A Practical Simulation of Dispersed Bubble Flow

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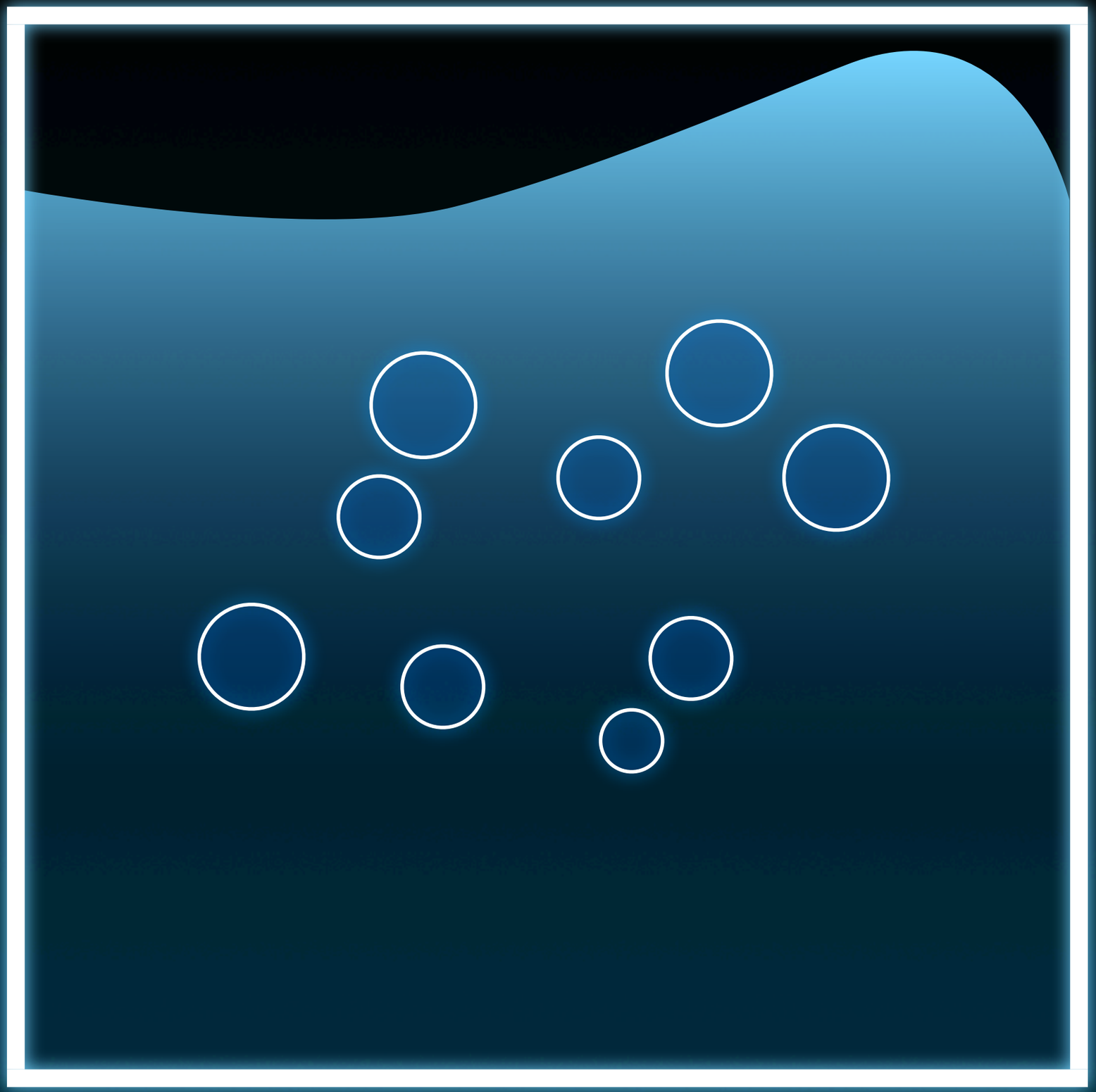
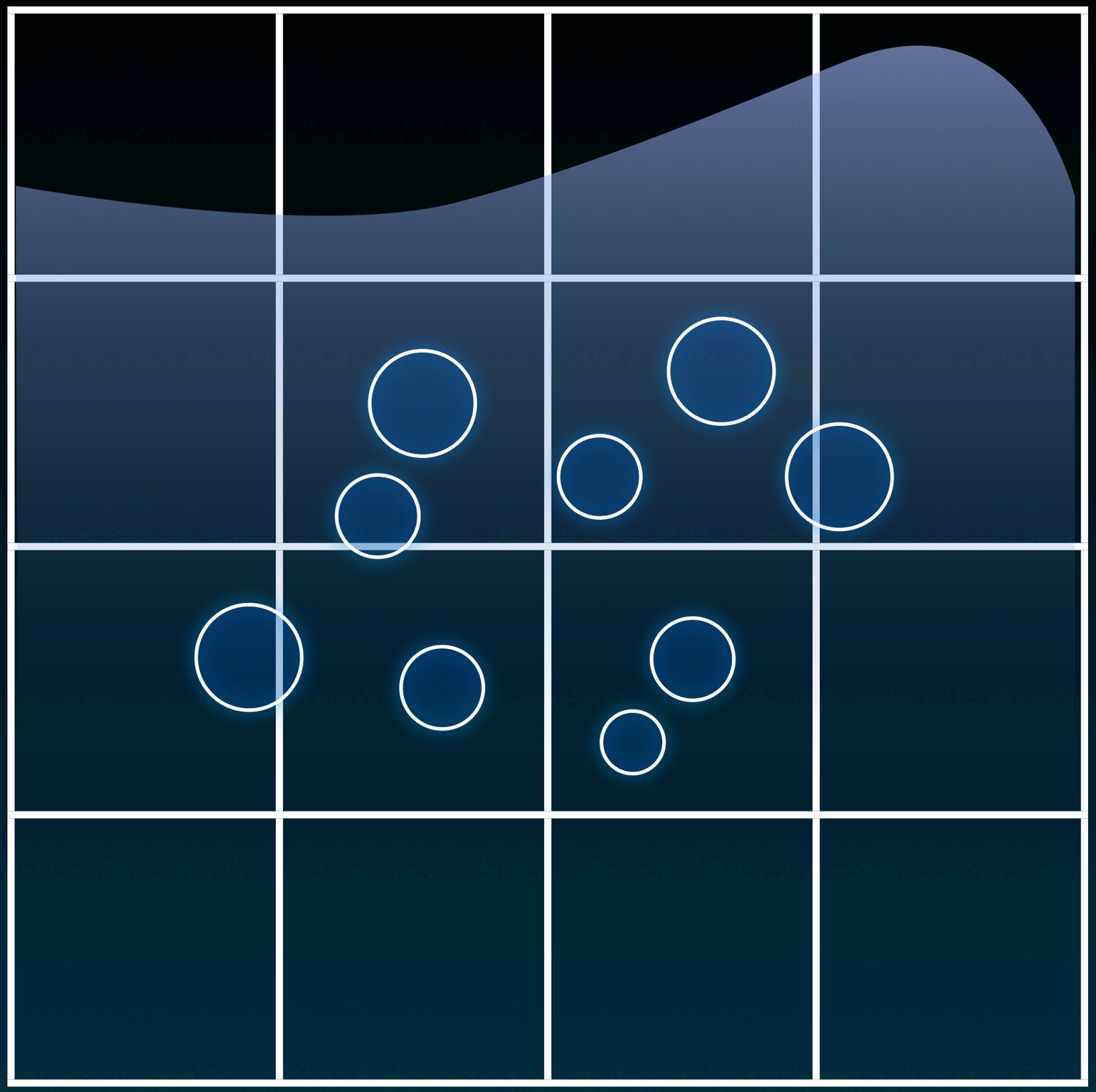
Presented by Doyub Kim

