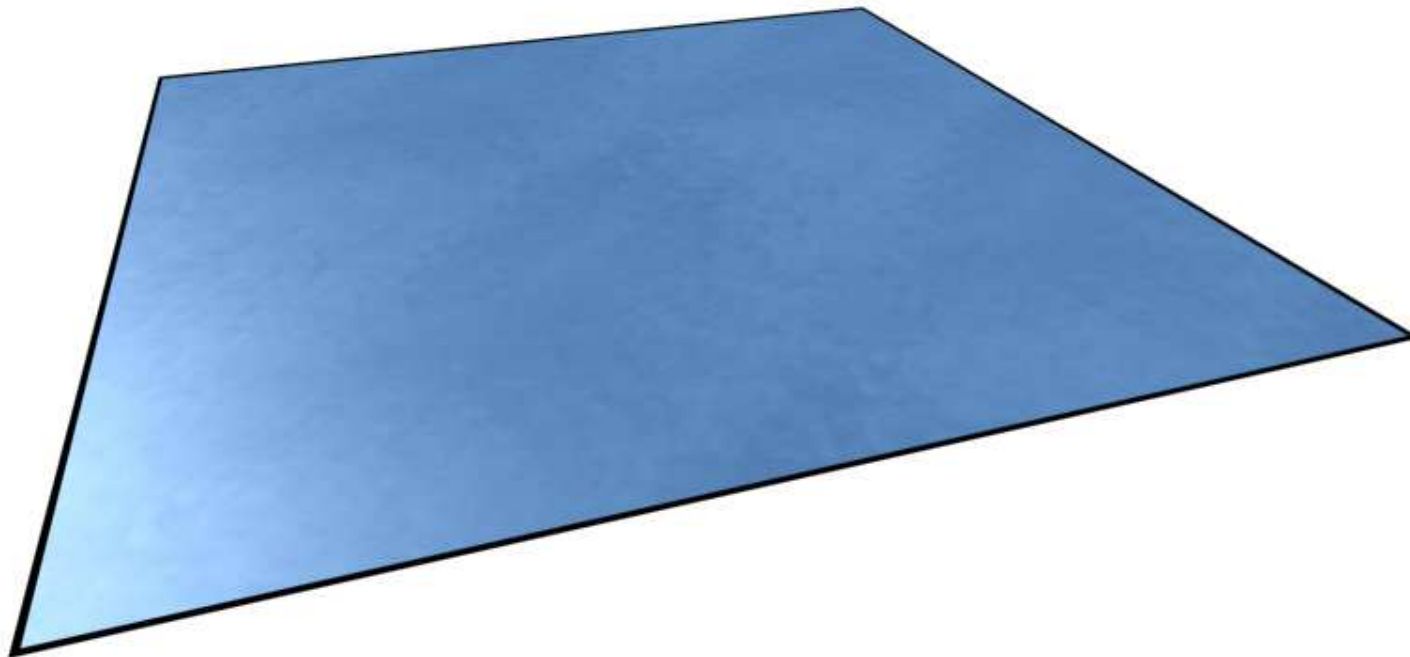


Wave Particles



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- Fluid surface

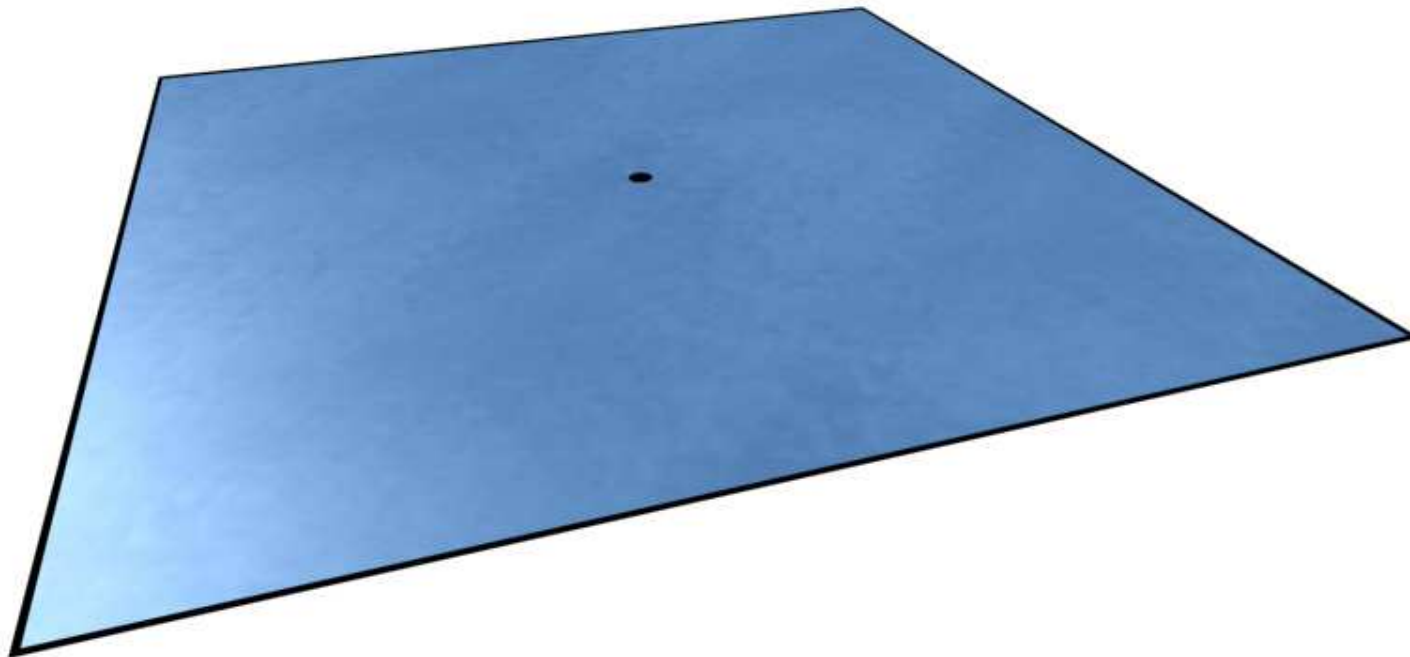


Wave Particles



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- Wave particle

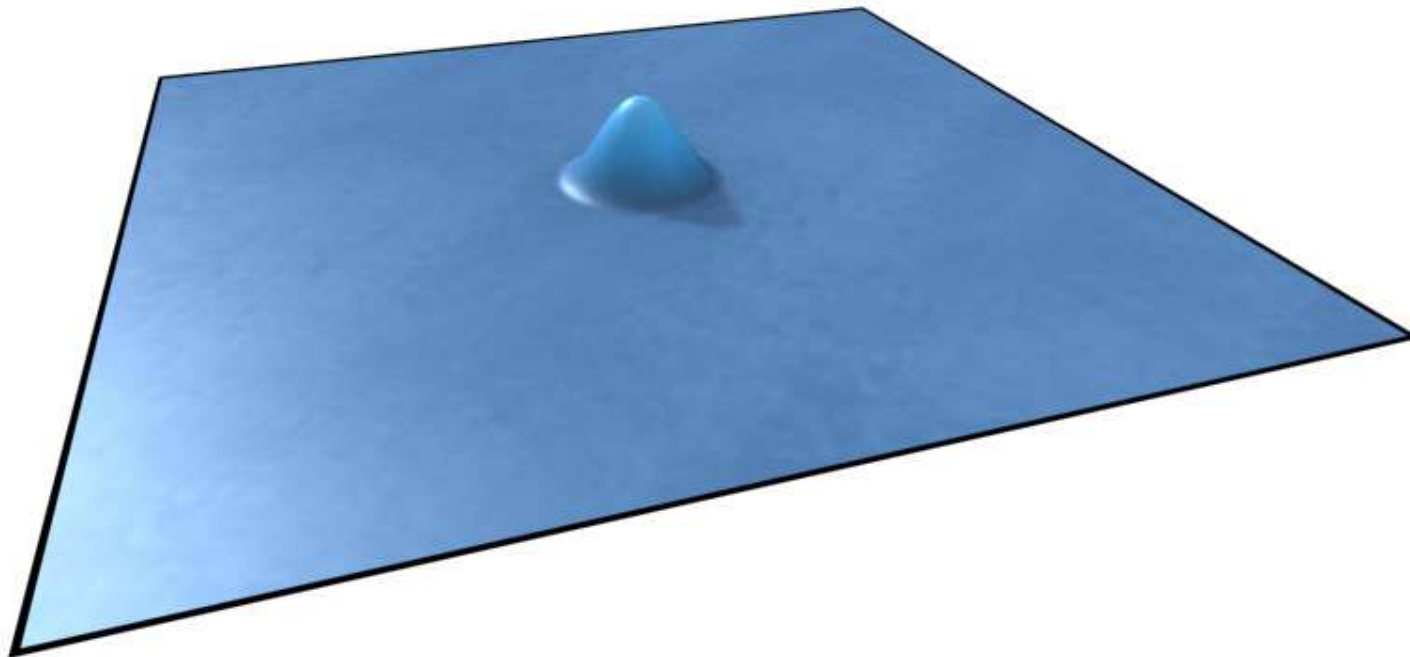


Wave Particles



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- Bump

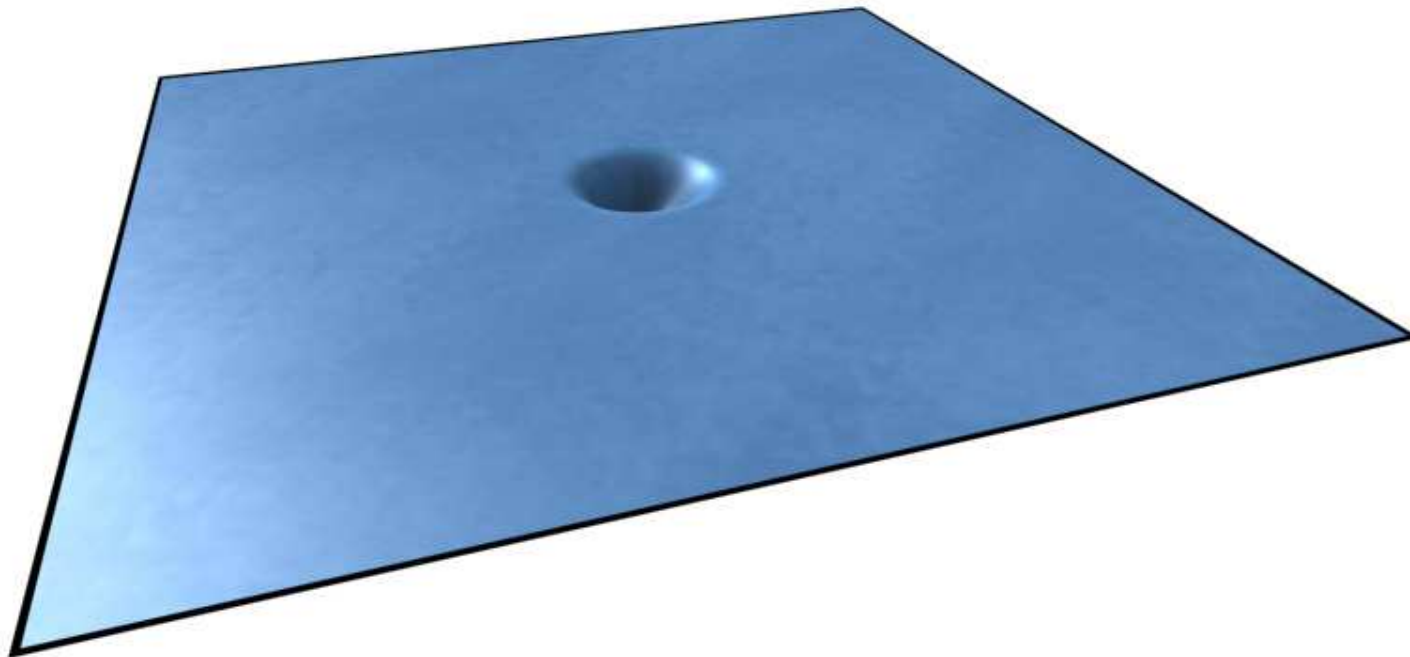


Wave Particles



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- Dent

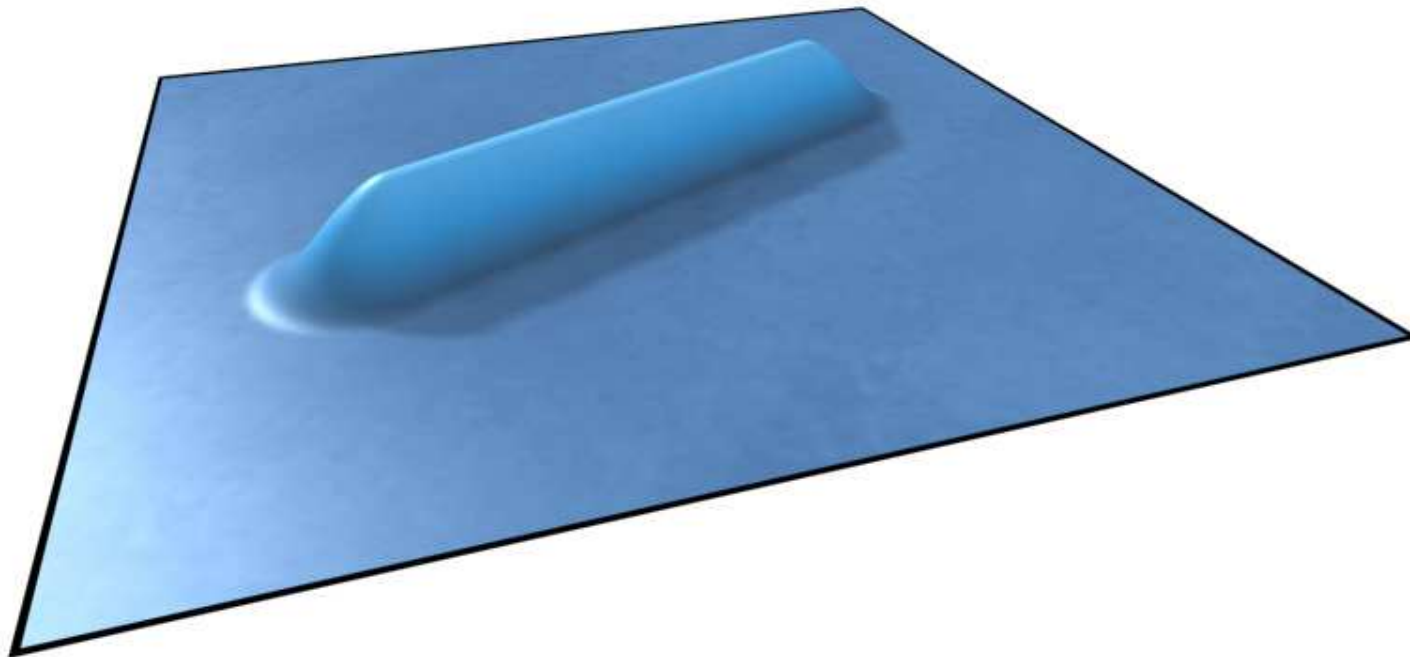


Wave Particles



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- Wavefront

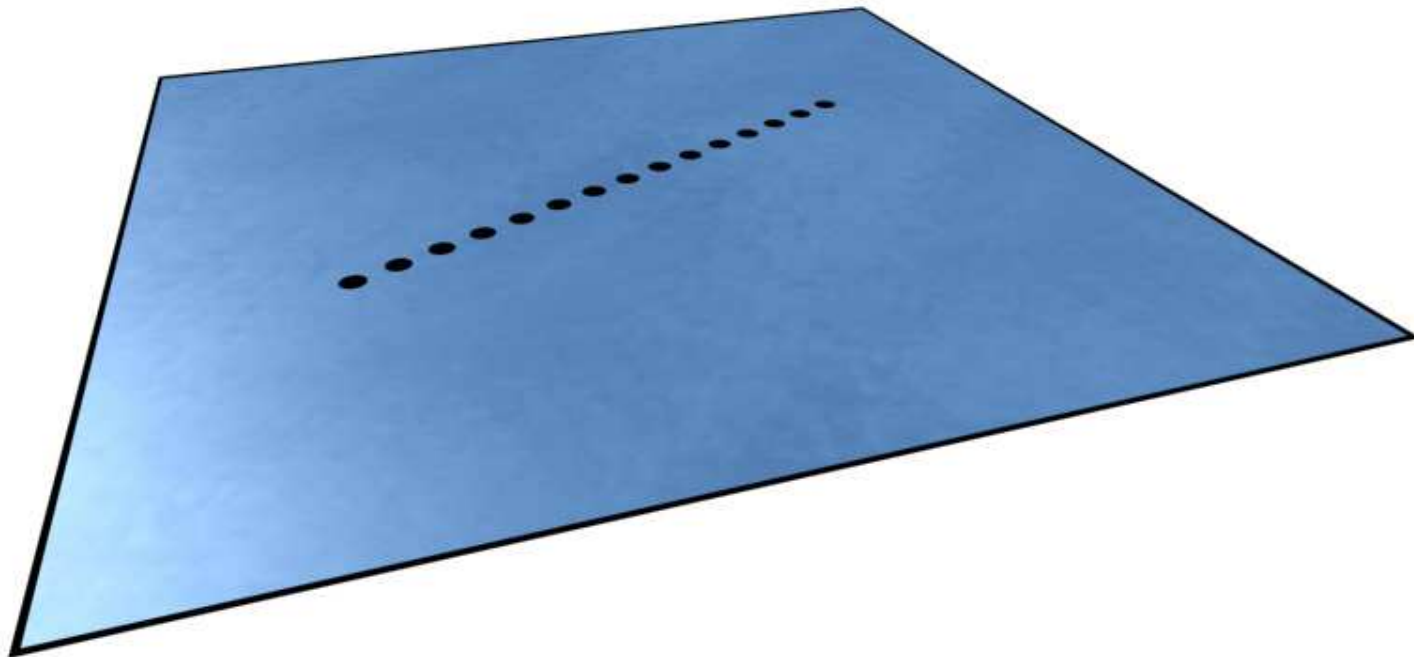


Wave Particles



