Particle-Based Fluid Simulation for Interactive Applications

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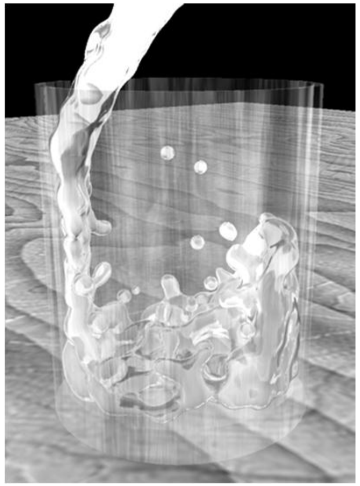
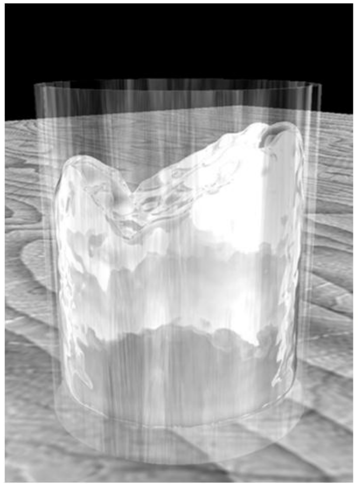




Obsah

Å CieŎa motivácia

Å Smoothed Particle Hydrodynamics

Å Modelovanie kvapalín pomocou Ļ astíc

Å Kernelové funkcie

Å Renderovanie povrchu

Å Výsledky a pokraĻ ovanie

Úvod

- Kvapaliny
- Off-line simulácia
- Real-time simulácia
  - interakcia

Predchádzajúca práca

Å Computational Fluid Dynamics (1822)

Å Navier-Stokes Equations

Å Ļ asticové systémy

CieŎ

Å Modelovanie kvapalín pomocou ļ asticových systémov postavených na Smoothed Particle Hydrodynamics

Å Real-time rýchlosŞ aby sa dalo so systémom interagovaŠ

SPH

Å Interpolaļ ná metóda pre ļ asticové systémy

Å SPH pravidlo:

$$As(r) = \sum_j m_j \frac{A_j}{\rho_j} W(r - r_j, h)$$

ï m_j ï hmotnosŠ r_j ï pozicia, ɉ $_j$ ï hustota, W ï kernelova funkcia

SPH(2)

- Rovnica pre hustoru v mieste r

$$\rho_s(r) = \sum_j m_j \frac{\rho_j}{\rho_j} W(r - r_j, h) = \sum_j m_j W(r - r_j, h)$$

Modelovanie kvapalín

Å Grid-based

ï Rovnica zachovania hmoty

ï Rovnica zachovania hybnosti (Navier-Stokes)

$$\rho\left(\frac{\partial v}{\partial t} + v \circ \nabla v\right) = -\nabla p + \rho g + \mu \nabla^2 v$$

ï g ï externé sily, µ ï viskozita kvapaliny

$$\rho\left(\frac{\partial v}{\partial t} + v \circ \nabla v\right) = -\nabla p + \rho g + \mu \nabla^{2} v$$

Rovnice pre SPH

$$\frac{\partial v}{\partial t} + v \circ \nabla v = \frac{Dv}{Dt}$$

$$f = -\nabla p + \rho g + \mu \nabla^{2} v$$

$$a_i = \frac{dv_i}{dt} = \frac{f_i}{\rho_i}$$

ï v_i ï rýchlosŠļ astice

Tlak

Å Aplikujme SPH pravidlo na: $-\nabla p$

$$f_i^{pressure} = -\nabla p(r_i) = -\sum_j m_j \frac{p_j}{\rho_j} \nabla W(r_i - r_j, h)$$

Å NesymetrickosŠ takģe upravím na:

$$f_i^{pressure} = -\sum_j m_j \frac{p_i + p_j}{2\rho_j} \nabla W(r_i - r_j, h)$$

Viskozita

Å Aplikujme SPH pravidlo na: $\mu \nabla^2 v$

$$f_i^{viscosity} = \mu \nabla^2 v(r_i) = \mu \sum_j m_j \frac{v_j}{\rho_j} \nabla^2 W(r_i - r_j, h)$$