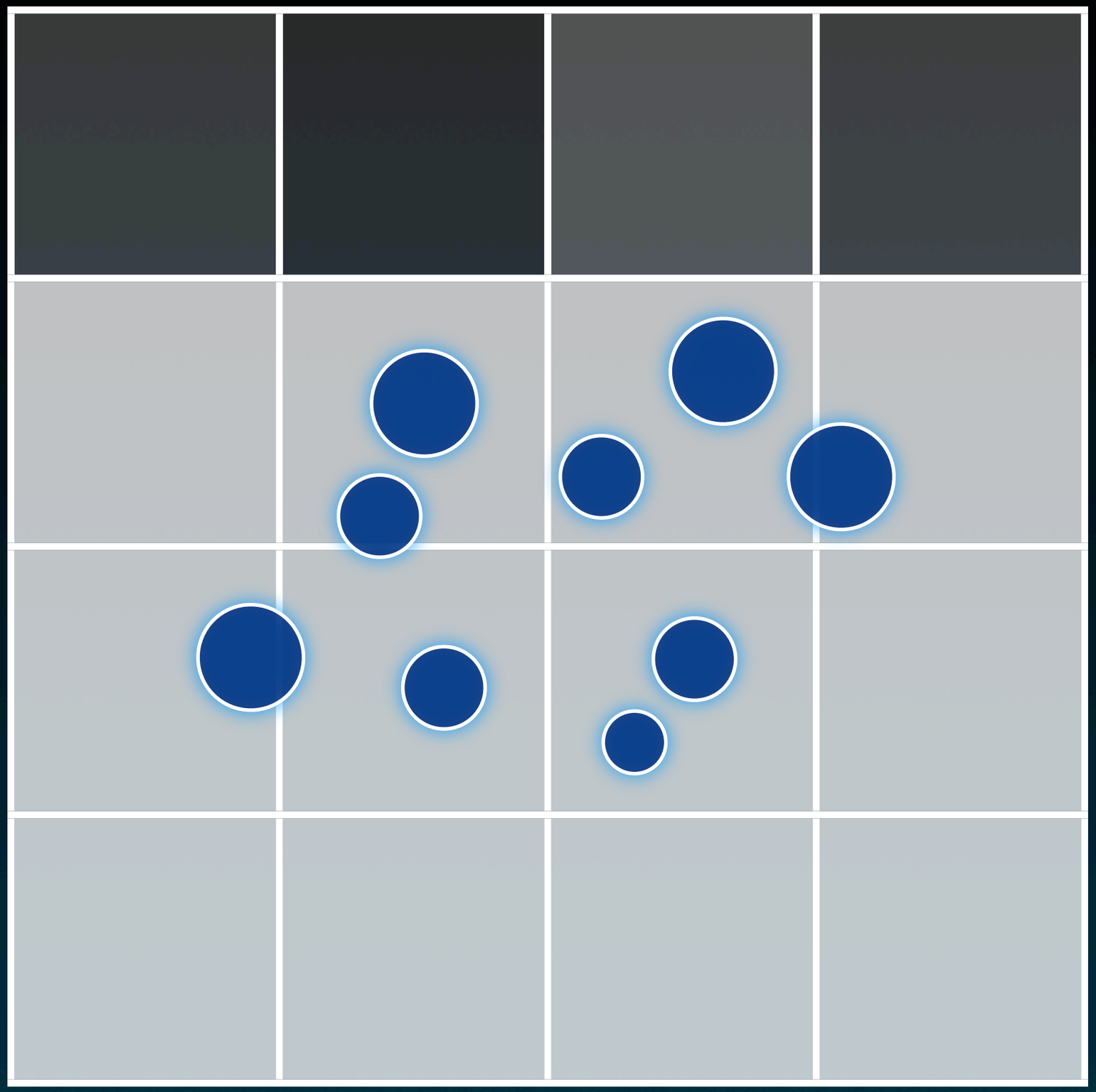
ACM SIGGRAPH 2010

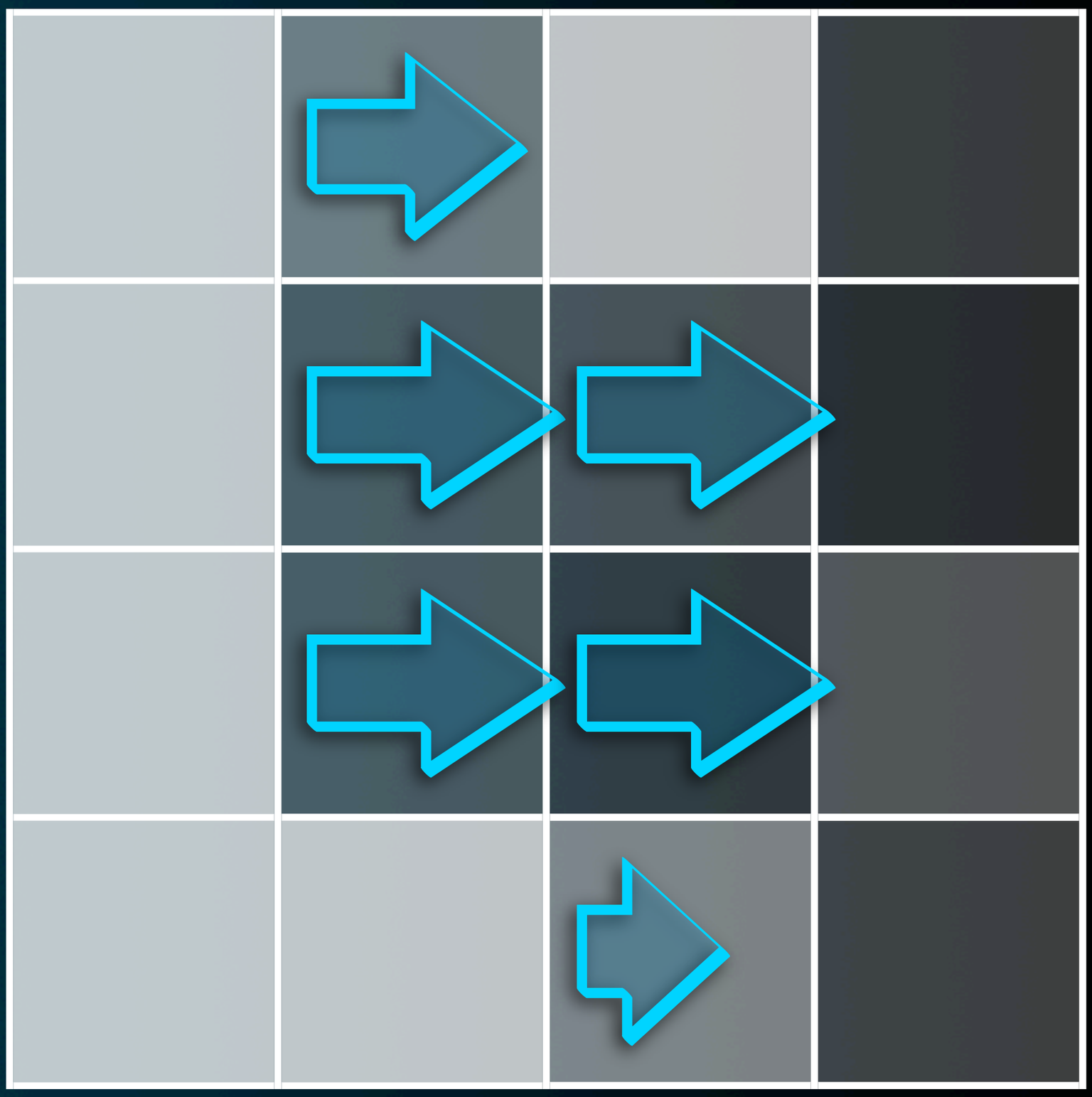
- Tons of Micro-Bubbles
- Mixture of Bubbles & Liquid
- Complex Bubble Interaction