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- Wave particles

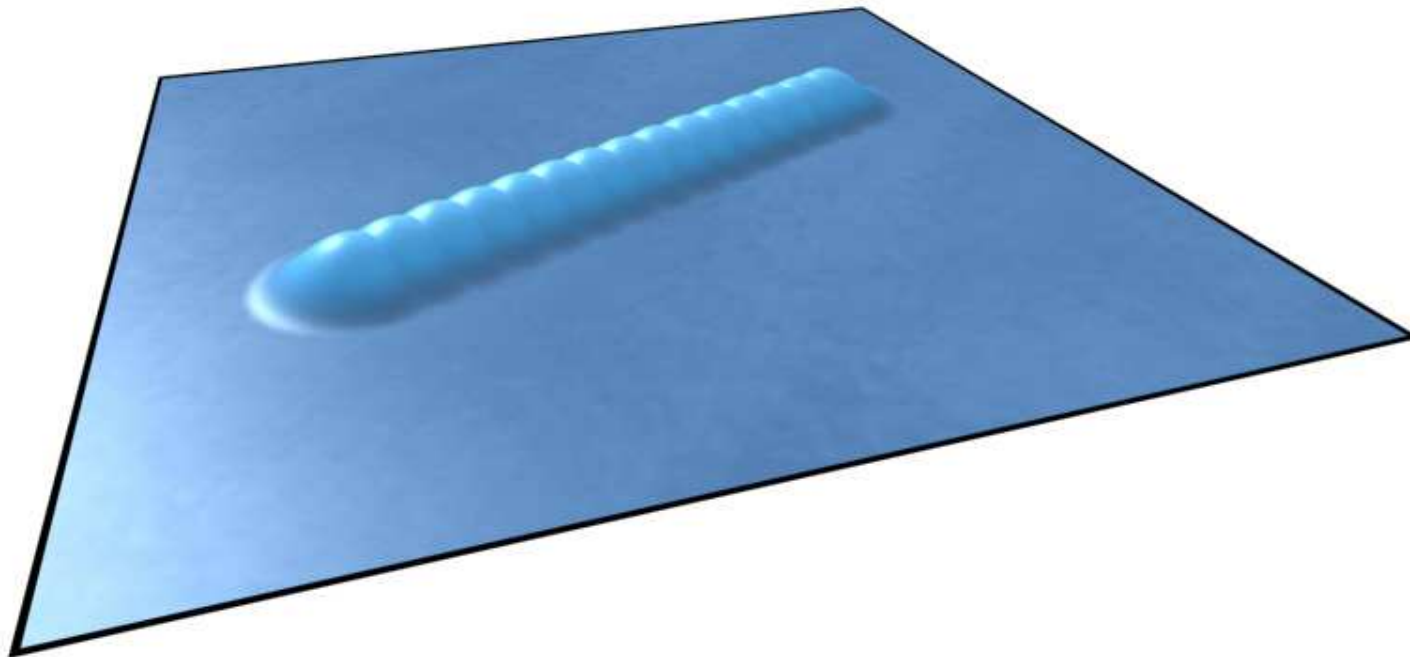


Wave Particles



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- Bumps

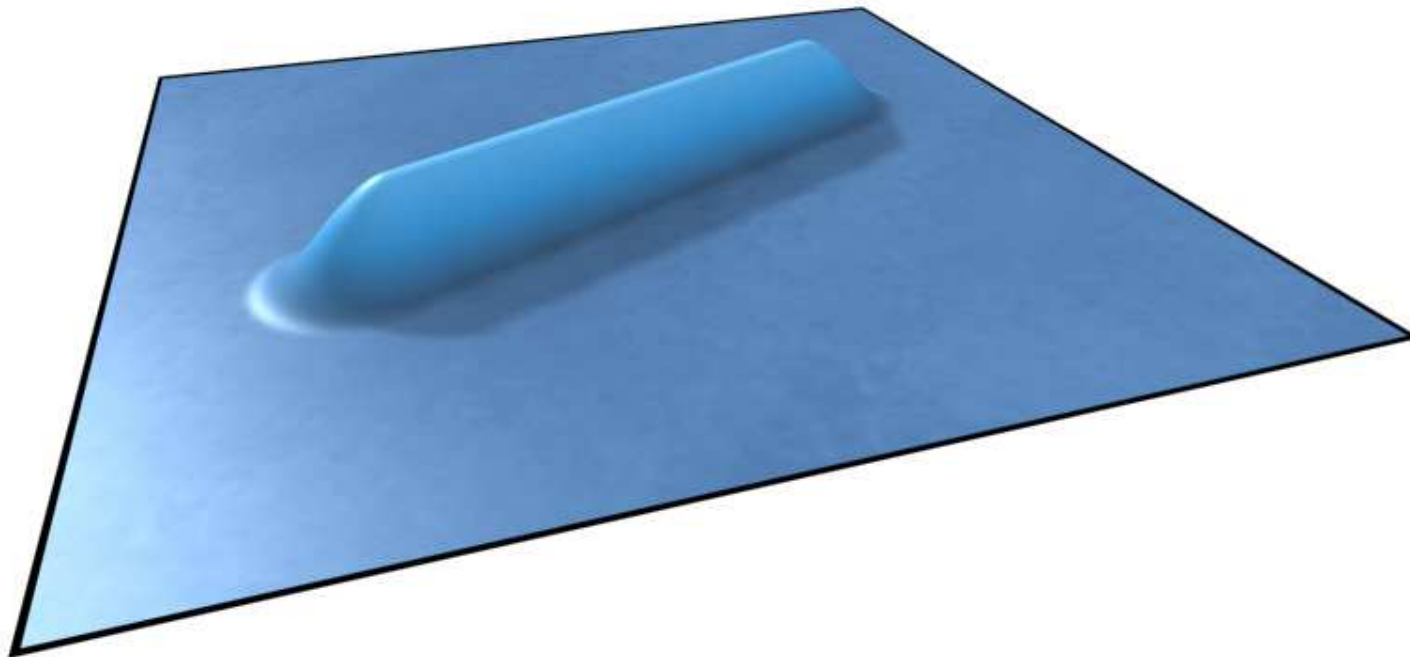


Wave Particles



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- Wavefront

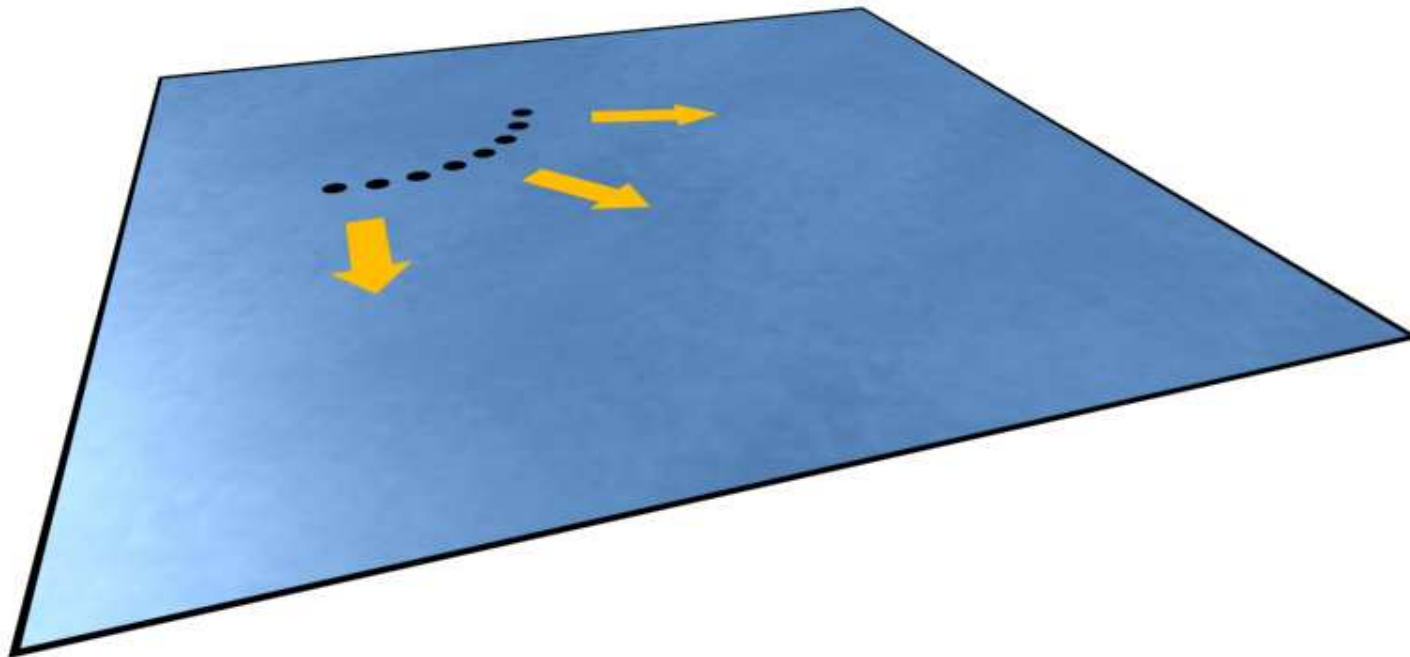


Wave Particles



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- Expanding wavefront

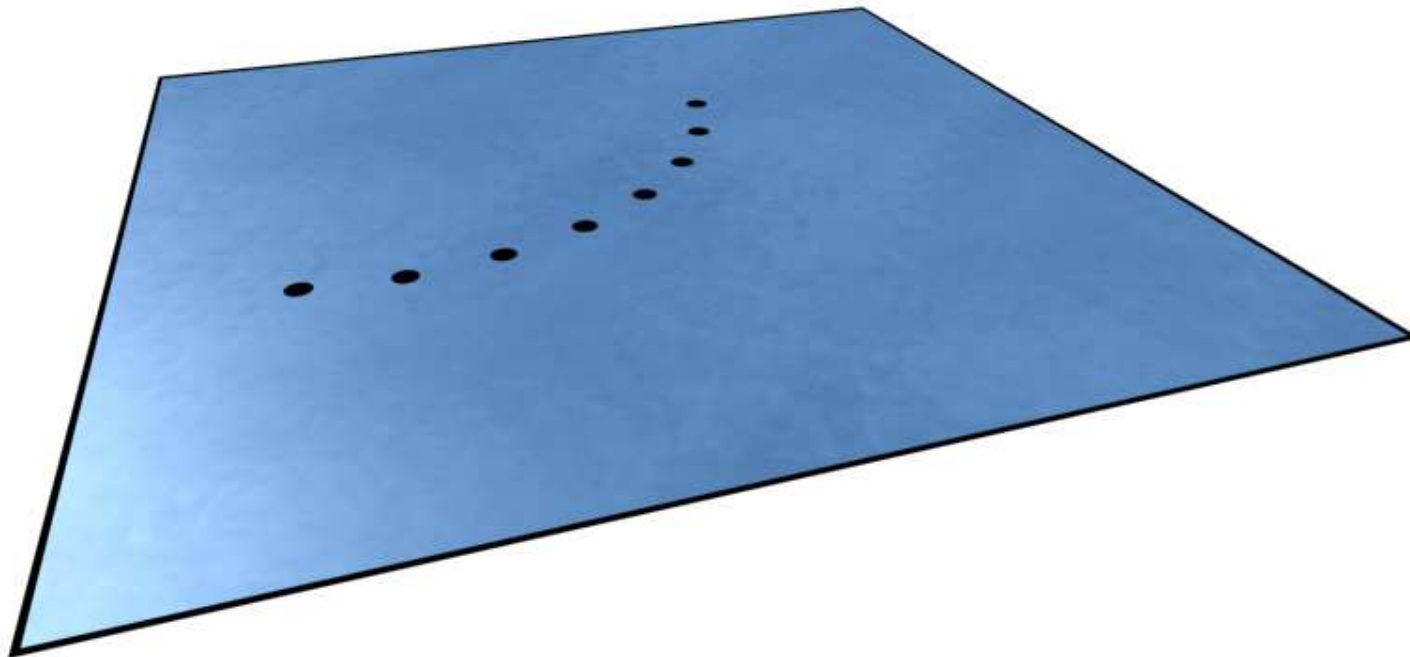


Wave Particles



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- Subdivision

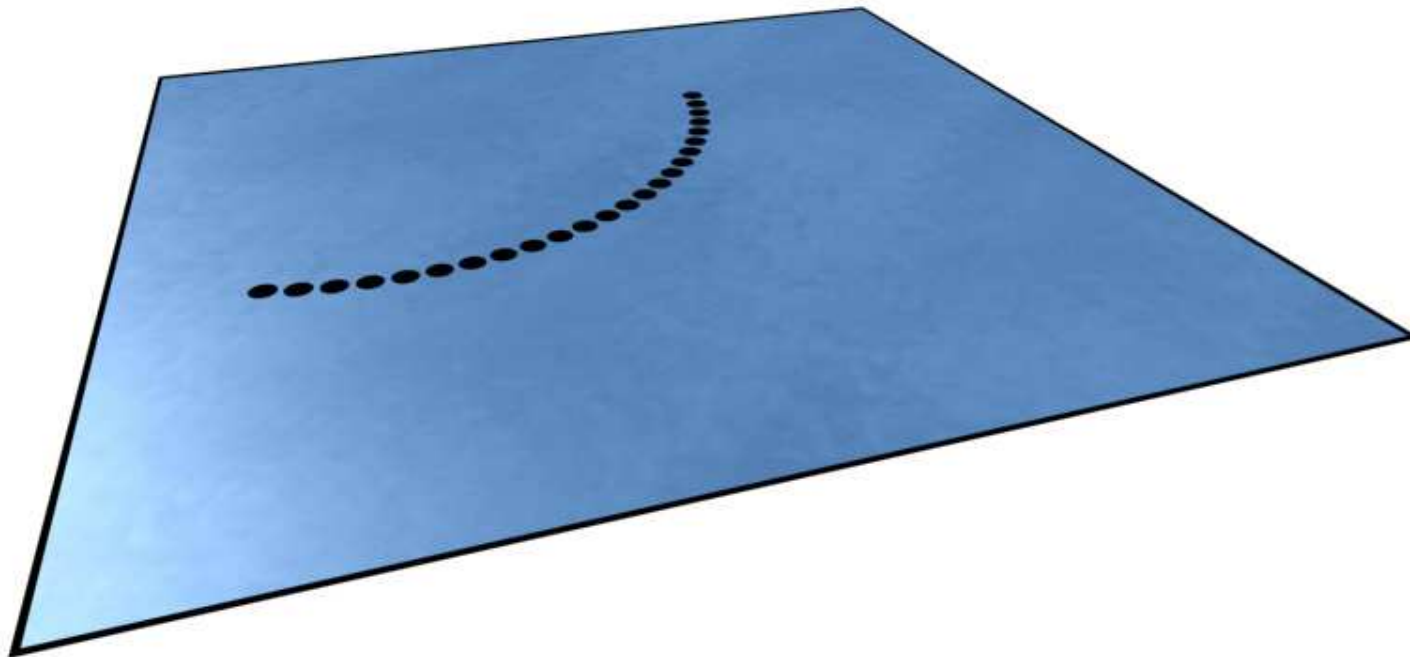


Wave Particles



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- Subdivision