Å Symetrizujem na:

$$f_i^{viscosity} = \mu \sum_j m_j \frac{v_j - v_i}{\rho_j} \nabla^2 W(r_i - r_j, h)$$

Povrchové trenie

Å Color field:

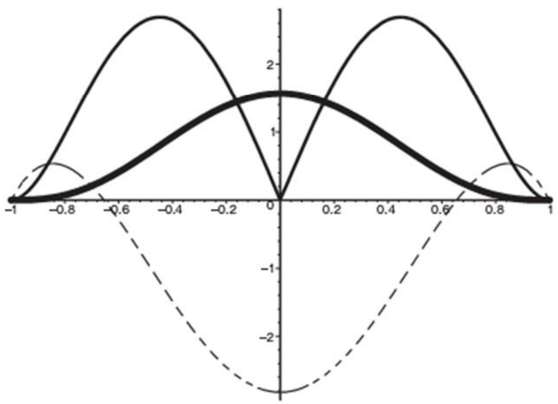
$$cs(r) = \sum_j m_j \frac{1}{\rho_j} W(r - r_j, h)$$

Å Úpravami vznikne:

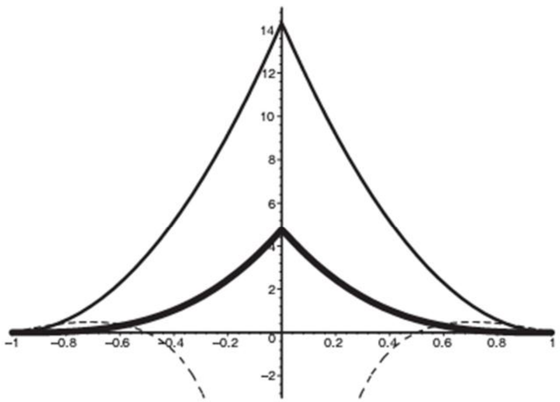
$$f^{surface} = \sigma k n = -\sigma \nabla^2 cs \frac{n}{|n|}$$

Smoothing Kernels

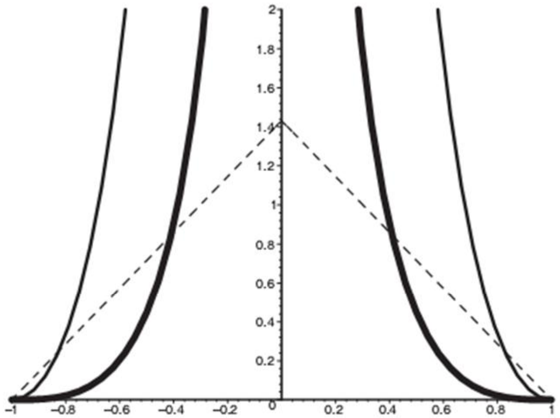
Å Pouģité kernelové funkcie:



W^{poly}



W^{press}



W^{visco}

Kernelové funkcie

$$W_{poly6}(r,h) = \frac{315}{64\pi h^9}\begin{Bmatrix} (h^2 - r^2)^3 & 0 \le r \le h \\ 0 & otherwise \end{Bmatrix}$$

$$W_{spiky}(r,h) = \frac{15}{\pi h^6}\begin{Bmatrix} (h - r)^3 & 0 \le r \le h \\ 0 & otherwise \end{Bmatrix}$$

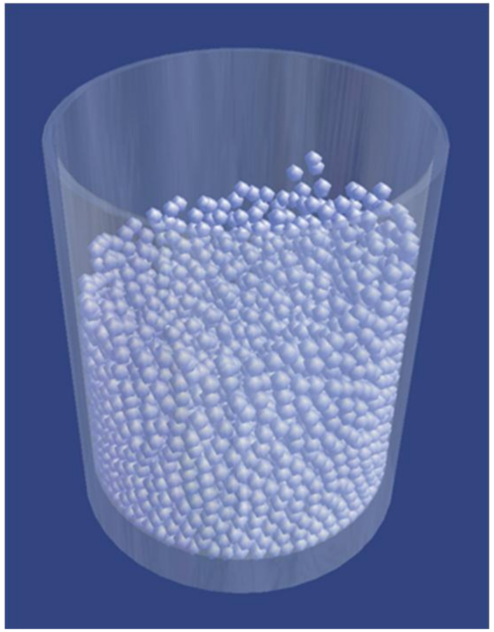
$$W_{viscosity}(r,h) = \frac{15}{2\pi h^3}\begin{Bmatrix} -\frac{r^3}{2h^3} + \frac{r^2}{h^2} + \frac{h}{2r} - 1 & 0 \le r \le h \\ 0 & otherwise \end{Bmatrix}$$