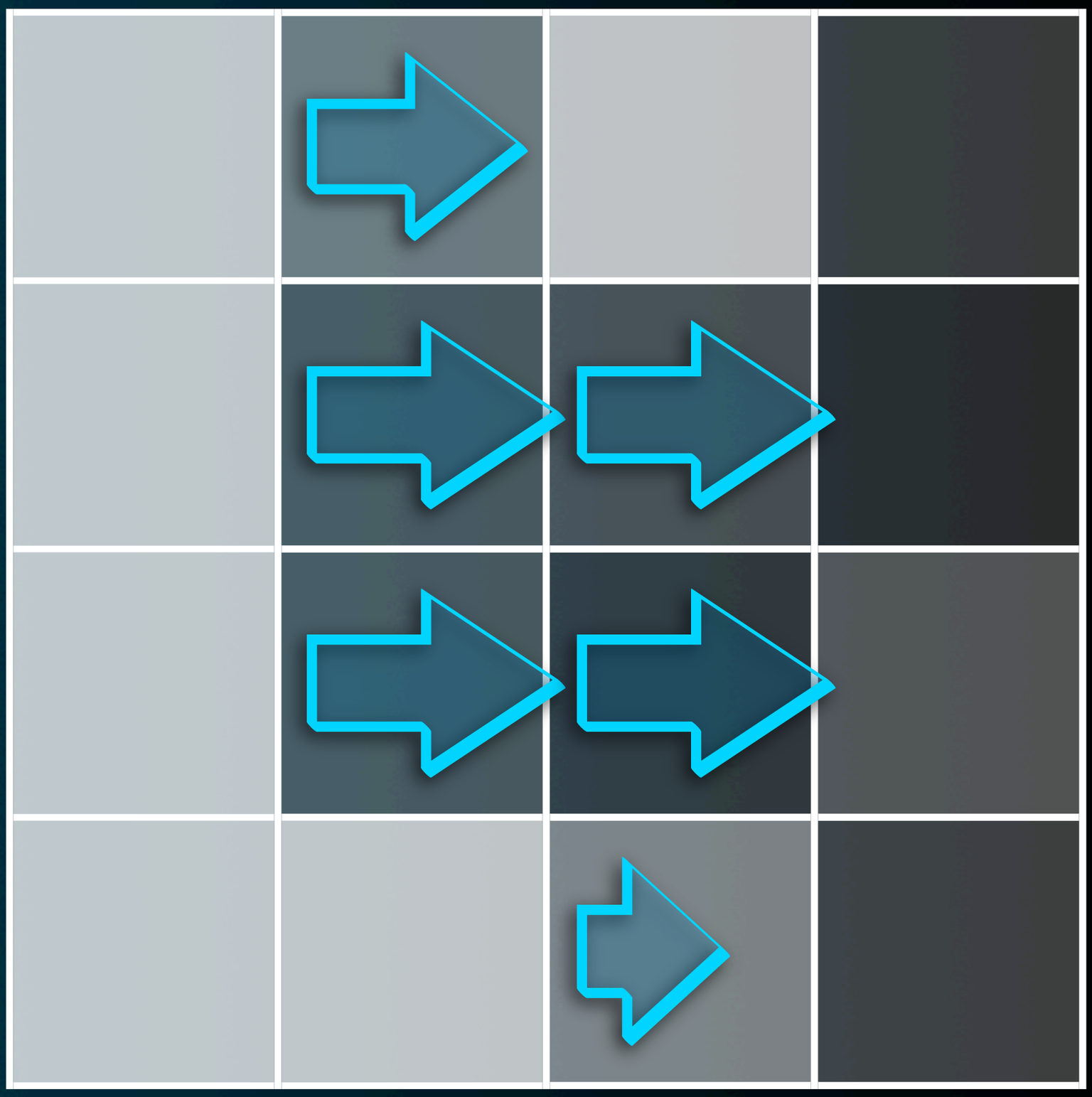
Dispersed Bubble Flow

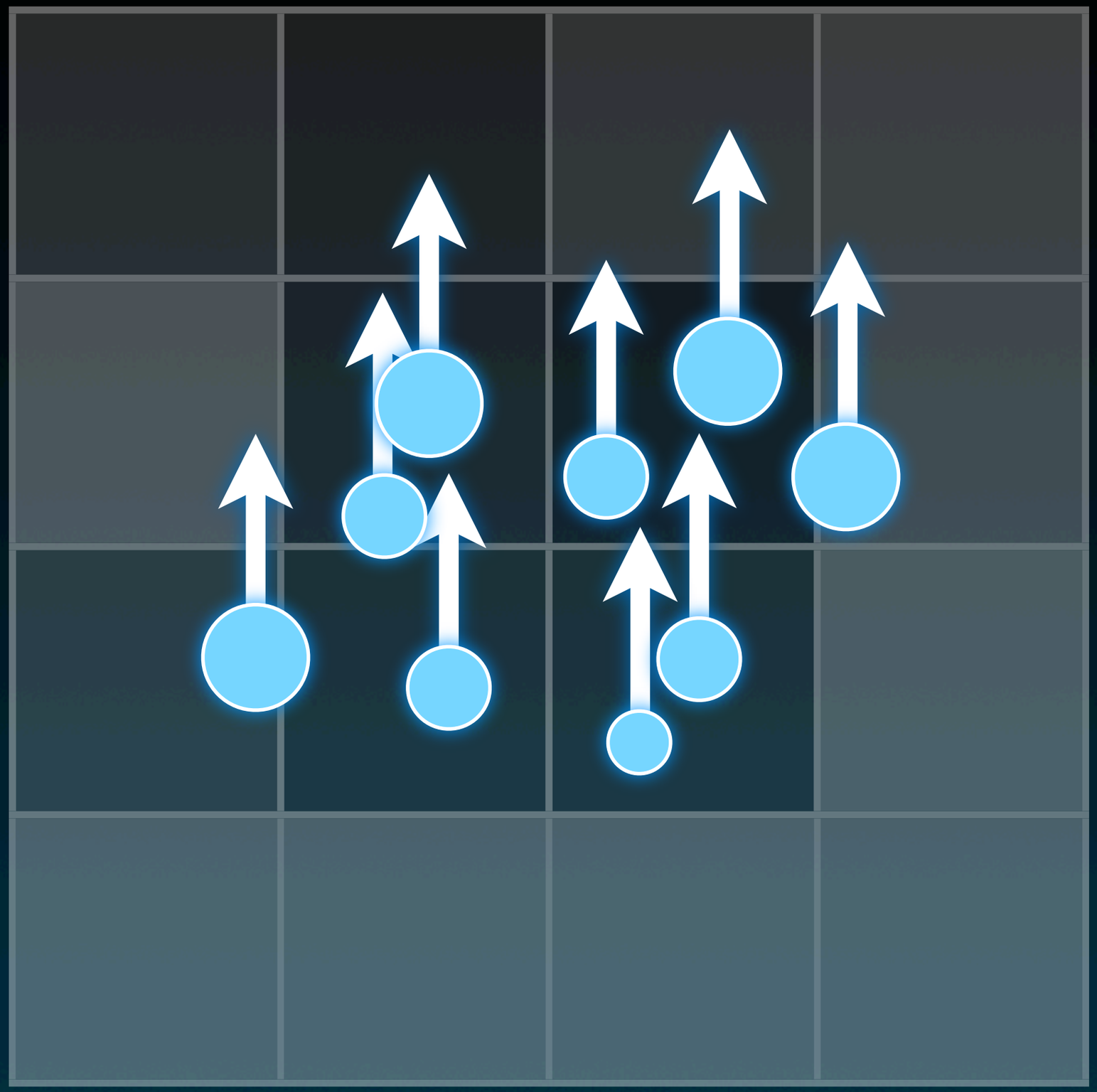


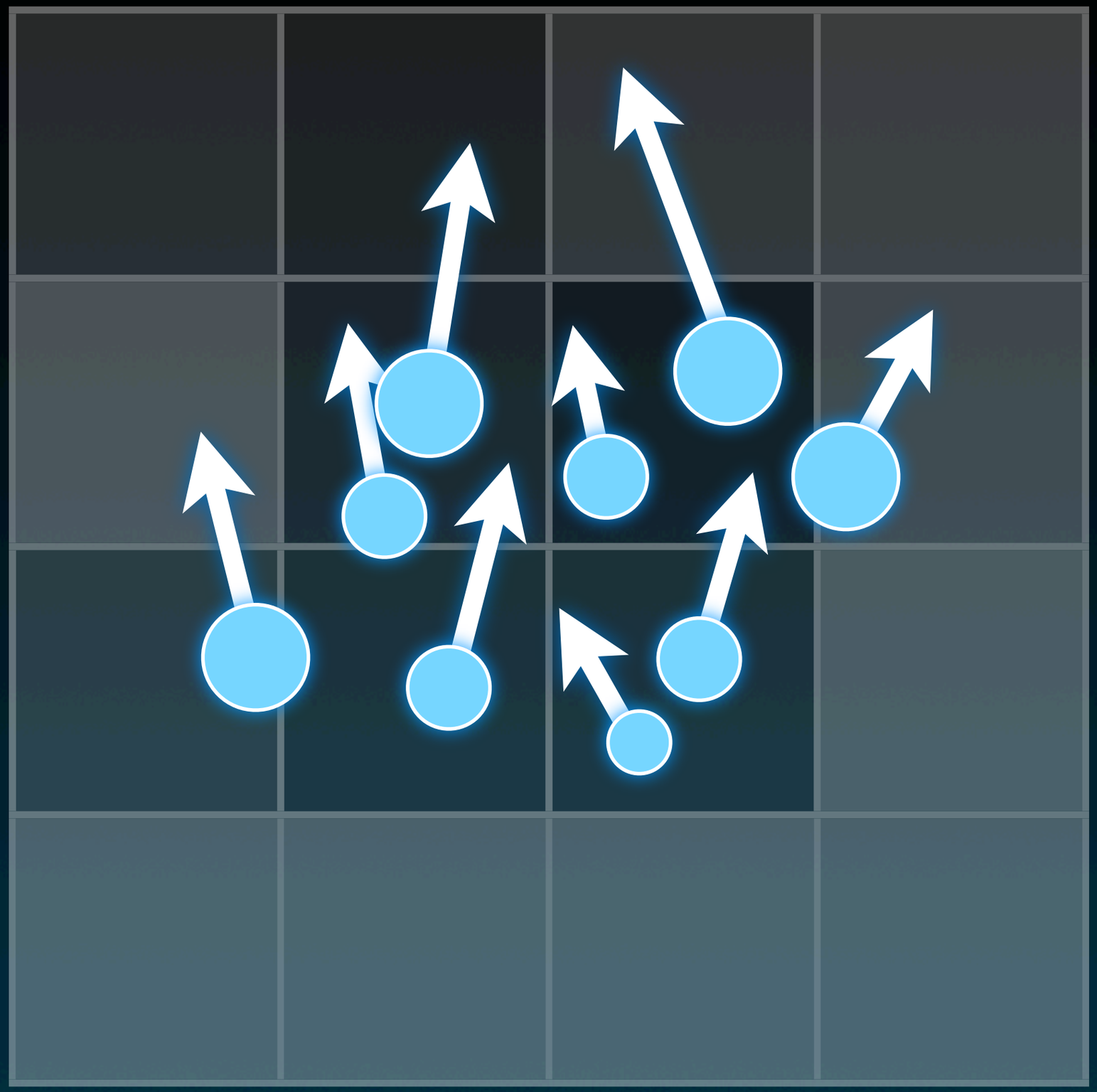




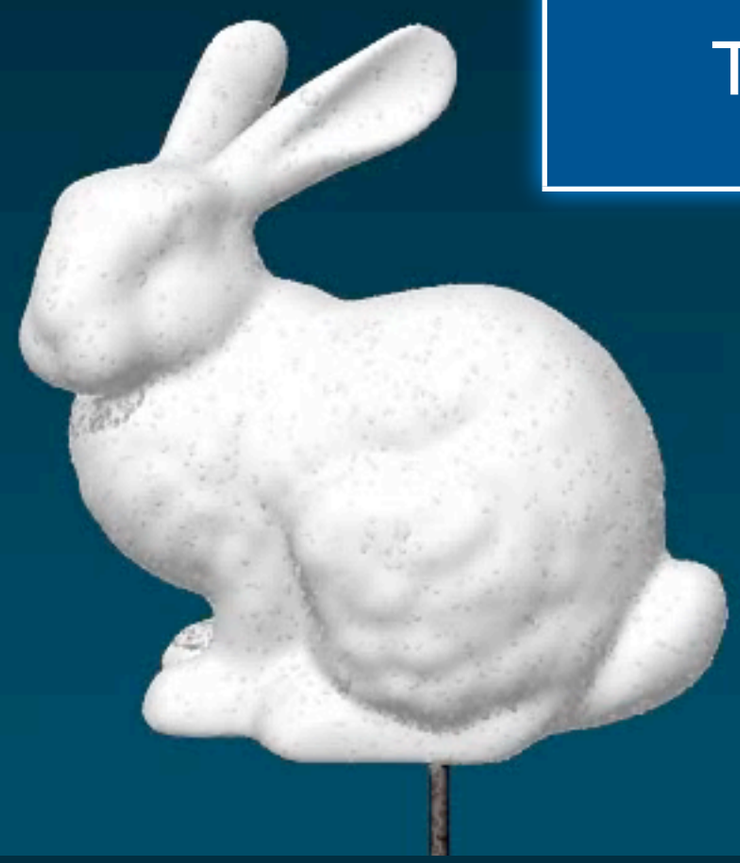


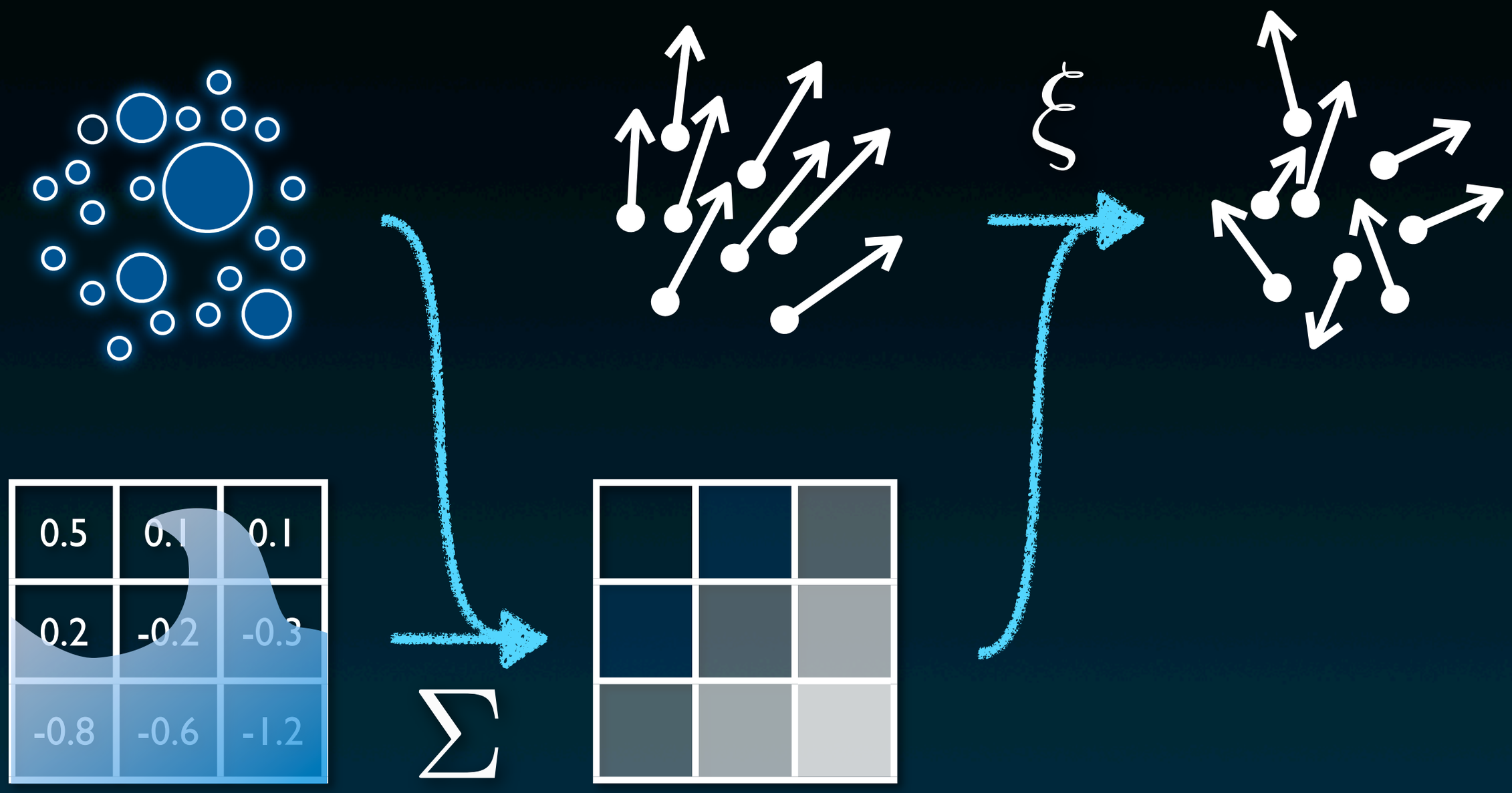




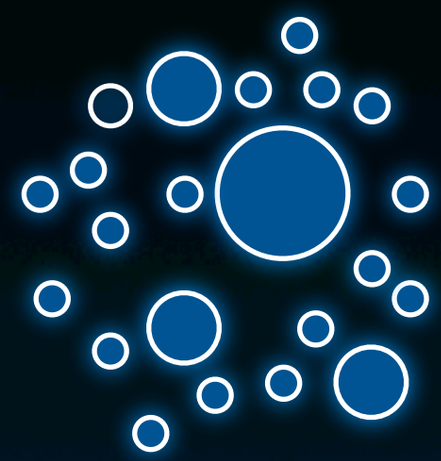


# Bubbles	1,570,000
Time	7 sec/frame

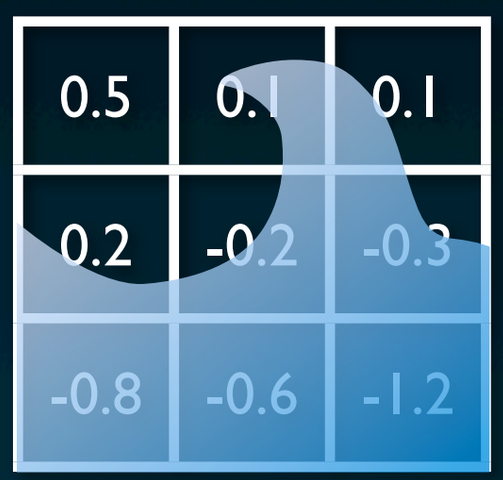



0.5
0.1
0.1
0.2
-0.2
-0.3
-0.8
-0.6
-1.2
Σ
ξ

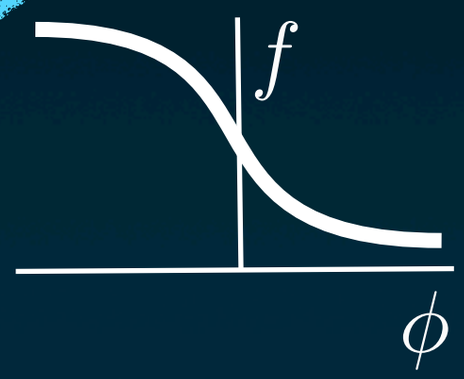
Continuum Solver



$$f_{cell} = f^{\phi}_{cell} - \sum_{i \in cell} \frac{4\pi}{3}(r_i/h)^3$$



Level Set ϕ

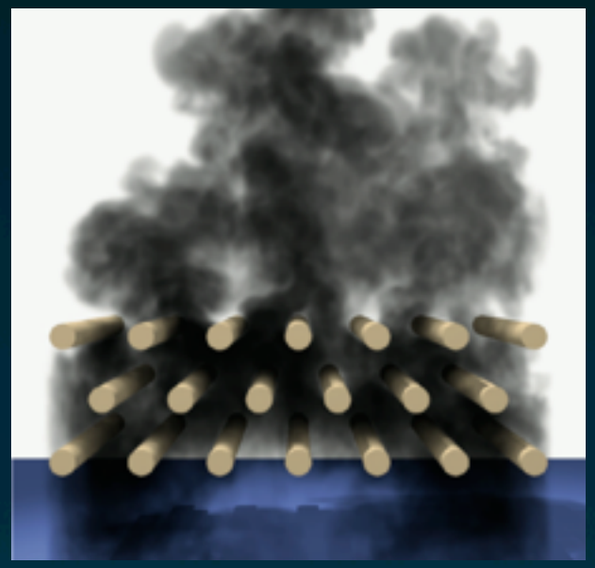