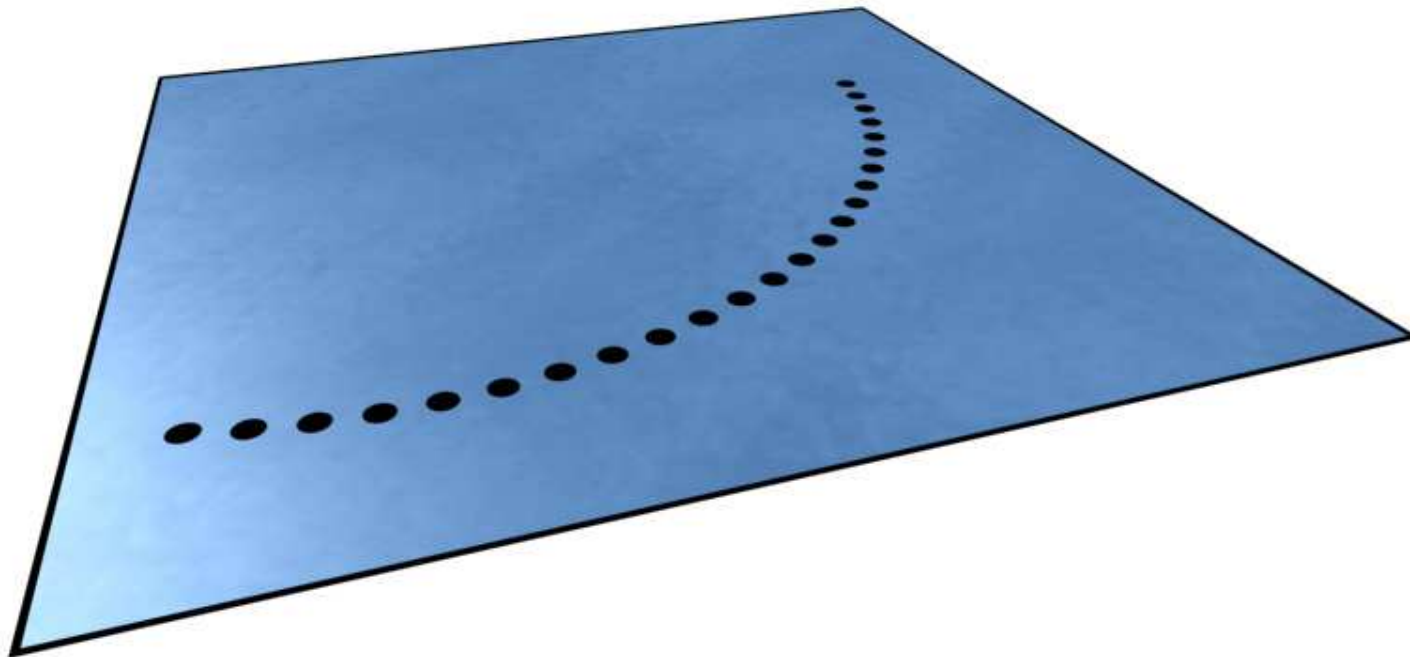


Wave Particles



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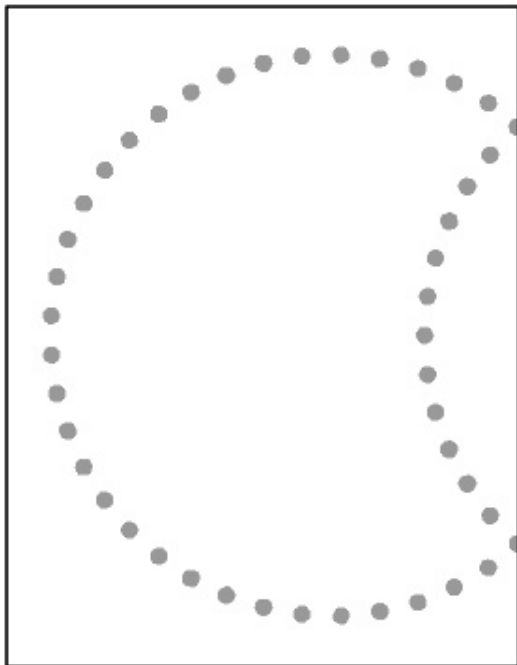
- Subdivision



Boundaries

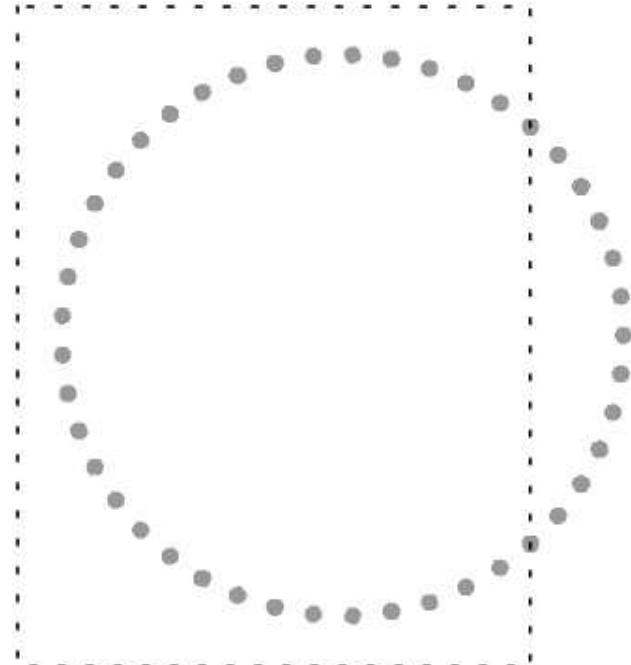
□ Boundary collision

- Waves reflect
- Wave particles bounce back



□ No boundaries

- Infinite ocean!
- Wave particles continue on



Wave Particles



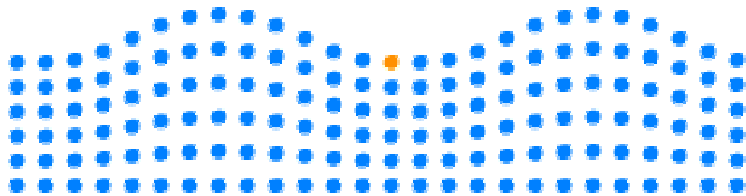
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- Wave particles
 - Collectively represent wavefronts
 - DO NOT interact
 - Move independently
 - Reflect independently
 - Subdivide independently
 - into smaller wave particles
 - Die when too small

