Particle-Based Fluid-Fluid Interaction

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Introduction

- Definition of fluid
- Particle system
- Simulation types:
  - multiple fluids
  - trapped air
  - phase transitions

Related work

- Foster N. et al. – fluid animation to CG (Eulerian and particle-based)
- Carlson et al. – fluid solid interaction
- Greenwood et al. & Hong et al. – simulating bubbles in liquids
- Muller et al – fluid-solid interaction

SPH model based on their work

SPH Model

- Set of particles i ϵ [1…N]
- – positions x_i, masses m_i, additional atr. A_i.
- Smooth continuous field A(x)

$$A(x) = \sum_j m_j \; A_j / p_j * W(x - x_j, h) \qquad (1)$$

$$p_i = p(x_i) = \sum_j m_j * W(x_i - x_j, h) \qquad (2)$$

SPH Model 2

- W(r,h,)

For |r| > h

$\int W(r,h)\, dr = 1$

$W(r,h) = 0$

SPH Model 3

$$\nabla A(x) = \sum_j m_j \; A_j / p_j * \nabla W(x - x_j, h) \qquad (3)$$

$$\nabla^2 A(x) = \sum_j m_j \; A_j / p_j * \nabla^2 W(x - x_j, h) \qquad (4)$$

$$f_i^{presure} = - \sum_j m_j \; (P_i + P_j)/2p_j * \nabla W(r_{ij}, h) \qquad (5)$$

$$f_i^{viscosity} = \mu \sum_j m_j \; (v_j - v_j)/p_j * \nabla^2 W(r_{ij}, h) \qquad (6)$$

SPH Model 4

$P_i = k(p_i - p_0)$ (7)

$a_i = 1 / p_i(f_i^{presure} + f_i^{viscosity} + f_i^{external})$ (8)

Multiple Fluids

- standard approach, our approach for single fluid
- New stored attributes
  - Color and temperature

Attribute	Description	Unit
m	mass	kg
$\mathbf{x}$	position	m
$\mathbf{v}$	velocity	m/s
$\mathbf{f}$	accumulated body forces	N/m^3
ρ_0	rest density	kg/m^3
ρ	actual density	kg/m^3
μ	viscosity	Ns/m^2
k	gas constant (stiffness)	Nm/kg
c^i	color for interface tension	1
c^s	color for surface tension	1
T	Temperature	Celsius

Multiple Fluids 2

$$f_i^{viscosity} = \mu \sum_j m_j \ (v_j - v_j)/p_j * \nabla^2 W(r_{ij}, h)$$

- Modifying (6) - carrying own viscosity of each particle

$$f_i^{viscosity} = \sum_j (\mu_i + \mu_j)/2 * m_i * (v_j - v_i)/p_j * \nabla^2 W(r_{ij}, h) \qquad (9)$$

Interaction Methods

- Immiscible Liquids (water-oil)
- Diffusion
- Trapped Air
  - Air Particle Generation
  - Air Particle Deletion
  - Artificial Buoyancy

Immiscible Liquids

- Physic in short (water+oil)
- Adapting water-air model to immiscible liquids

- $\mathbf{f}^{interface} = -\sigma^{i} \nabla^{2} c^{i} \, n / |n|$
- $\mathbf{f}^{surface} = -\sigma^{s} \nabla^{2} c^{s} \, n / |n|$

Diffusion

- Heat distributing and dissolving
- $\partial A / \partial t = c \nabla^2 A$
- $\partial A_i / \partial t = c \sum_j m_j \; (A_j - A_i) / p_j \nabla^2 W(r_{ij},h)$
- $A_i \leftarrow A_i + \Delta t \, \partial A_i / \partial t$
- Simulate lava lamp
- $p_0 \sim 1/V \sim 1/T$