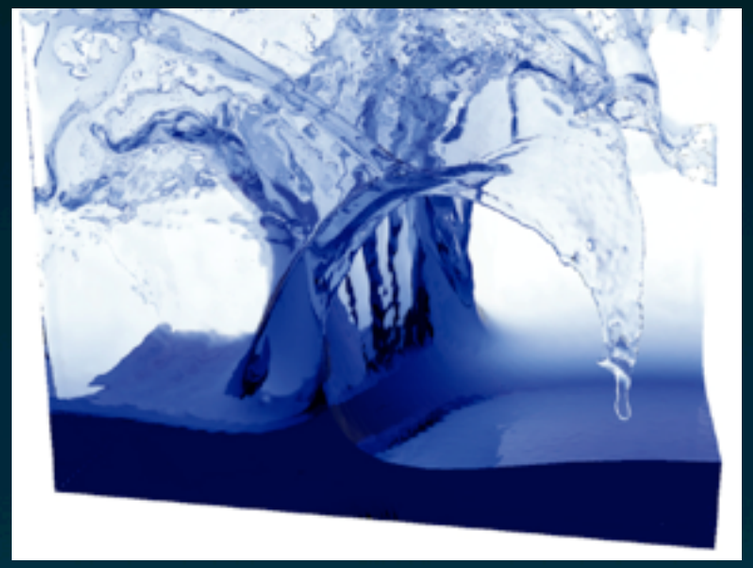
Volume Fraction f

Continuum Solver

$$\rho(\mathbf{u}_t + \underbrace{\mathbf{u} \cdot \nabla \mathbf{u}}_{\text{Advection}}) + \nabla p = \nabla \cdot (\mu \nabla \mathbf{u}) + \mathbf{f}$$

USCIP advection solver [Kim et al. 2008]





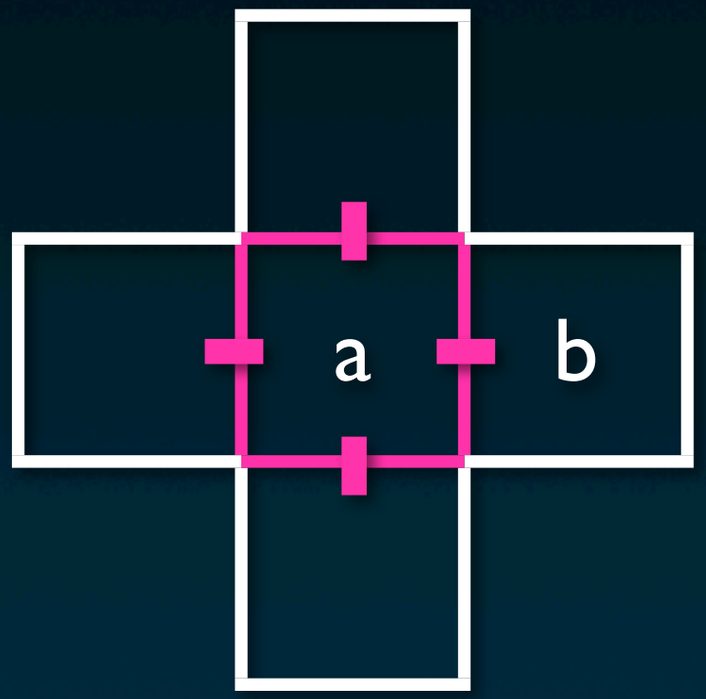
Continuum Solver

$$\rho(\mathbf{u}_t + \mathbf{u}\cdot\nabla\mathbf{u}) + \underline{\nabla p} = \nabla\cdot(\mu\nabla\mathbf{u}) + \mathbf{f}$$

Pressure

$$\sum_{faces} \frac{p_a^* - p_b^*}{\rho_{faces}} = \sum_{faces} \mathbf{u}_{faces}\cdot\mathbf{n}_{faces}$$