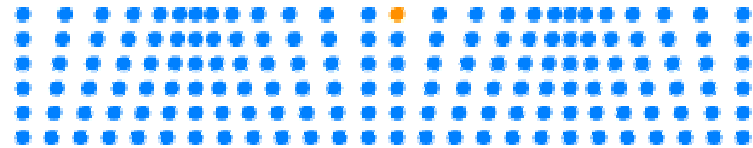
Water Waves



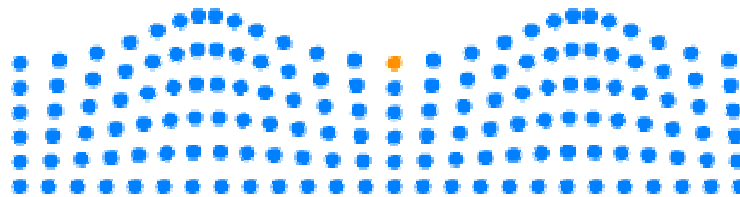
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transverse waves



longitudinal waves



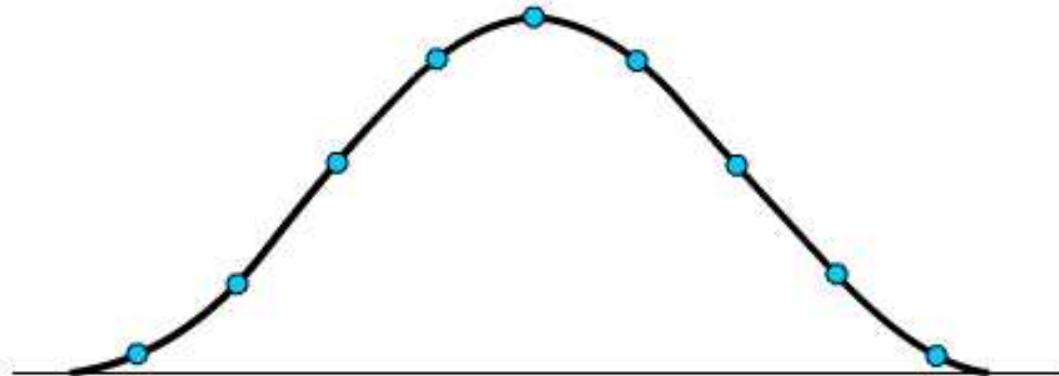
water waves

Wave Particles



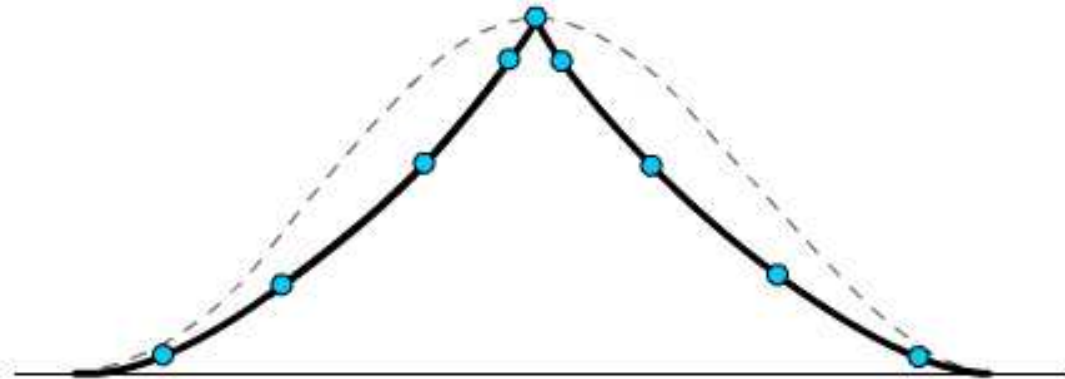
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- Vertical deviation
 - cosine based



Wave Particles

- Horizontal deviation
 - sine based



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SIGGRAPH2007

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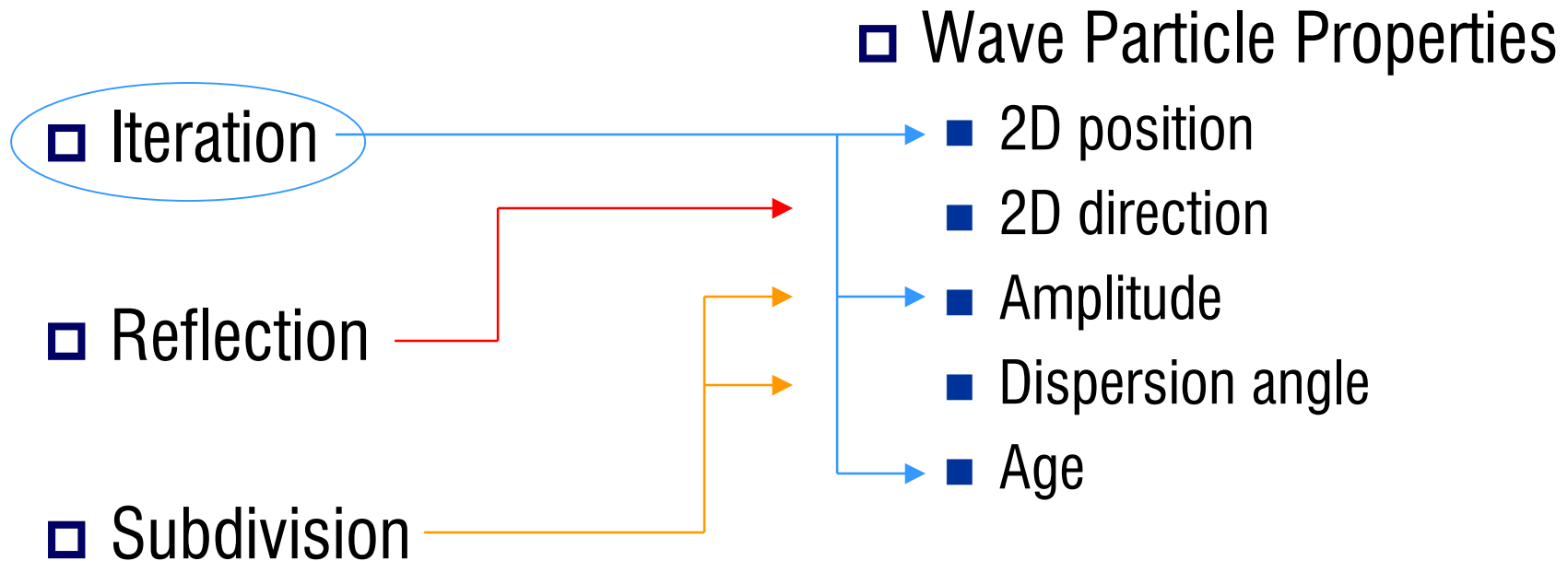


Wave Particle Iteration



- Wave Particle Properties
 - 2D position
 - 2D direction (not velocity)
 - Amplitude
 - Dispersion angle
 - Age

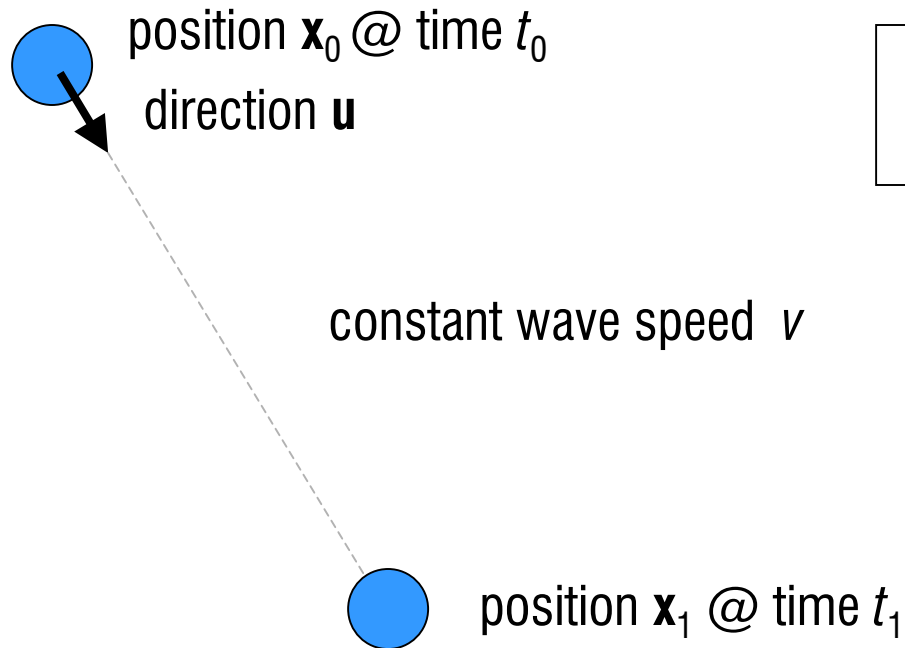
Wave Particle Iteration



Iteration: numerical integration on CPU / GPU / **Neither!**

Wave Particle Iteration

□ Neither ?



$$\mathbf{x}_1 = \mathbf{x}_0 + \mathbf{u} (t_1 - t_0) v$$

Wave Particle Iteration

□ Wave Particle Properties

- ~~2D position~~ 2D birth position
- 2D direction
- Amplitude
- Dispersion angle
- ~~Age~~ Birth time