Trapped Air

- Problem of Dissappearance
- Simulating air as a separate fluid
- On the Fly

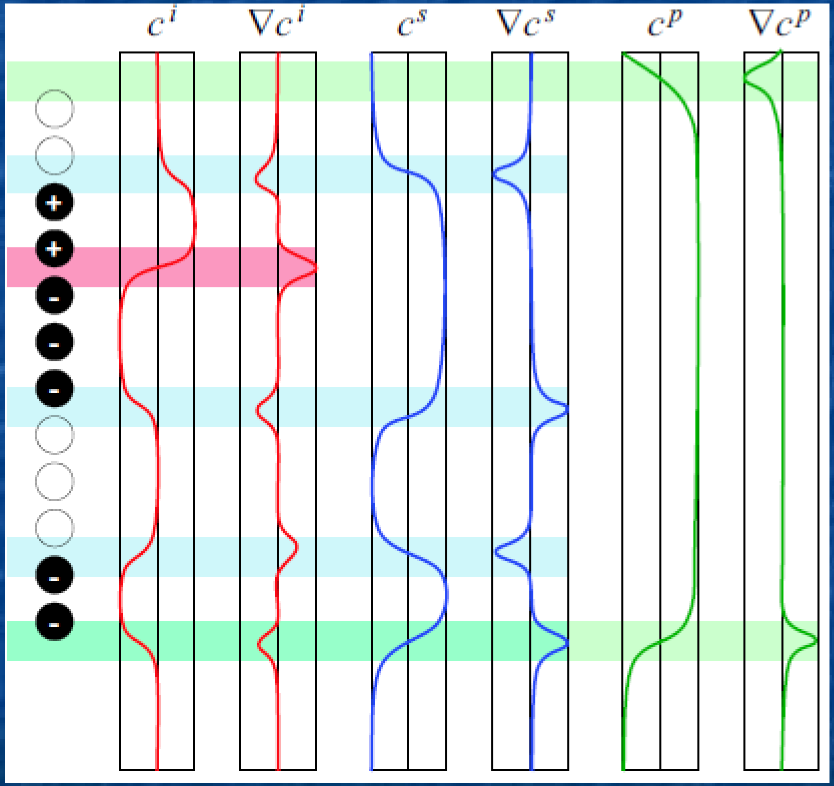
Air Particle Generation 1

- Color atribute $c^p = 1$
- $\nabla c^p, \nabla c^s$ = large
- Location of air particles
  liquid particle shifted by vector $-d\nabla c^p$

If $|\nabla c^p|_x > t_p$ and $\nabla c^p \cdot e_y|_x > 0.0$

generateAirParticle $(x - d\,\nabla c^p\,|_x, v)$;

Air Particle Generation 2



Air Particle Deletion

- Vertical component ∇c^p = negative
- -> deletion of wrong particles
- How to avoid another problems
- -> delete only small ∇c^s (inside bubles)
- -> to test ∇c^p > treshold (inside bubles close to zero)
- -> to test actual density p < treshold
- If ($|\nabla c^s|_x < t_s$ and $|\nabla c^p|_x > t_p$) or $p<t_p$

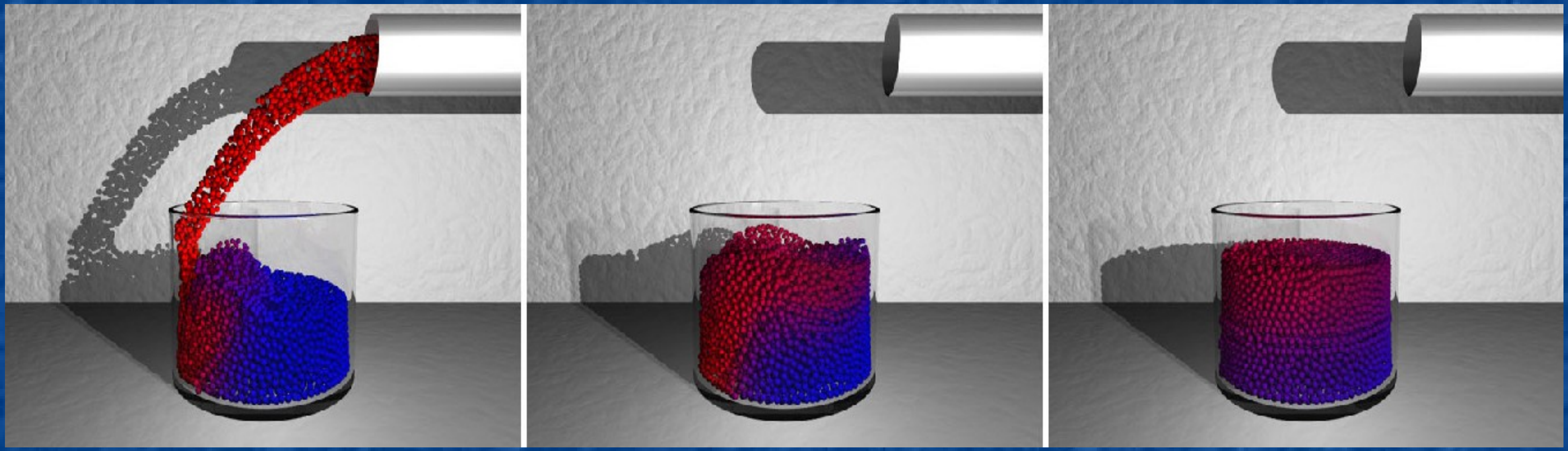
  deleteAirParticle();