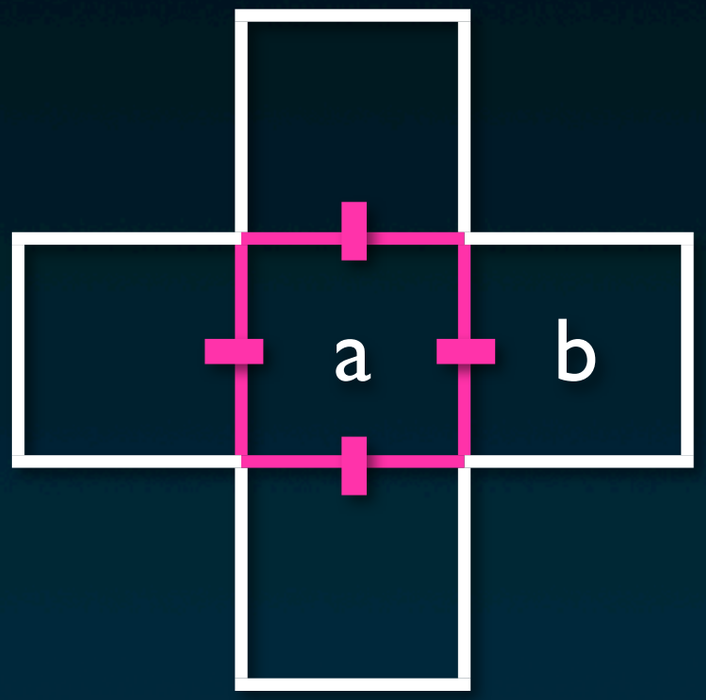
$$\rho_{face} = \rho_{gas} + (\rho_{liquid} - \rho_{gas}) f_{face}$$



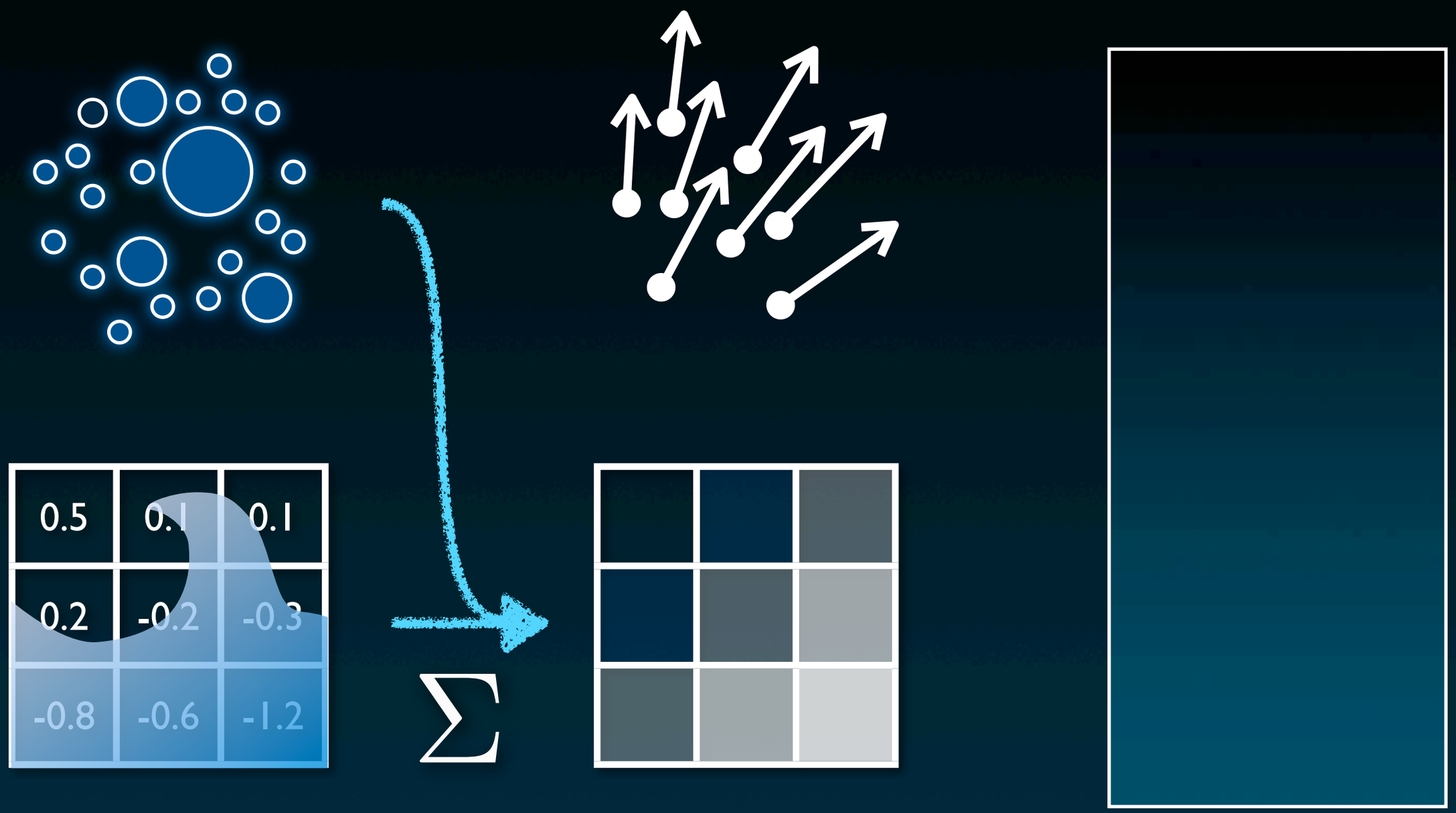
Continuum Solver

$$\rho(\mathbf{u}_t + \mathbf{u} \cdot \nabla \mathbf{u}) + \nabla p = \underbrace{\nabla \cdot (\mu \nabla \mathbf{u})}_{\text{Diffusion}} + \mathbf{f}$$

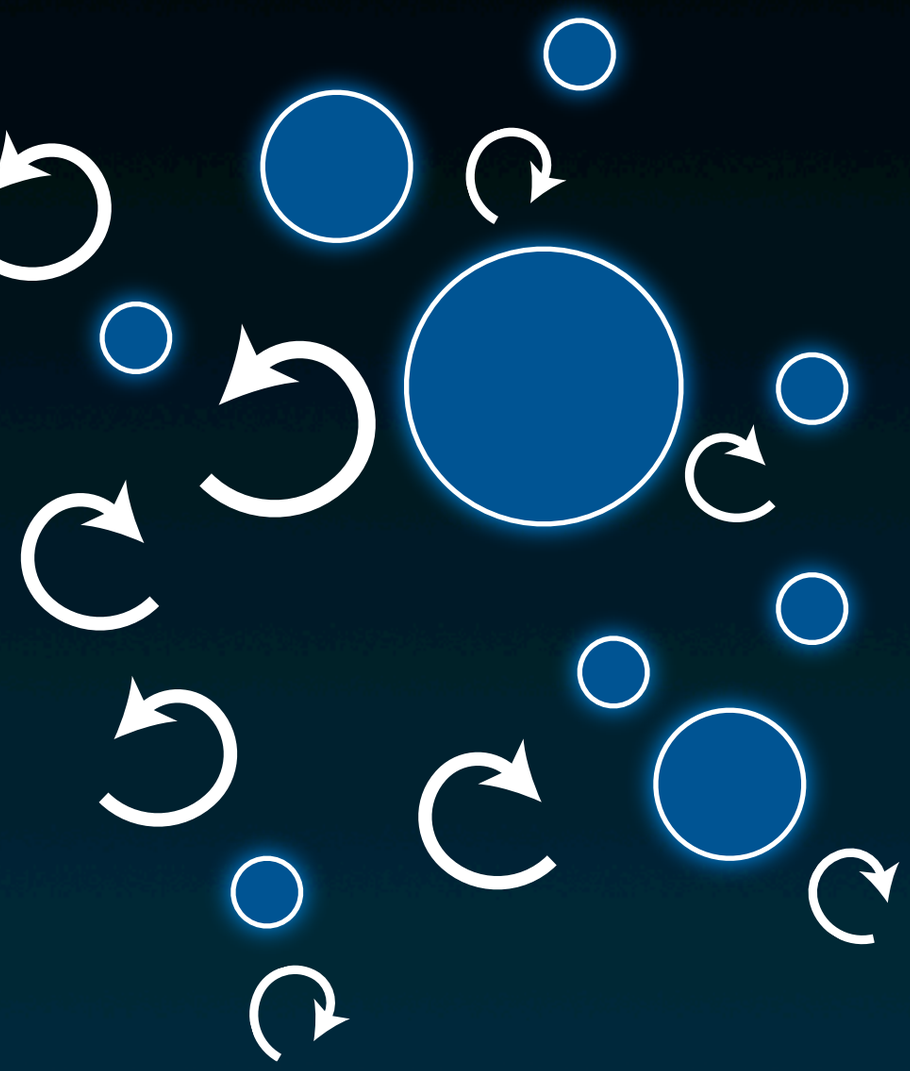
$$\mu_{face} = \mu_{gas} + (\mu_{liquid} - \mu_{gas}) f_{face}$$