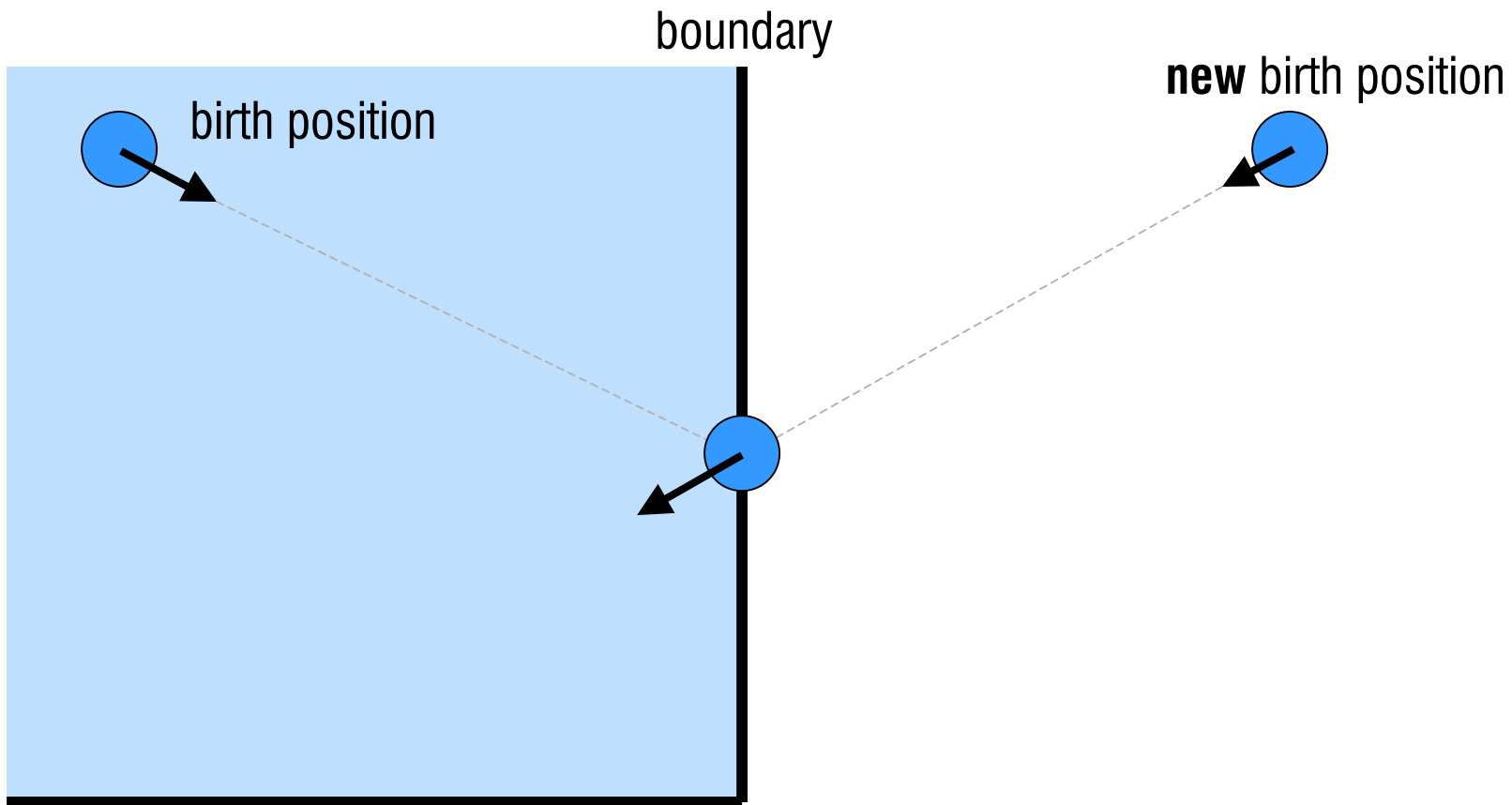
~~□ Iteration~~

□ Reflection

□ Subdivision

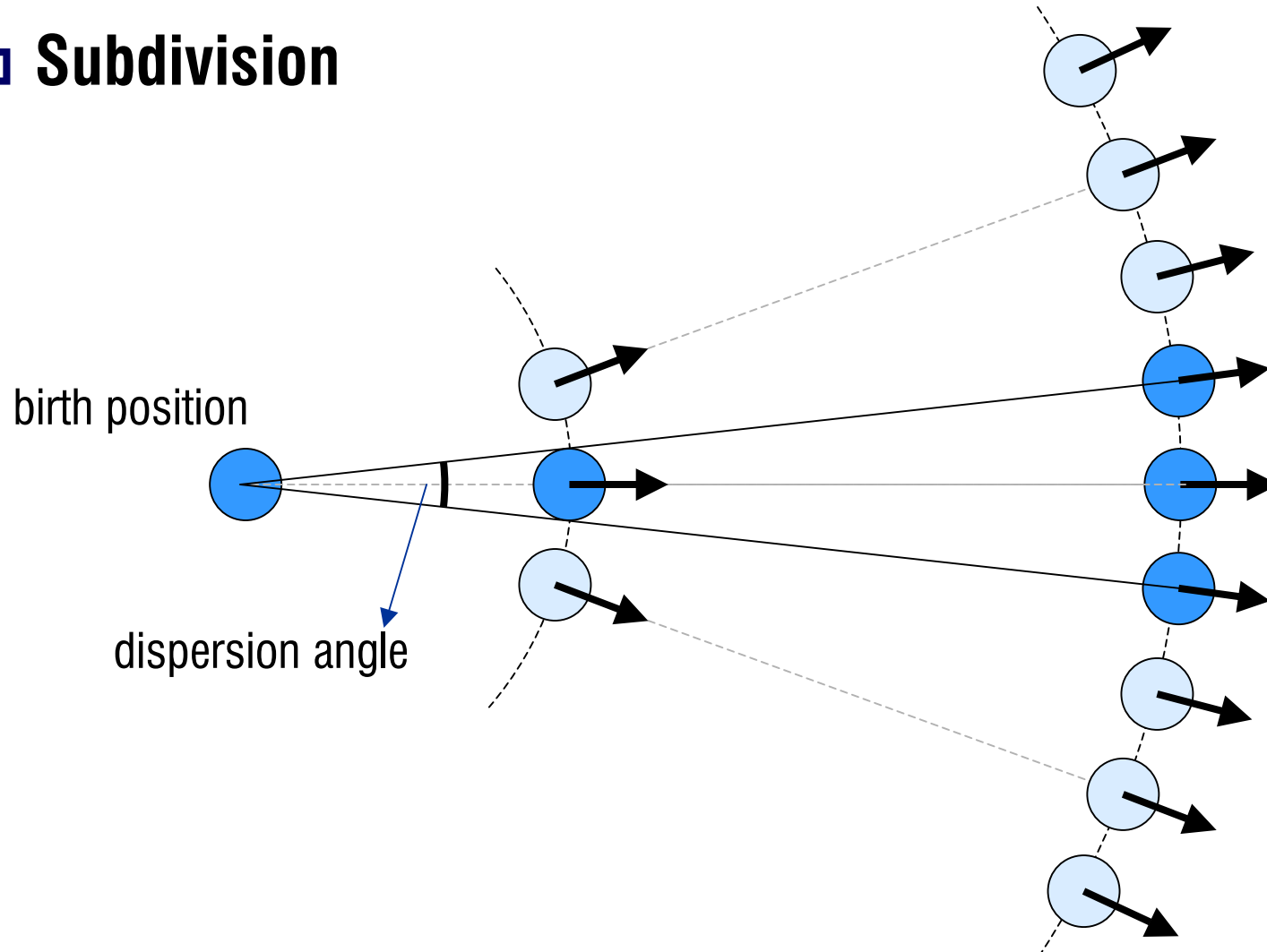
Wave Particle Iteration

□ Reflection



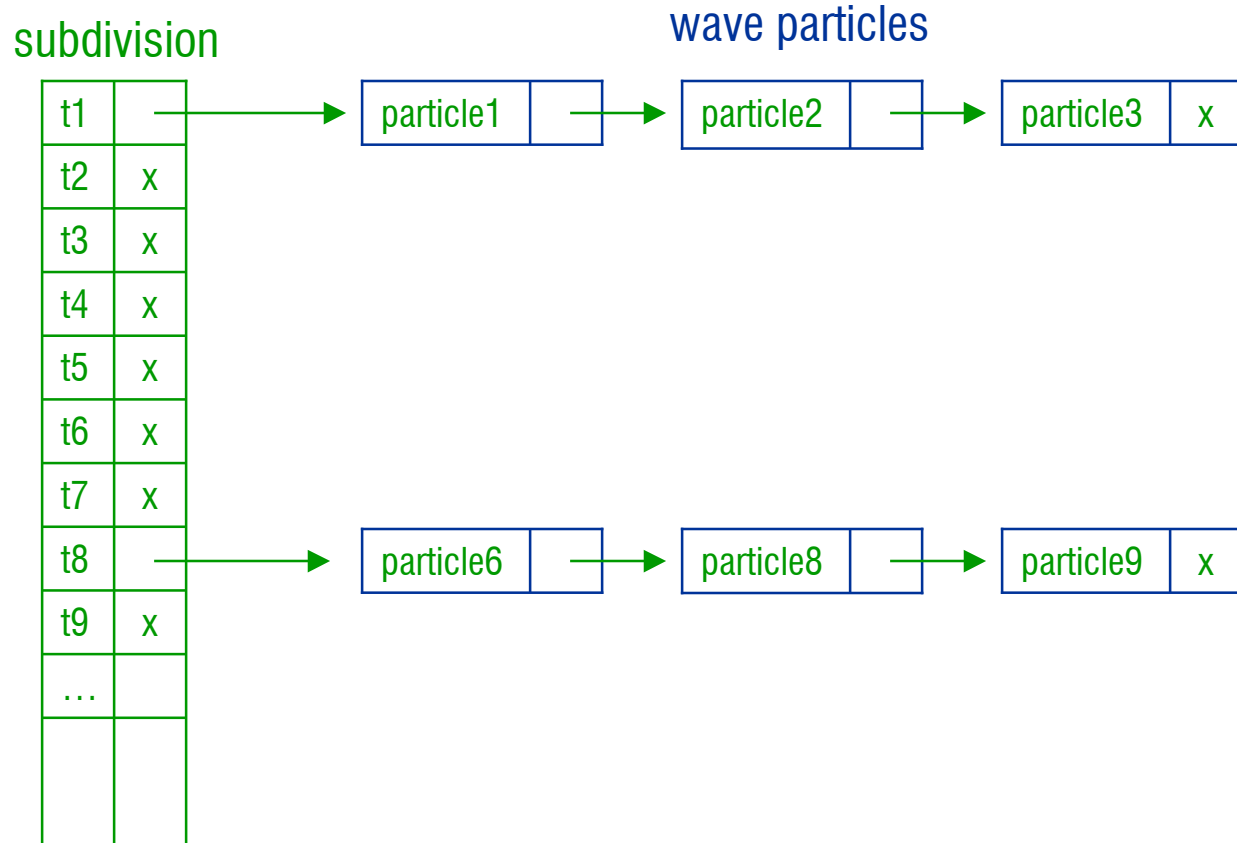
Wave Particle Iteration

□ Subdivision



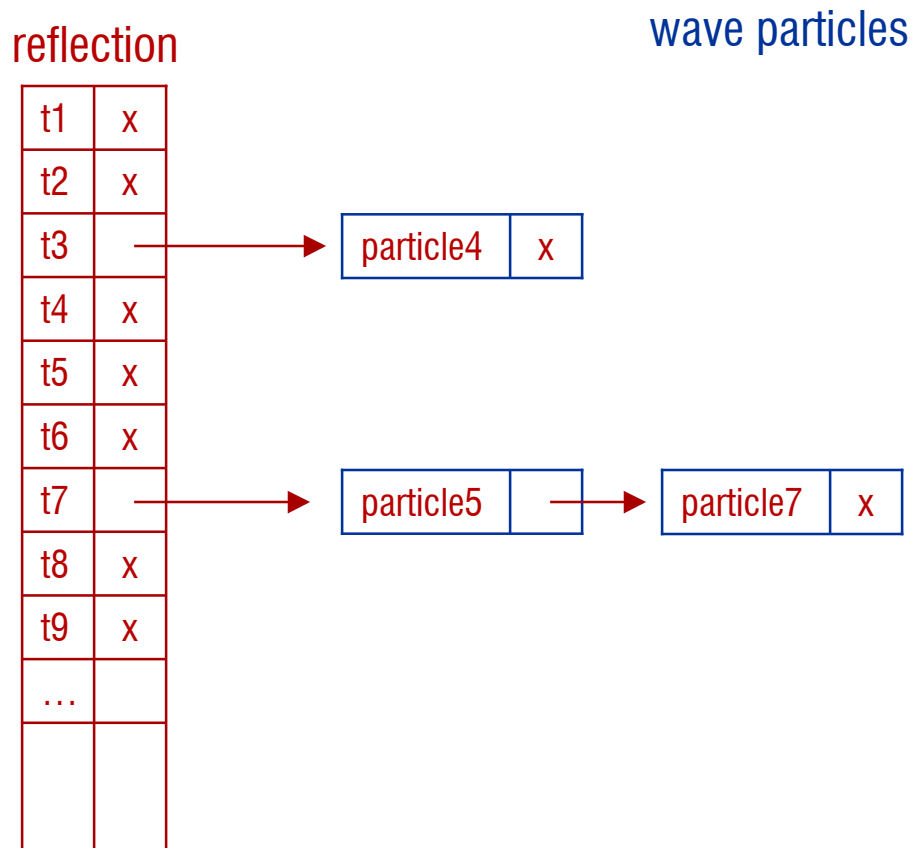
Wave Particle Iteration

□ Time table of events



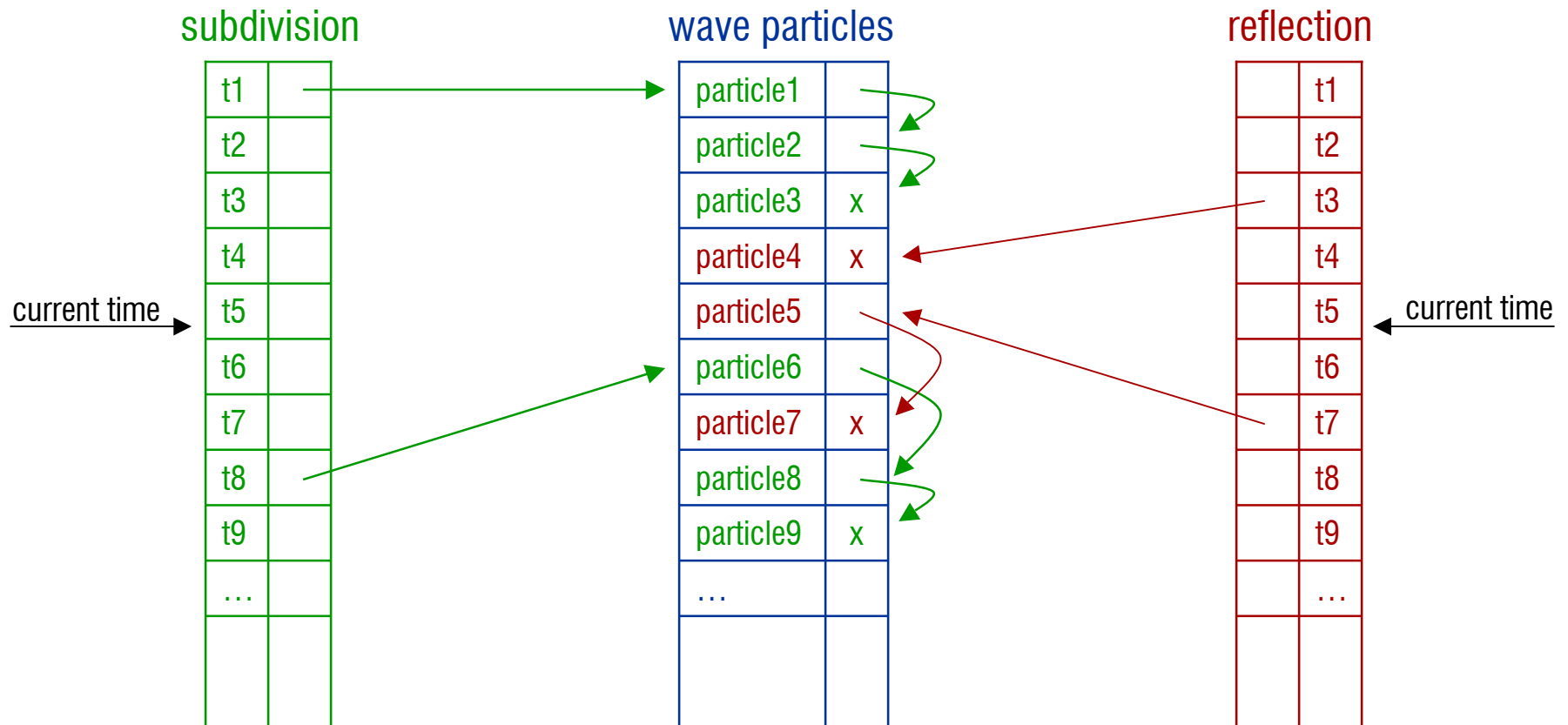
Wave Particle Iteration

□ Time table of events



Wave Particle Iteration

□ Time table of events



Wave Particle Iteration

- When creating
 - Find subdivision time
 - Find reflection time
 - If (reflection time < subdivision time)
 - Place in reflection list at the reflection time
 - Else
 - Place in subdivision list at the subdivision time