Renderovanie povrchu

Å Moģné implementácie:

- ï Point Splatting
- ï Marching Cubes

Dosiahnuté výsledky



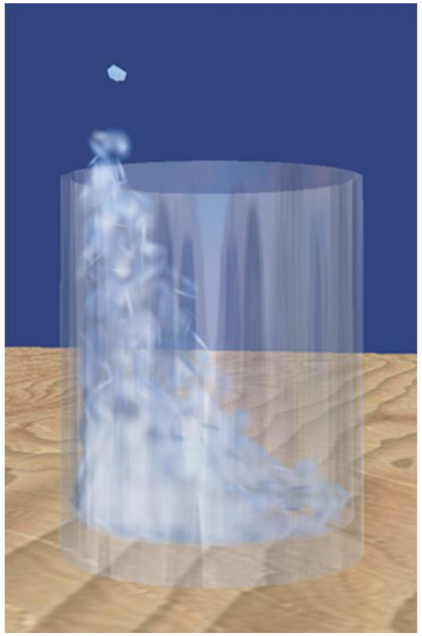
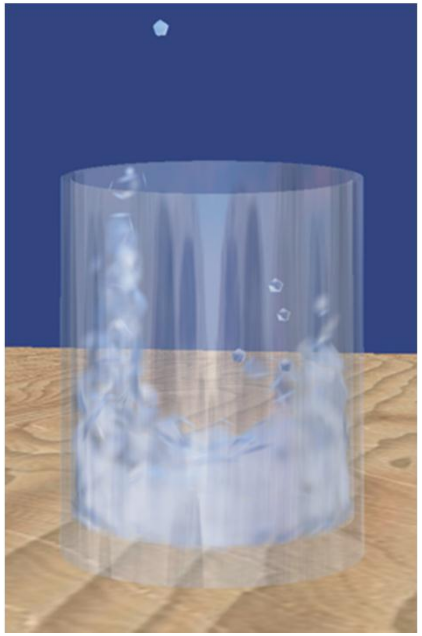
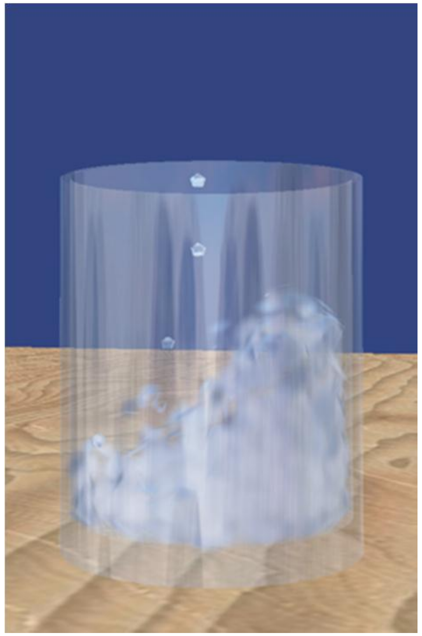
Iba ļ astice

Point splatting

Marching Cubes

Dosiahnuté výsledky(2)

Å UǵívateǑnteraguje

Dosiahnuté výsledky(3)

Å Naliatie vody do pohára:

Záver

- Å VytvoriŠmetódu na modelovanie kvapalín, ktorá pouģíva ļ asticové systémy a Smoothed Particle Hydrodynamics
- Å VŅaka kernelom stabilná a rýchla (real-time), vhodná na interakciu
- Å Renderovanie povrchu je stále otvorený problém (zvýģenie rýchlosti Marching Cubes algoritmu)

ń akujem za pozornosŠ