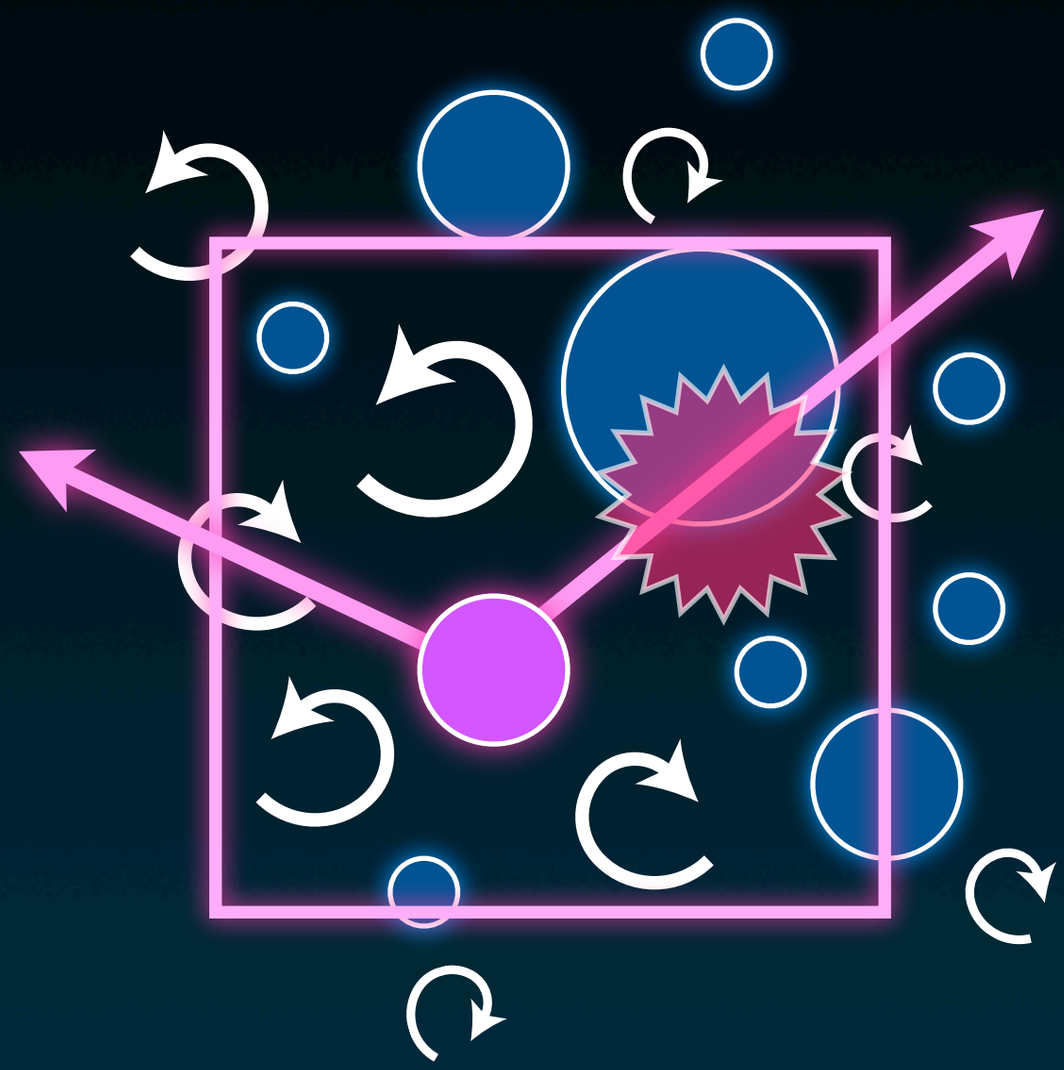
Global Motion of Bubbles



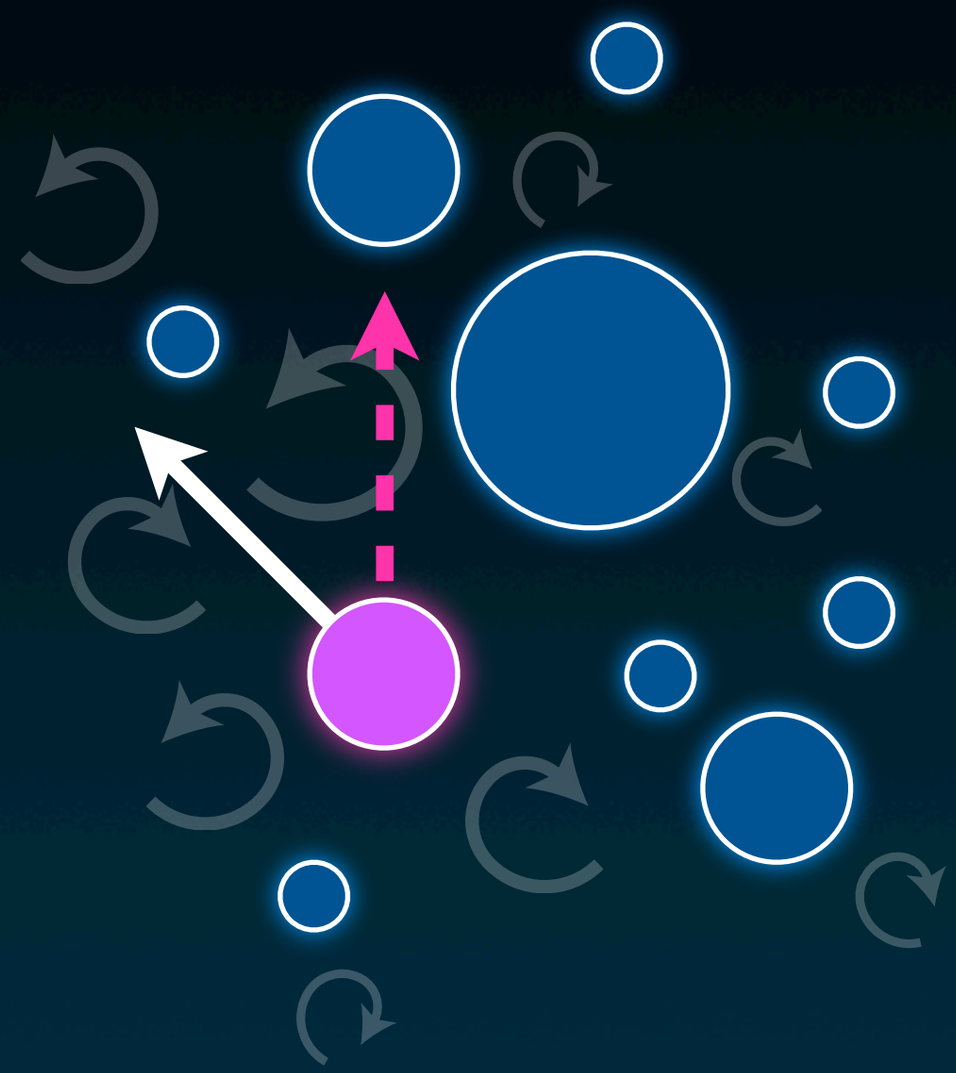
Subgrid Stochastic Solver



Subgrid Stochastic Solver



Subgrid Stochastic Solver



Scattering Event $\xi < s$

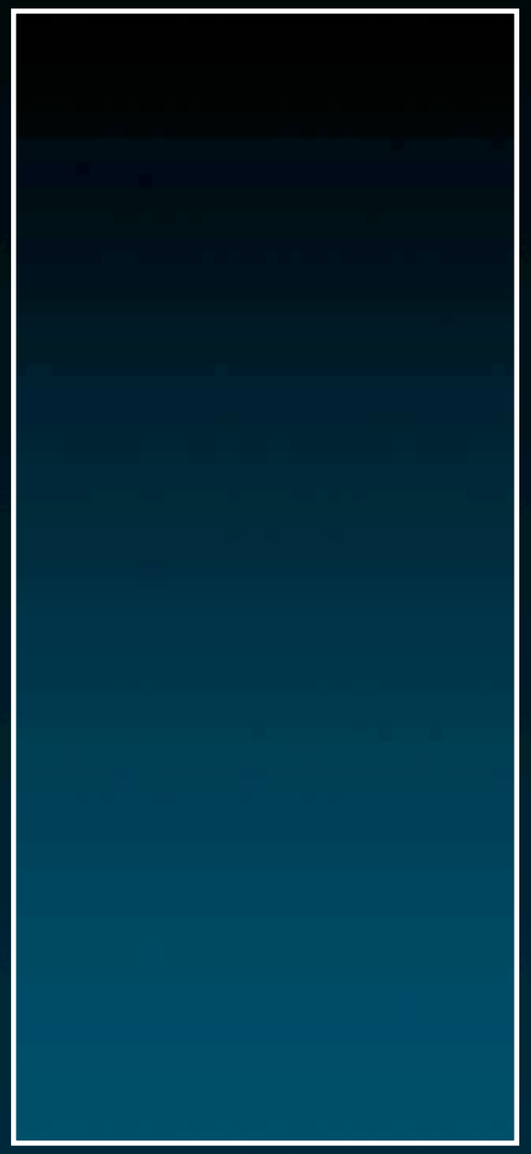
$$s(\mathbf{x}) = \nu \rho_{gas}[1 - f(\mathbf{x})]|\mathbf{u}(\mathbf{x})|^2$$