- After subdivision or reflection
 - Place in the next list

Wave Particle Iteration

- Killing wave particles
 - Right before subdivision
 - Check amplitude
 - If below threshold, KILL
 - otherwise, subdivide

- Damping
 - Optional
 - Keep birth amplitude
 - $\text{amplitude} = \text{amplitude}_{\text{birth}} \exp(\text{damping} (\text{time} - \text{time}_{\text{birth}}))$

Wave Particle Iteration

- Summary
 - No numerical integration
 - Event handling only
 - Visits for subdivision or reflection
 - On CPU
 - Can be on a separate thread
 - Use pre-allocated arrays

Note: Early subdivision is OK

Outline



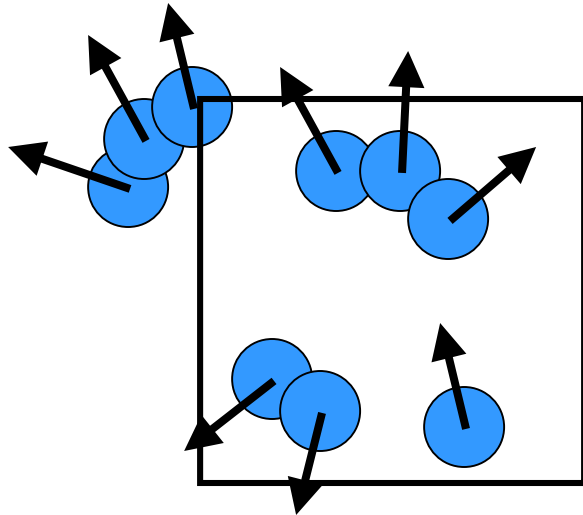
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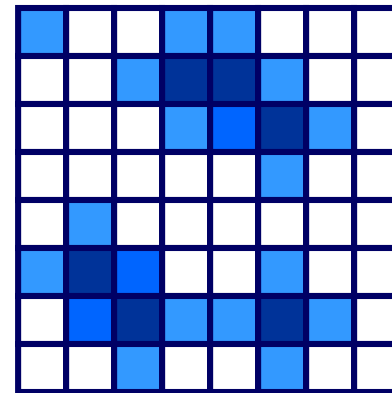
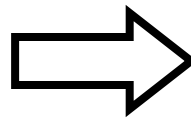


Rendering the Height Field

- Render to height field texture



Wave Particles



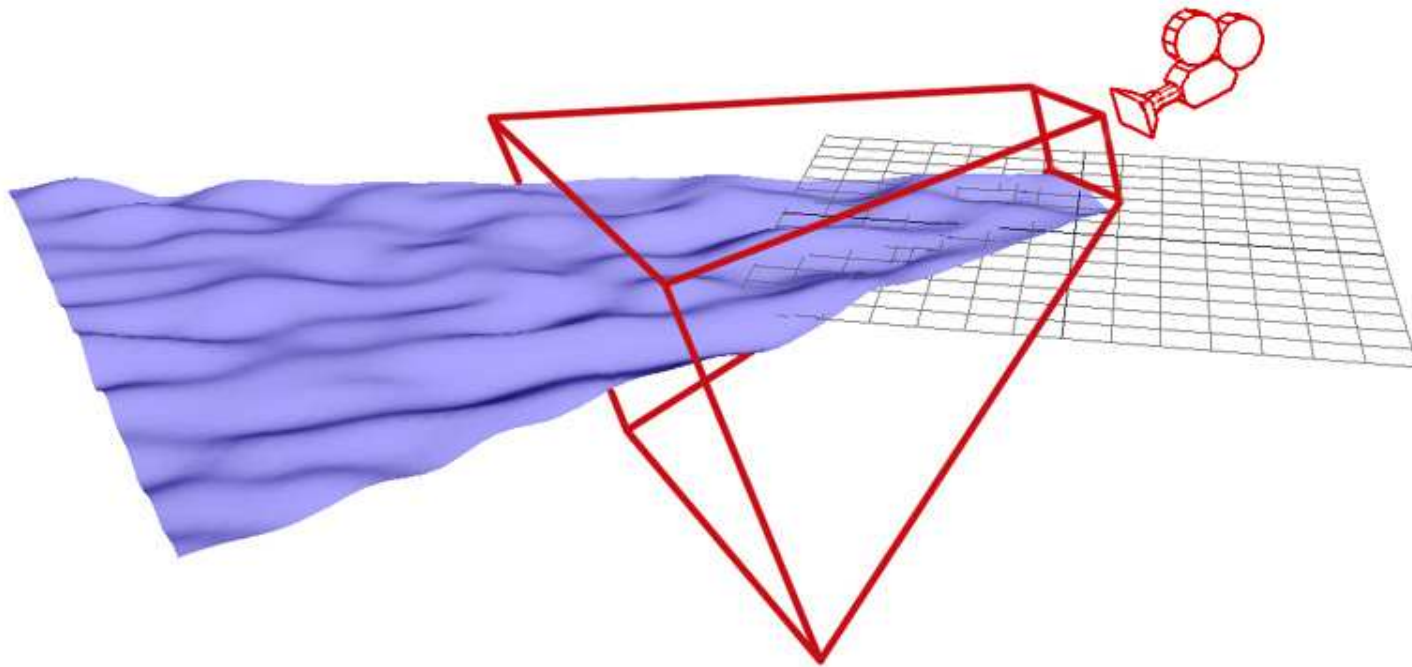
Height Field

Height Field



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- Surface attached to camera



Rendering the Height Field



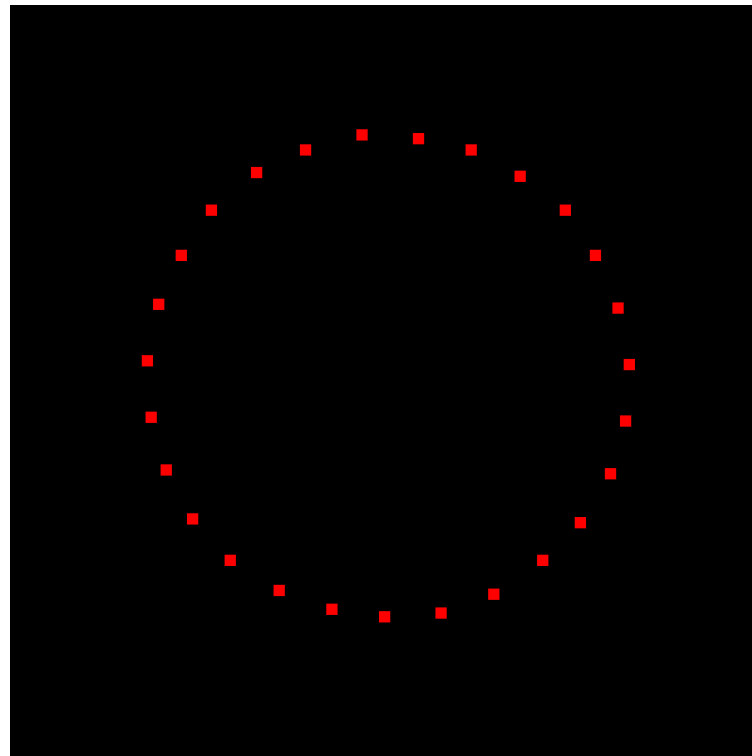
□ Point rendering method

- Approximate 👎
- FAST 👍

Rendering the Height Field



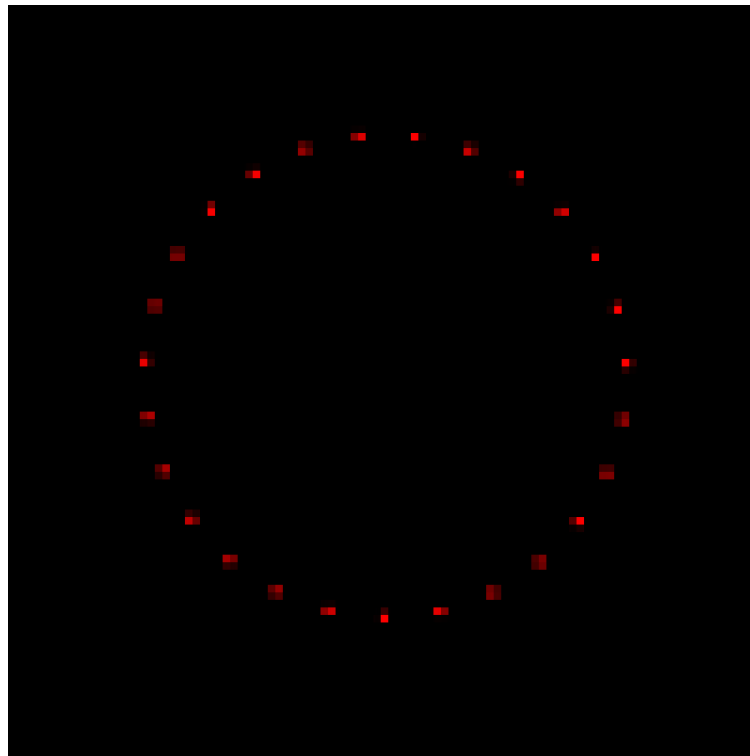
- Draw wave particles as points



Rendering the Height Field



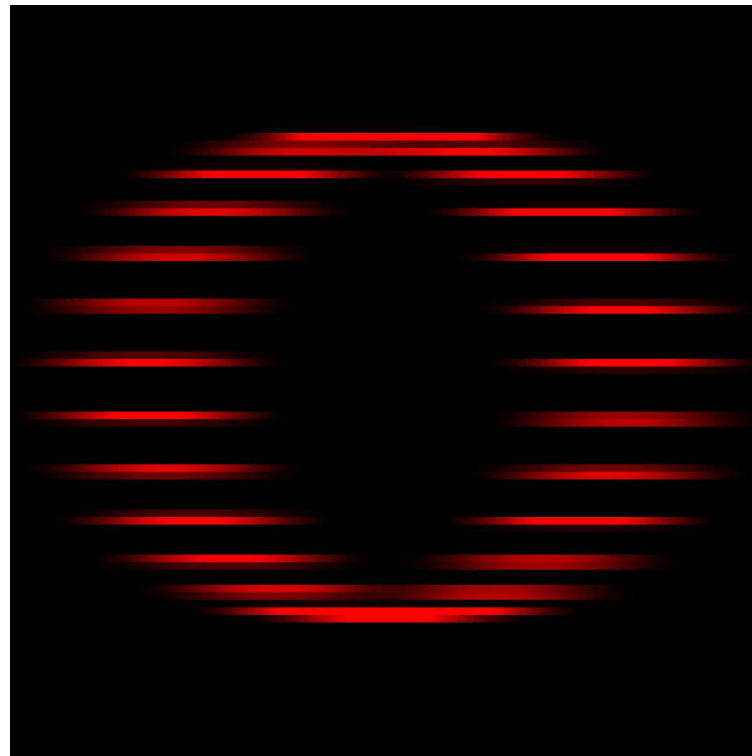
- Antialiased points
(Hardware antialiasing can be SLOW!)