Artificial Buoyancy

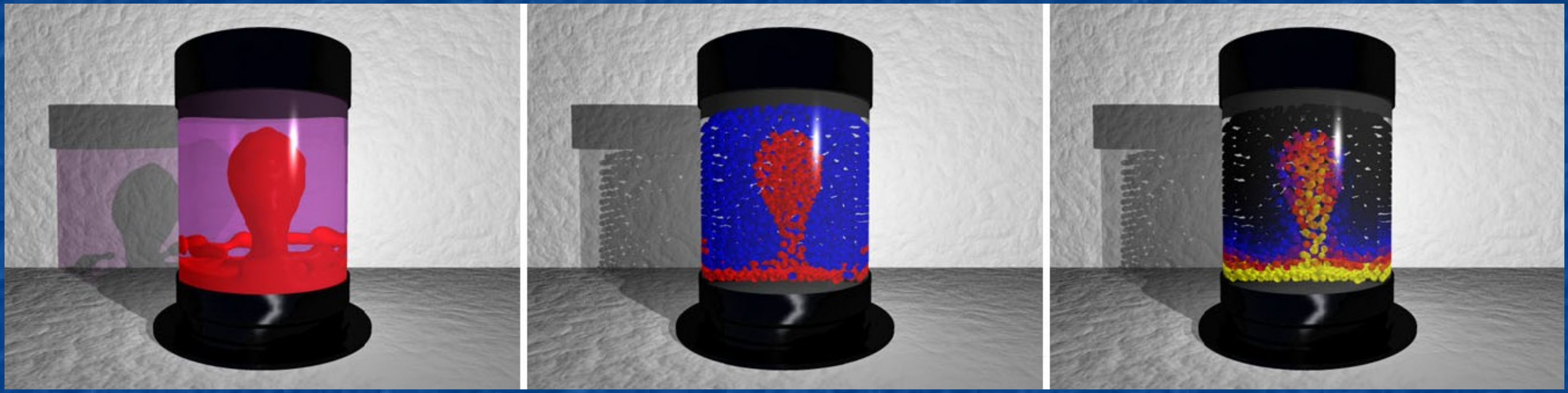
- Problem of large ratio between water and air density in a SPH simulation
- Not suited for small air bubbles

- $\mathbf{f}^{buoyant} = b(p - p_0)g$

Results – Diffusion effect



Results – Lava Lamp



Blue fluid density = 500kg/m3, particle mass 0.006kg

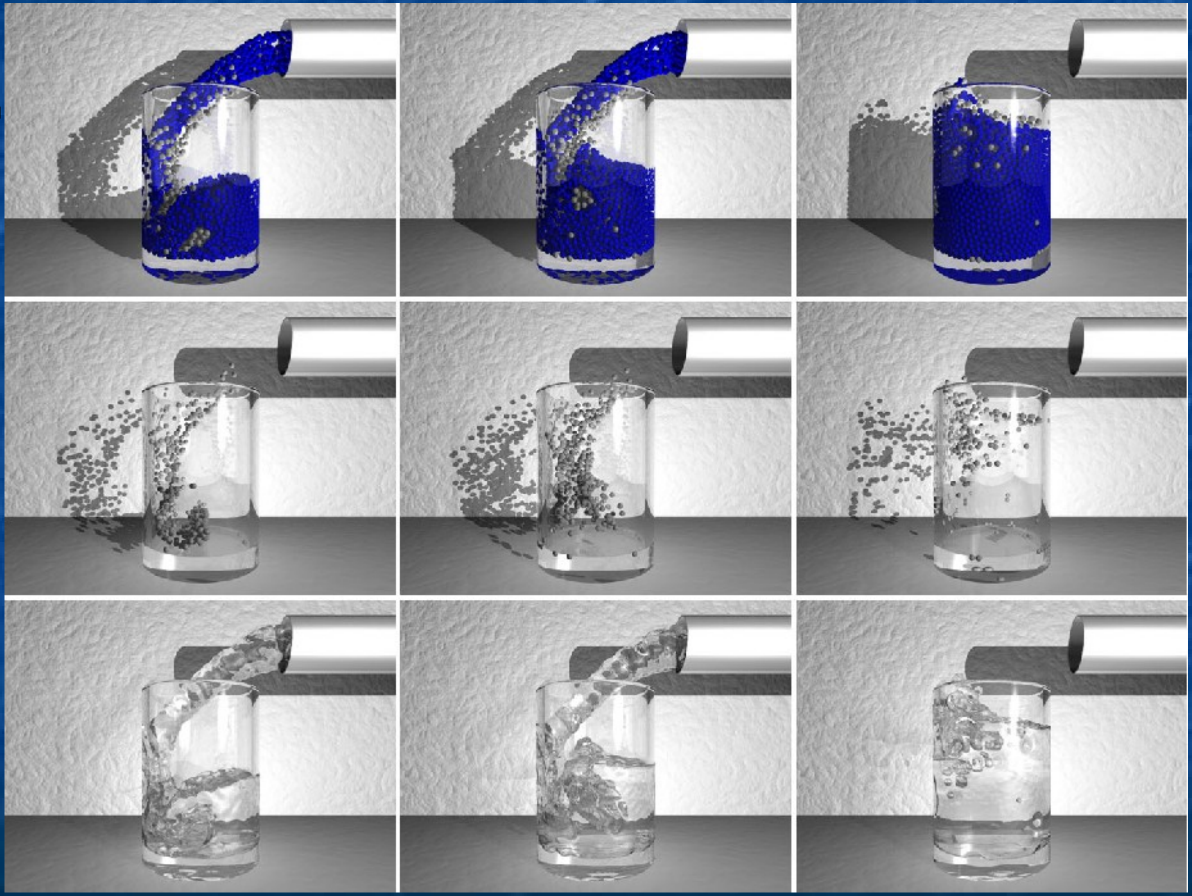
Red fluid density = 1000kg/m3, particle mass 0.012kg