User Param

Kinetic Energy

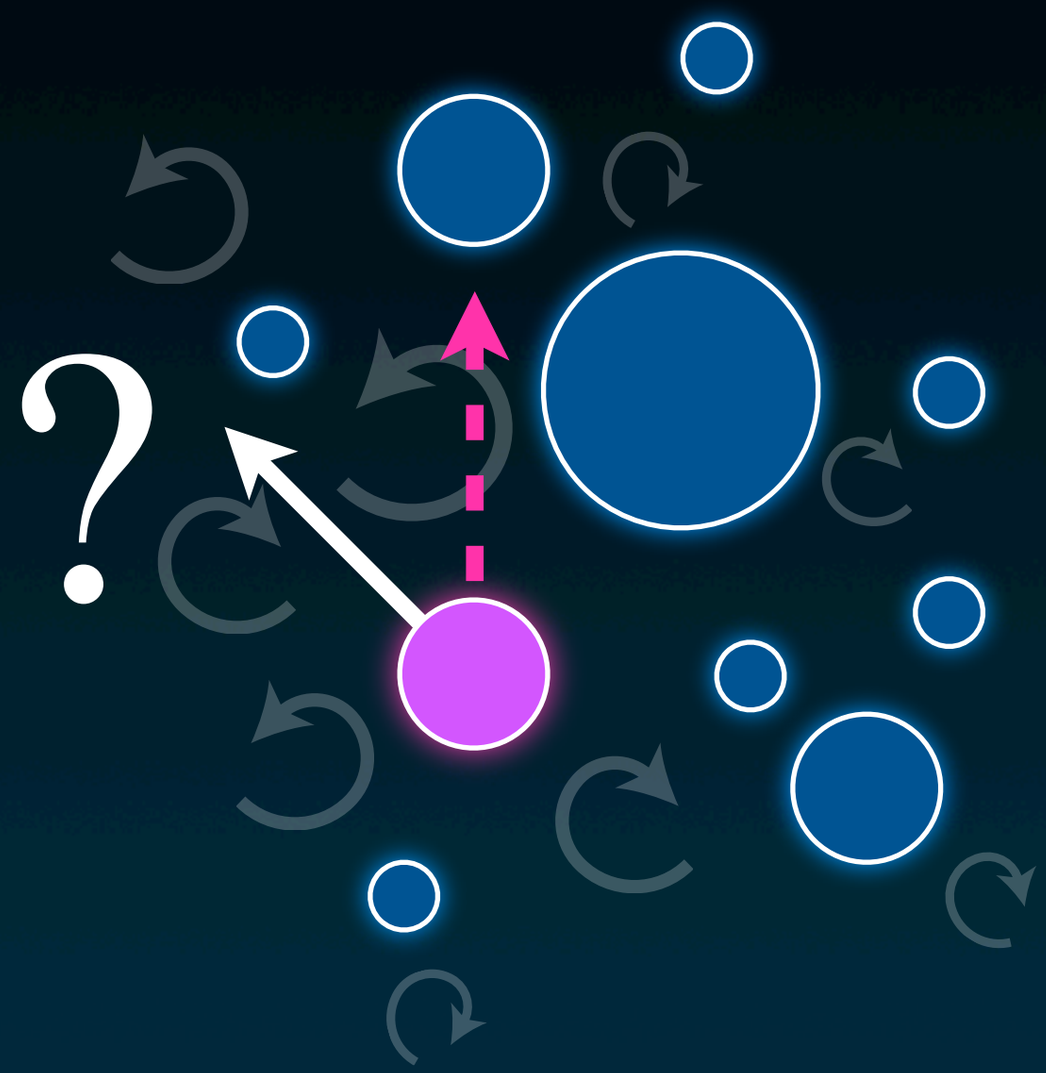
Parameter Comparison

$\nu = 0.25$



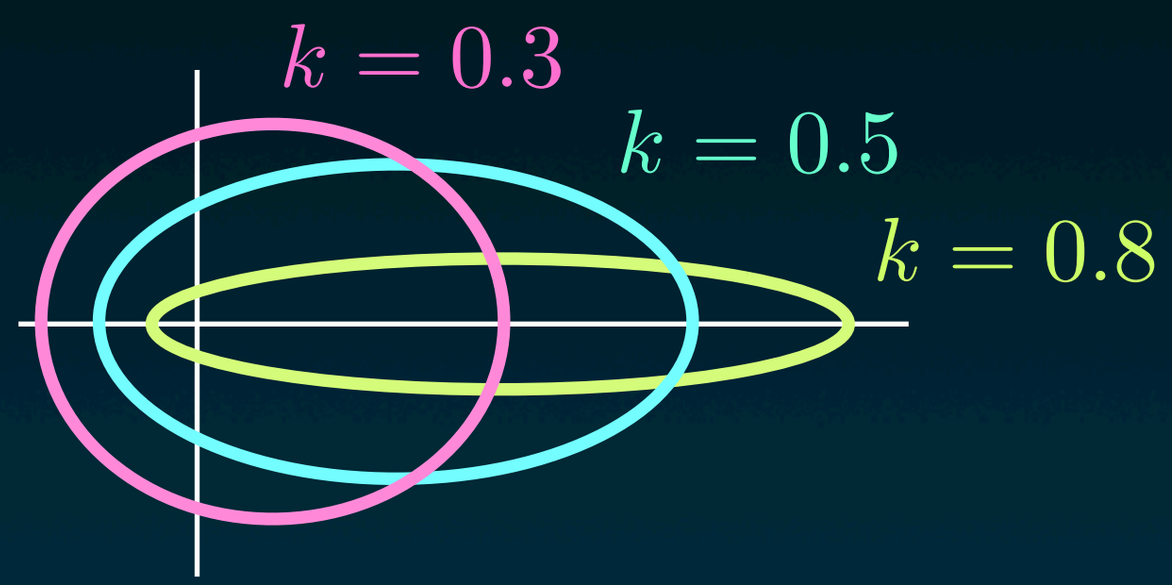
$\nu = 0.005$

Subgrid Stochastic Solver

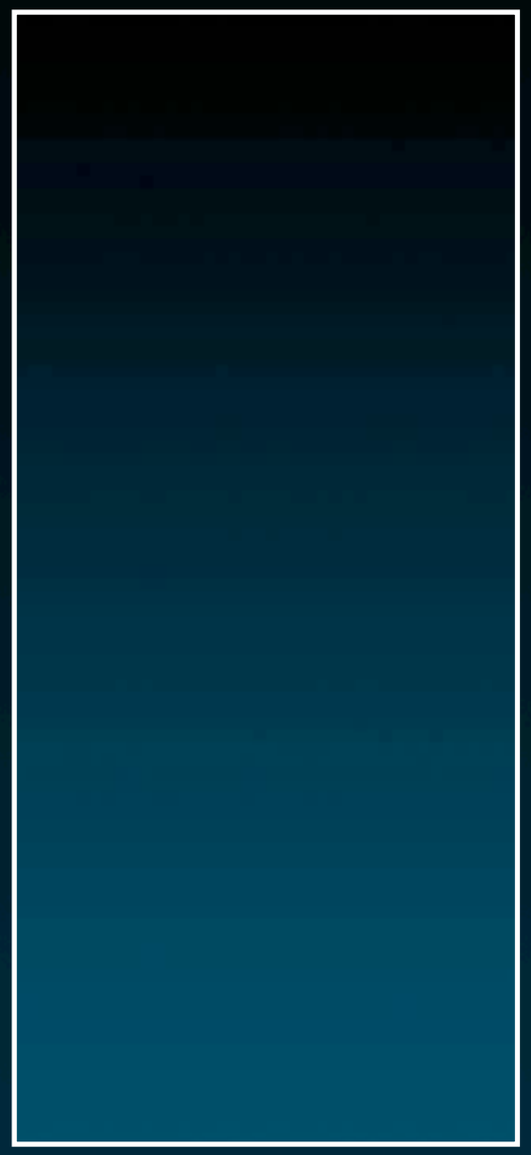


Scattering Direction

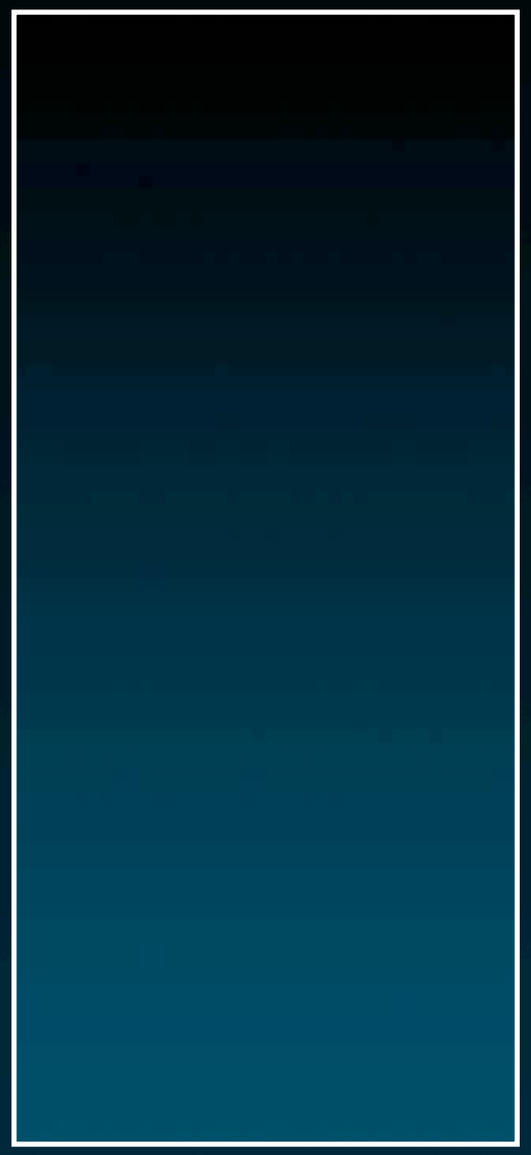
$$\cos\theta = (2\xi + k - 1)/(2k\xi - k + 1)$$