Rendering the Height Field



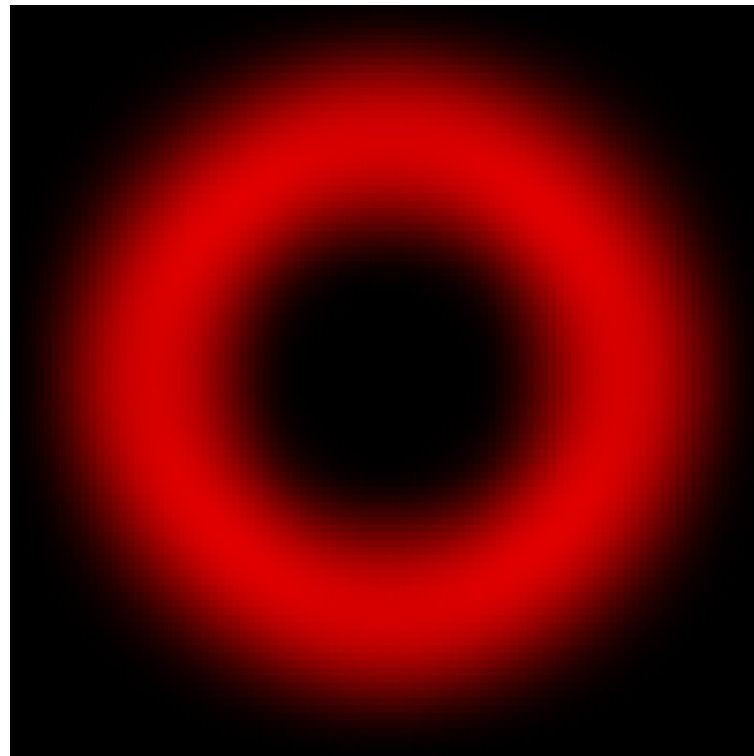
- X-Filter



Rendering the Height Field



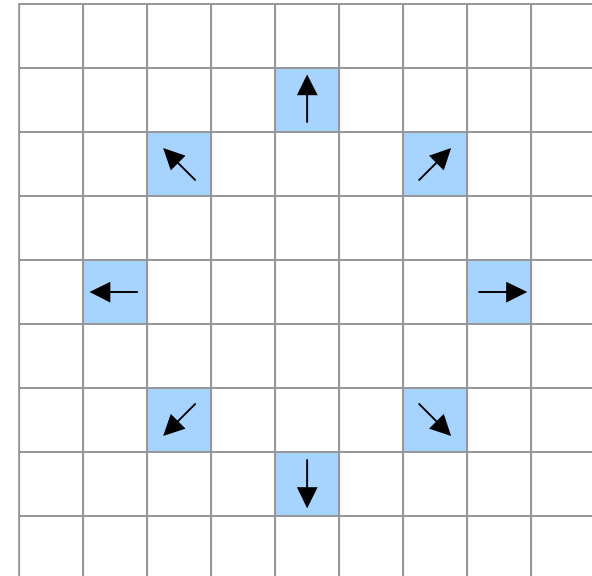
- Y-Filter



Rendering the Height Field



- Horizontal deviation
 - Render points
 - Write direction x amplitude
 - X-Filter
 - Compute x-deviation from x-direction
 - Filter y-direction
 - Y-Filter
 - Compute y-deviation from y-direction
 - Filter x-deviation



Outline



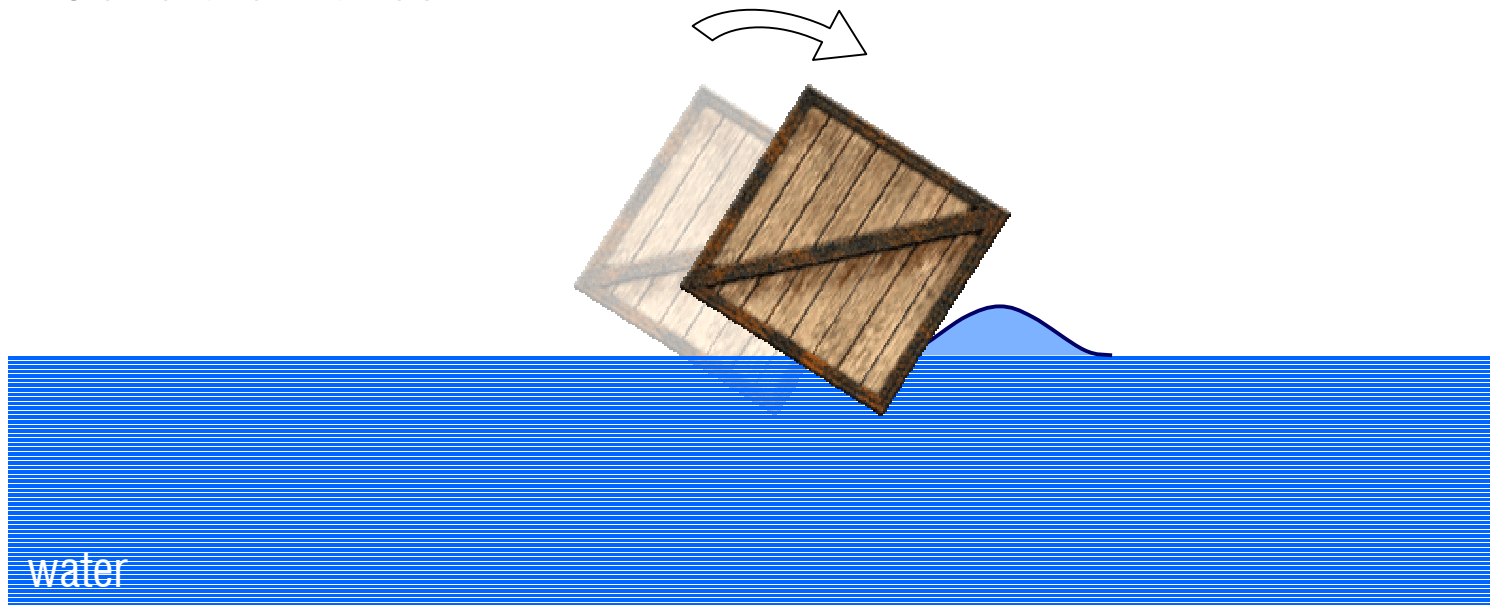
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Wave Generation

- Each time step
 - Compute object motion
 - Generate waves

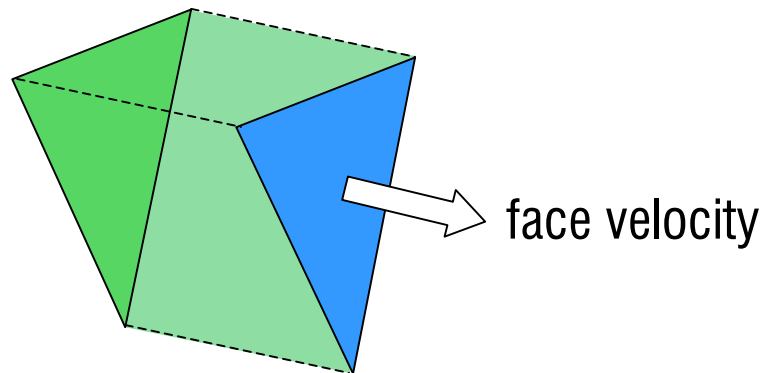


Wave Generation

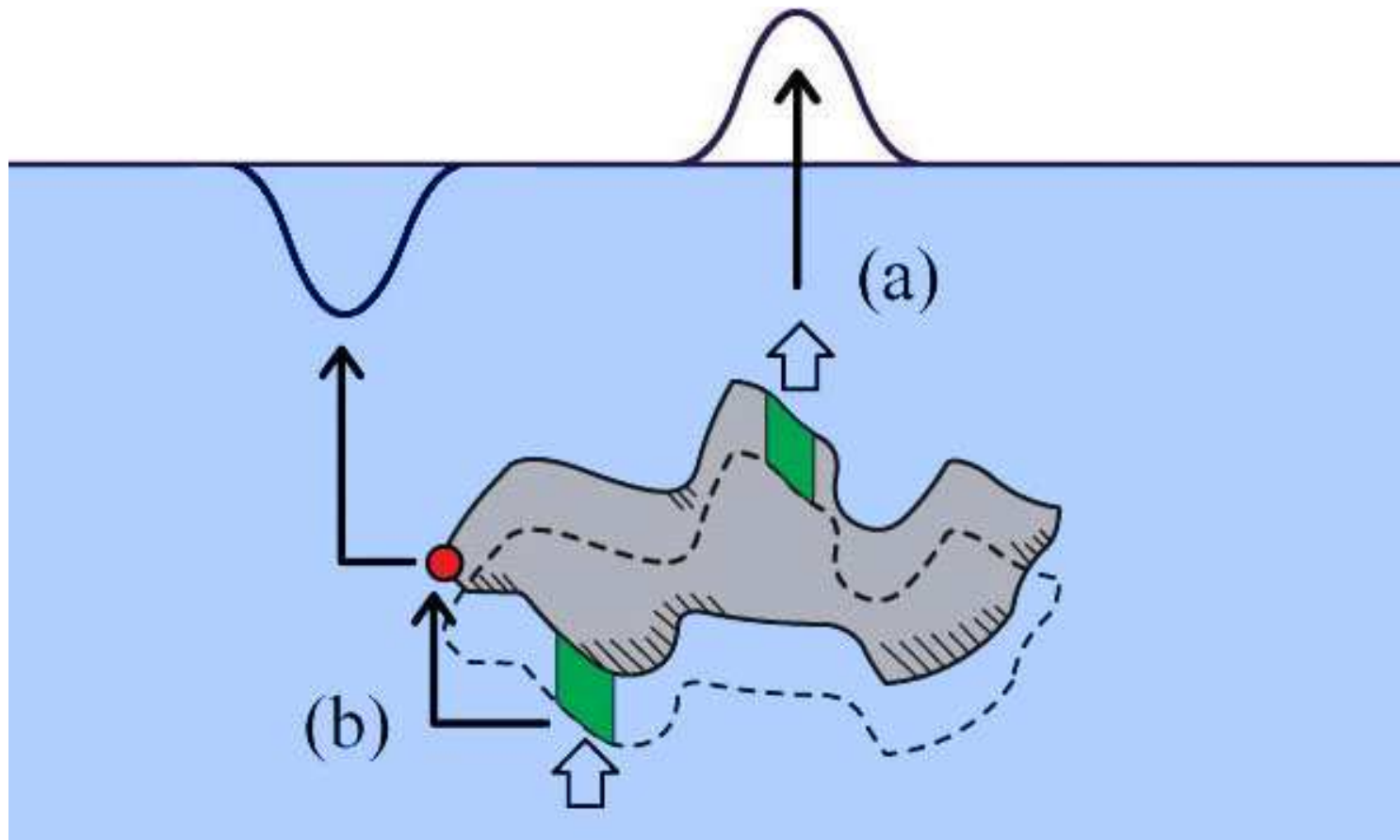


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- For each face
 - Find the velocity of the face
 - Find the area inside the fluid
 - Find the volume of fluid moved by the face (**wave effect**)
 - + Pushed
 - Pulled