Start temperature = 10 degrees

Results – Pouring Water into a Glass

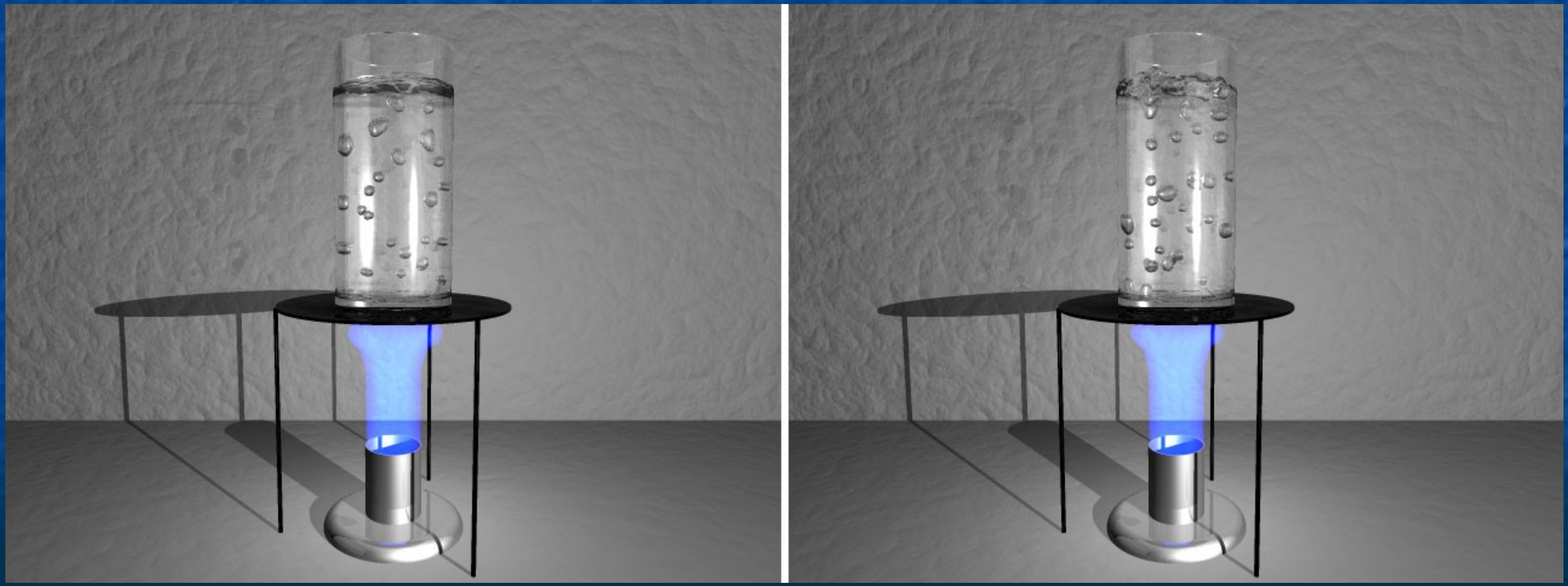
3000 water p.
400 air p.

Water dens.
1000kg/m3
Air dens.
100kg/m3



Results - Boiling Water

Flame temperature = 1000 degrees Celsius
Water temperature = 0 degrees
5 random cavitation sites at the bottom of glass
5500 water p. 3000 flame p.



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Ďakujem za pozornosť

Simulation of Lava Lamp