Parameter Comparison



$\nu = 0.25$
$k = 0.9$

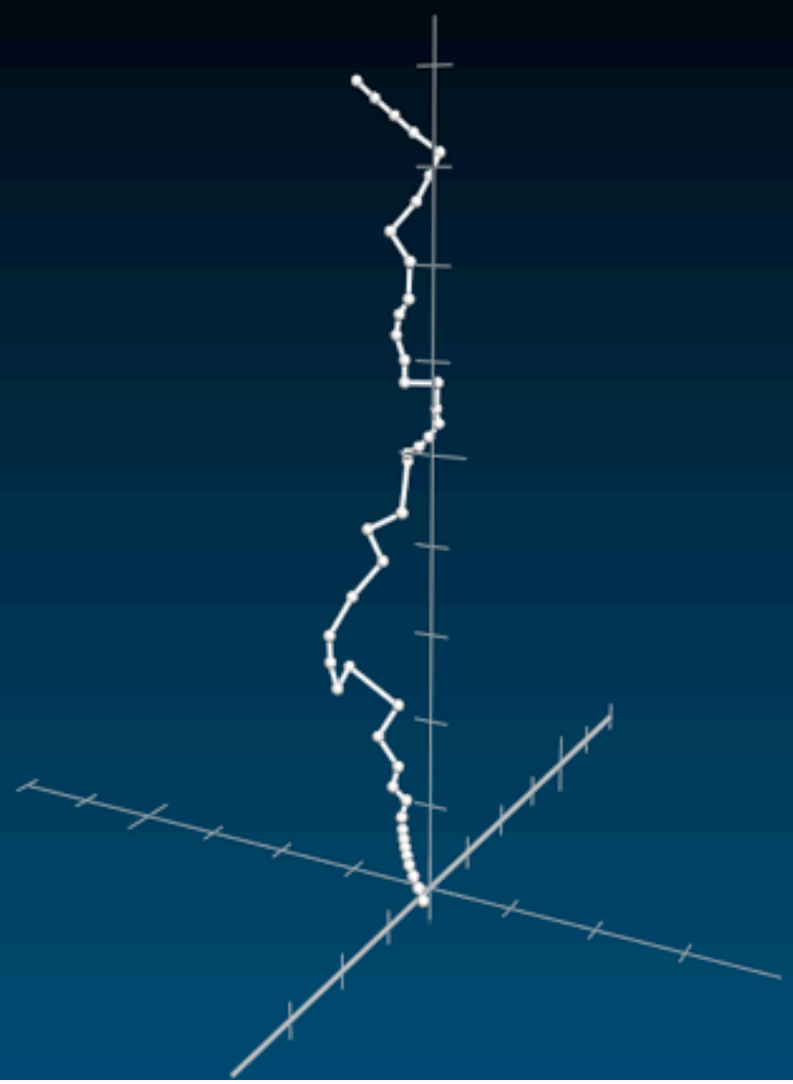


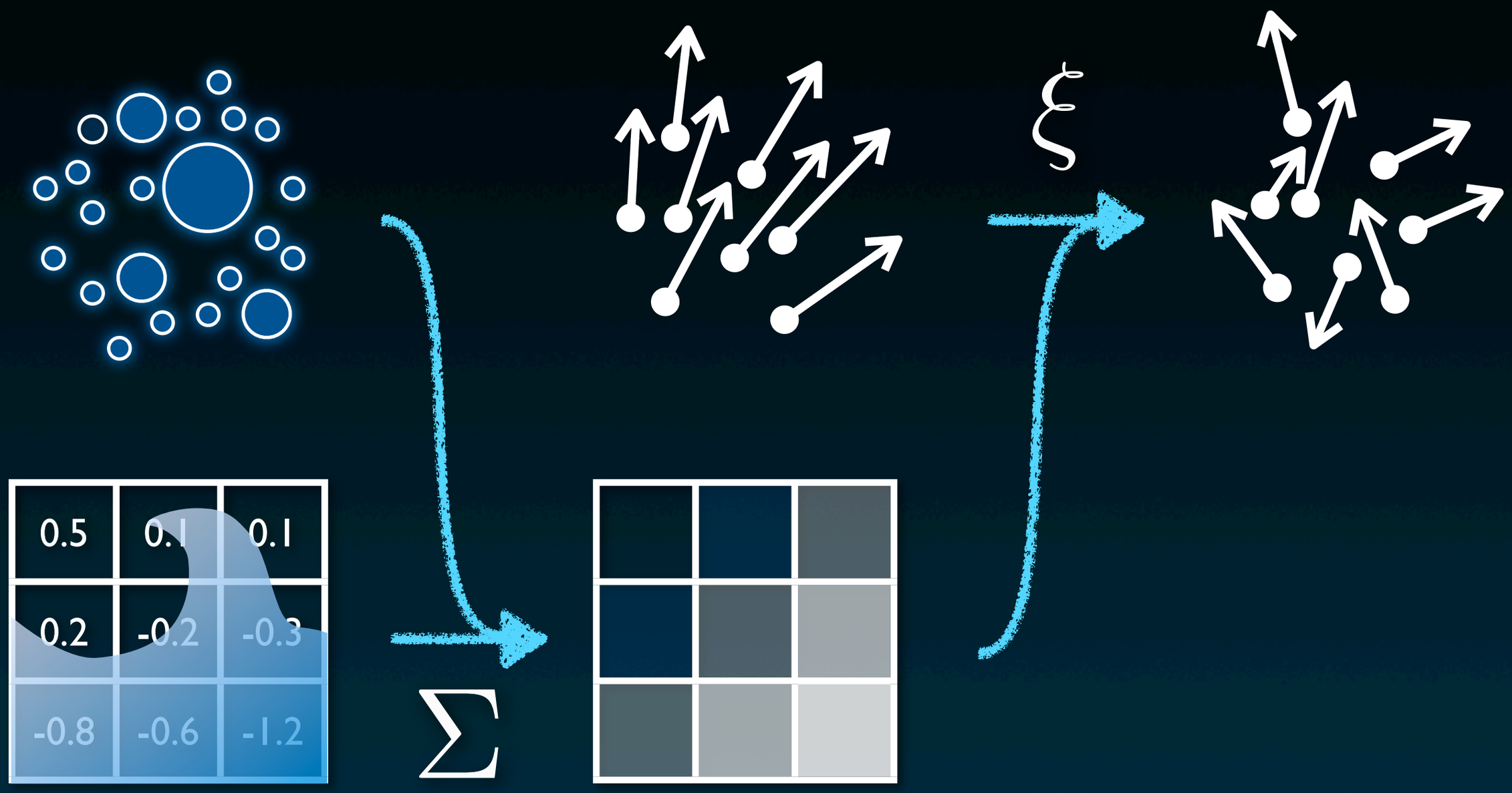
$\nu = 0.25$
$k = 0.1$

Parameter Comparison

$v = 0$	$v = 0.25$	$v = 0.25$	$v = 0.005$
$k = 0$	$k = 0.9$	$k = 0.1$	$k = 0.9$

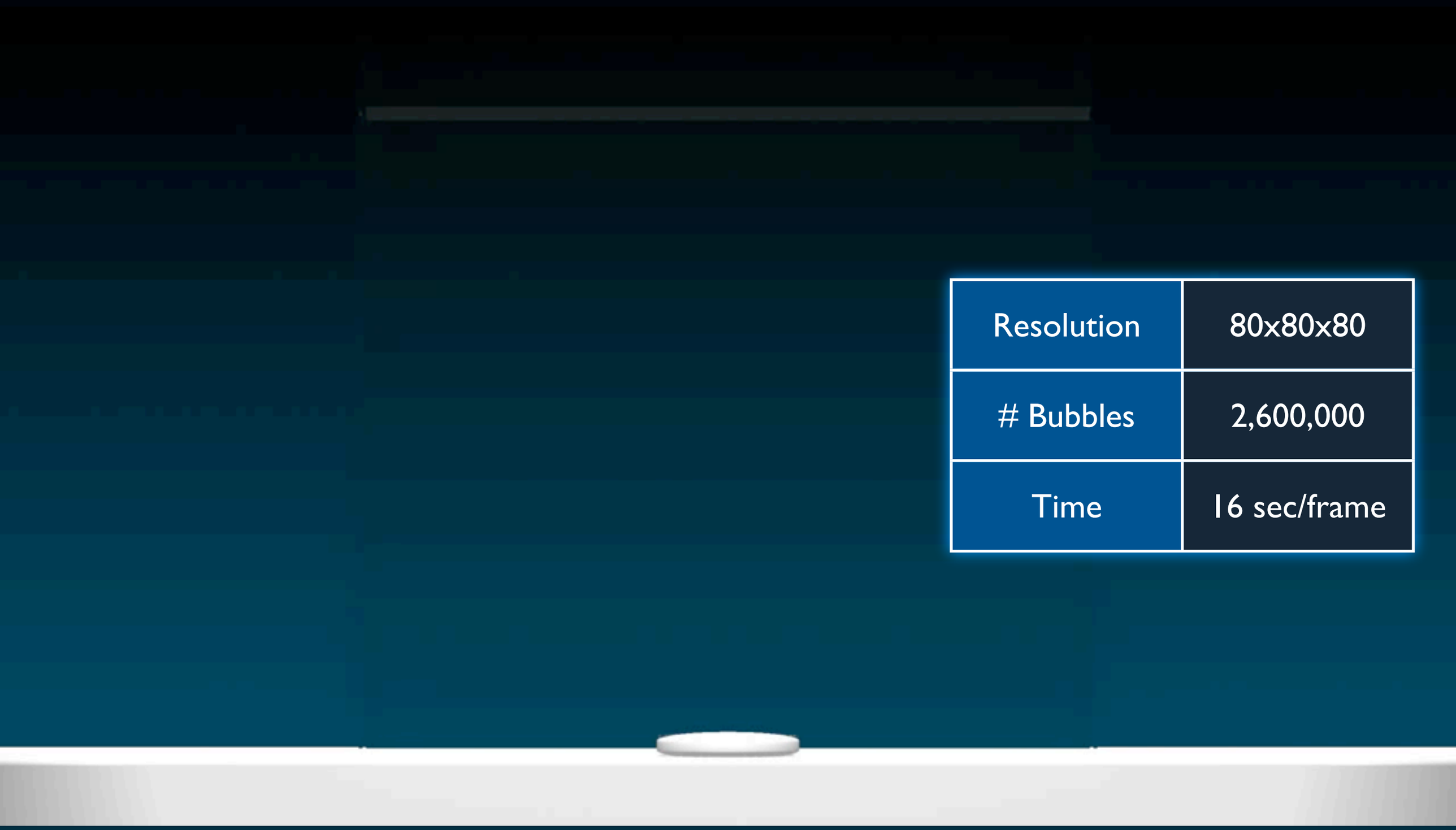
Bubble Path Instability




0.5
0.1
0.1
0.2
-0.2
-0.3
-0.8
-0.6
-1.2
Σ
ξ

Demo

Rising Bubbles from a Bubble Agent

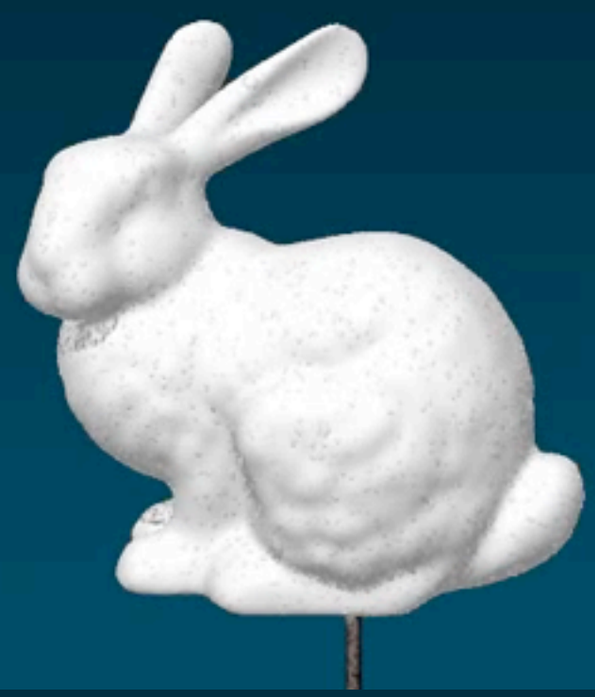


Resolution	80x80x80
# Bubbles	2,600,000
Time	16 sec/frame

Real-world Comparison

Comparison with Real Footage

Melting Bunny



Resolution	160x192x96
# Bubbles	1,570,000
Time	7 sec/frame

Boiling Water

Resolution	192x256x128
# Bubbles	1,160,000
Time	15 sec/frame

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Implementation

System:

- Intel Core i7 920 2.66GHz, 6GB RAM

Numerical solver:

- Uniform staggered grid
- Multigrid for Poisson solver

Parallelization:

- OpenMP with 8 threads (hyper threading enabled)

Limitations

Approximated bubble dynamics:

- No per-bubble collision
- No merging
- No shape variation

Future Work

Conclusions

Efficient Method for Dispersed Bubble Flow

Thanks to...

- SIGGRAPH Reviewers
- Graphics & Media Lab. Seoul National University
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Thank You

Questions?