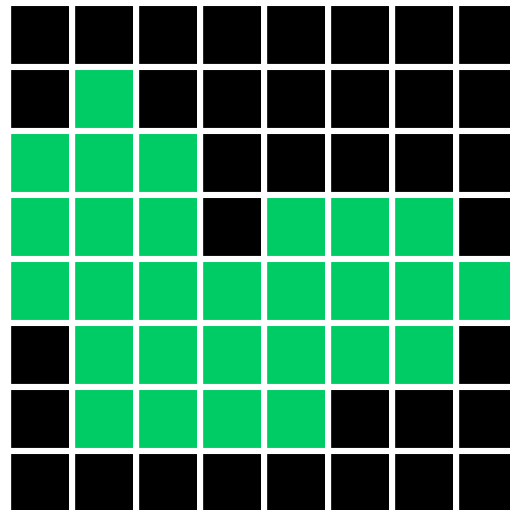
Wave Generation



Wave Generation

- Steps

1. Render low-resolution silhouette (in water)



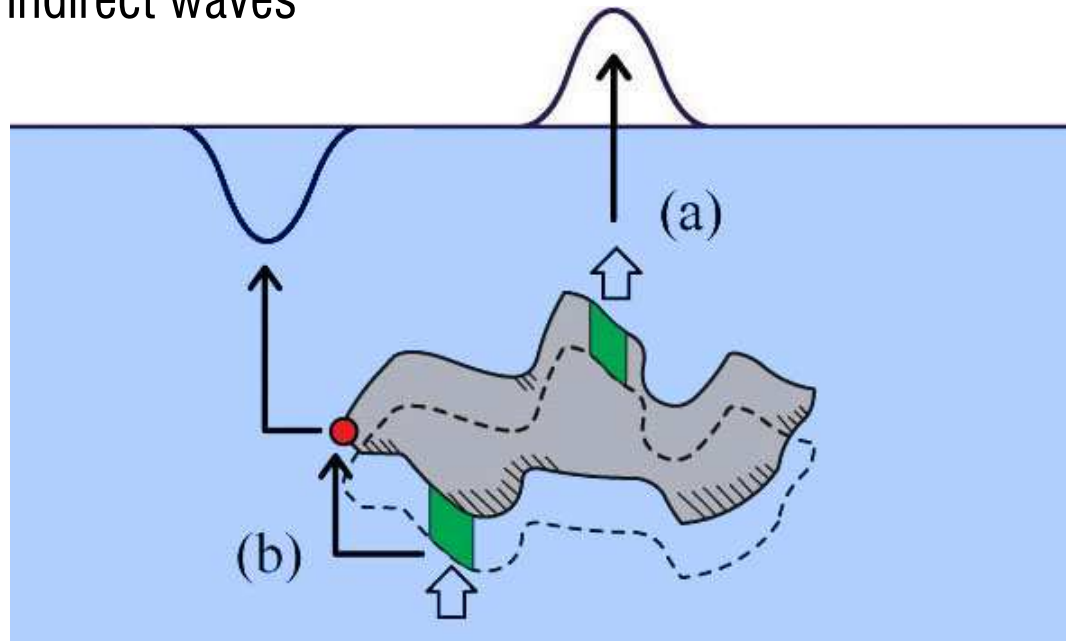
Wave Generation

□ Steps

5. Generate waves

(a) direct waves

(b) indirect waves



Wave Generation



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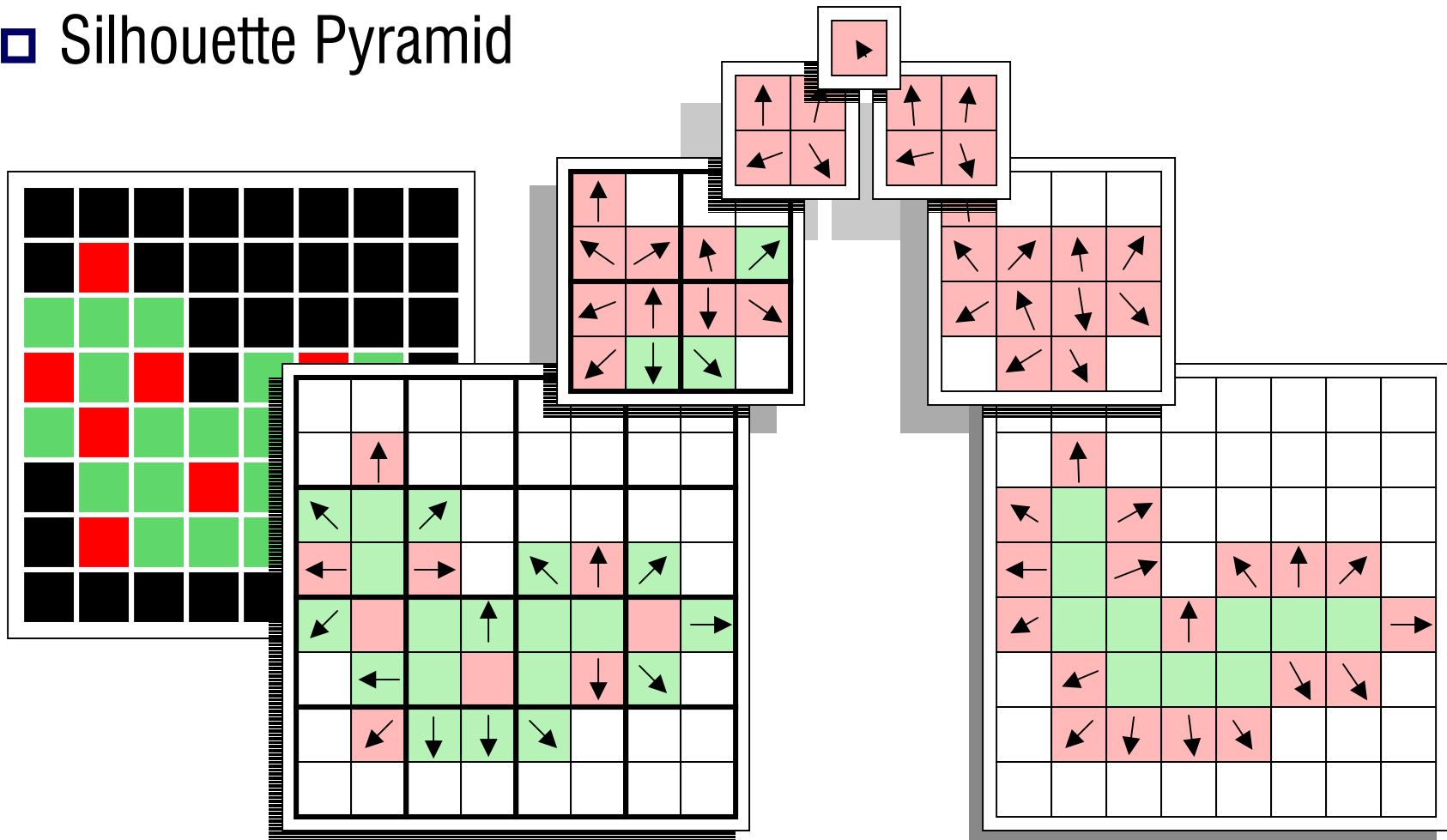
- How to distribute wave effects
- How to find wave direction
- How to find dispersion angle

Wave Generation



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□ Silhouette Pyramid



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Forces on Objects



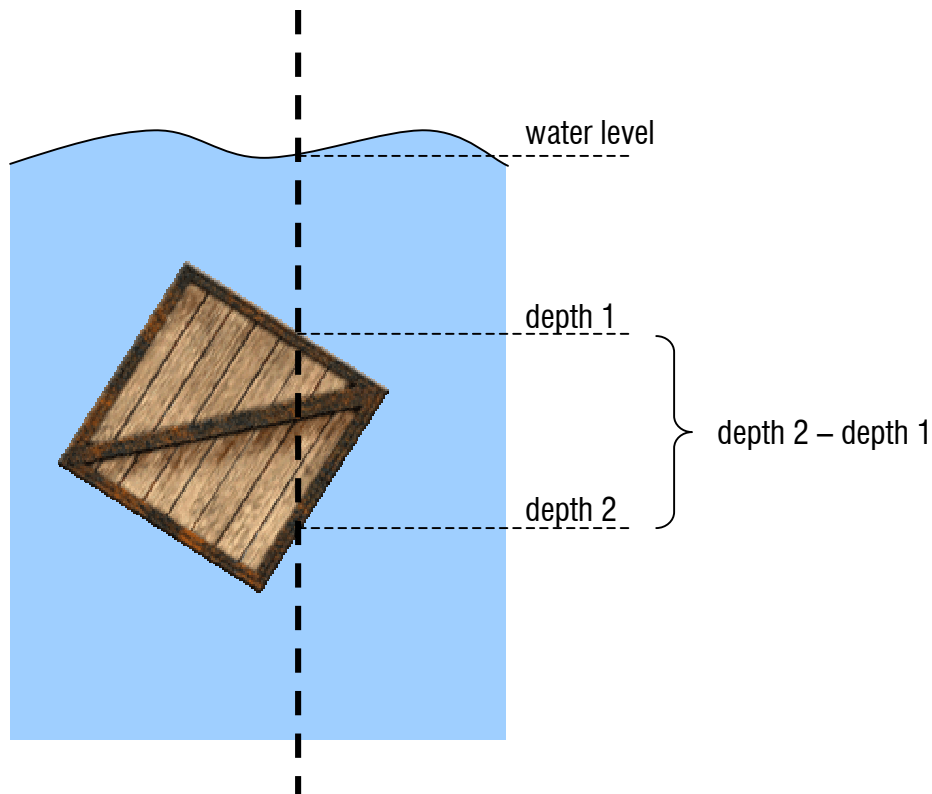
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- Static forces
 - Buoyant force

- Dynamic forces
 - Drag force
 - Lift force

Forces on Objects

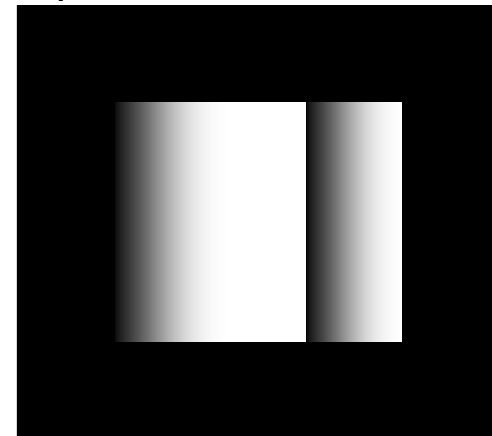
□ Buoyant force



Procedure:

- Render object from top view with additive blending
- For each fragment
 - Write + depth if backface
 - Write - depth if frontface

top view



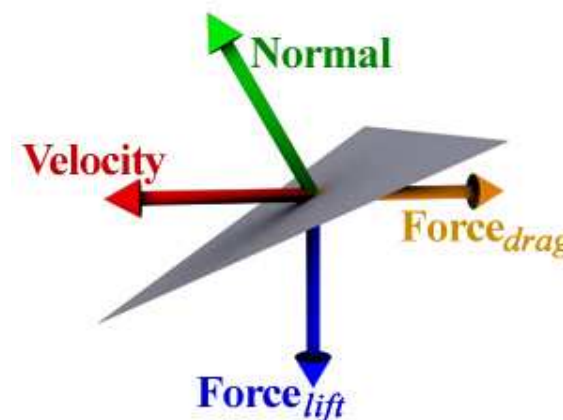


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Forces on Objects

- Drag and lift forces on each face
 - Can be on GPU
 - Render each face as a point
 - Distribute the computation between
 - Vertex shader
 - Fragment shader

- While computing forces
 - Compute wave effect!



Outline

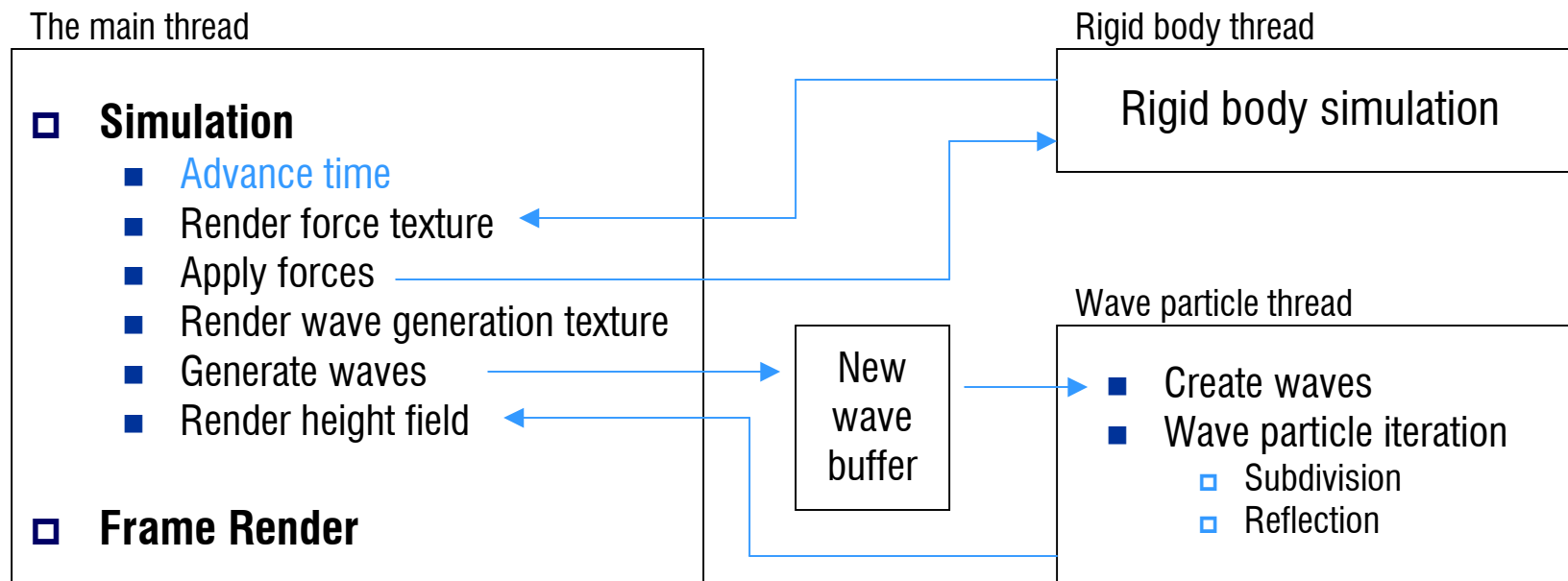


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- **The Overall System**



The Overall System



Thank you!



- Acknowledgements

Can Yuksel, Zeki Melek, Levent Yilmaz, Kuang-An Chang,
H. A. K. S. Ariyaratne, Scott Schaefer, Ozan O. Ozener,
NSF grant CCR-0220047 and ITR-0326194

- Wave particles web-page:

<http://www.cemyuksel.com/research/waveparticles/>

- “Wave Particles” paper presentation

- Fluids paper session, Thursday ~11:20 am