15-464/15-664 Reference List for March 30, 2020

We started out by talking about Smoothed Particle Hydrodynamics (SPH) simulation using notes on the Whiteboard (included at the end of this document). My notes were adapted from these slides: https://cg.informatik.uni-freiburg.de/course_notes/sim_10_sph.pdf

You may also find this tutorial useful: https://interactivecomputergraphics.github.io/SPH-Tutorial/

This paper is the one which introduced SPH to computer graphics:

Müller, Matthias, David Charypar, and Markus Gross. "Particle-based fluid simulation for interactive applications." In Proceedings of the 2003 ACM SIGGRAPH/Eurographics symposium on Computer animation, pp. 154-159. Eurographics Association, 2003.
https://dl.acm.org/doi/10.5555/846276.846298
https://www.youtube.com/watch?v=aaWqybIa4r4

Fluid Control

We then went on to discuss a number of advanced topics in fluid simulation. The first was fluid control. For example, how do we coerce a fluid into going where we want it to go or into taking on keyframes? The go-to reference for this topic is this one:

McNamara, Antoine, Adrien Treuille, Zoran Popović, and Jos Stam. "Fluid control using the adjoint method." In ACM Transactions On Graphics (TOG), vol. 23, no. 3, pp. 449-456. ACM, 2004.
http://grail.cs.washington.edu/projects/control/

The following paper builds on this approach to make it more efficient:

Pan, Zherong, and Dinesh Manocha. "Efficient solver for spacetime control of smoke." *ACM Transactions on Graphics (TOG)* 36, no. 4 (2017): 1. https://dl.acm.org/doi/abs/10.1145/3072959.301696
https://www.youtube.com/watch?v=-Sd2BTkWJX0

The following paper shows a different type of control, in this case allowing a director to manipulate the extent (width and length) of a fluid basin:

Flynn, Sean, Parris Egbert, Seth Holladay, and Bryan Morse. "Fluid carving: intelligent resizing for fluid simulation data." *ACM Transactions on Graphics (TOG)* 38, no. 6 (2019): 1-14.
https://dl.acm.org/doi/abs/10.1145/3355089.3356572
https://www.youtube.com/watch?v=bQNaaJalQc8

Fluid Style / Parameters

We then talked about approaches to control fluid style. The first attempted to transfer desired small scale features to a large scale existing flow.

Sato, Syuhei, Yoshinori Dobashi, Theodore Kim, and Tomoyuki Nishita. "Example-based turbulence style transfer." *ACM Transactions on Graphics (TOG)* 37, no. 4 (2018): 1-9.
https://dl.acm.org/doi/abs/10.1145/3197517.3201398
https://www.youtube.com/watch?v=Ie3bwzDTeSE&feature=youtu.be

The second showed how to obtain viscosity parameters from video:

Takahashi, Tetsuya, and Ming C. Lin. "Video-guided real-to-virtual parameter transfer for viscous fluids." *ACM Transactions on Graphics (TOG)* 38, no. 6 (2019): 237.
http://gamma.cs.unc.edu/ParameterTransfer/

Learning for Fluids

We then looked at two papers related to learning for fluids:

Kim, Byungsoo, Vinicius C. Azevedo, Nils Thuerey, Theodore Kim, Markus Gross, and Barbara Solenthaler. "Deep fluids: A generative network for parameterized fluid simulations." In *Computer Graphics Forum*, vol. 38, no. 2, pp. 59-70. 2019. http://www.byungsoo.me/project/deep-fluids/

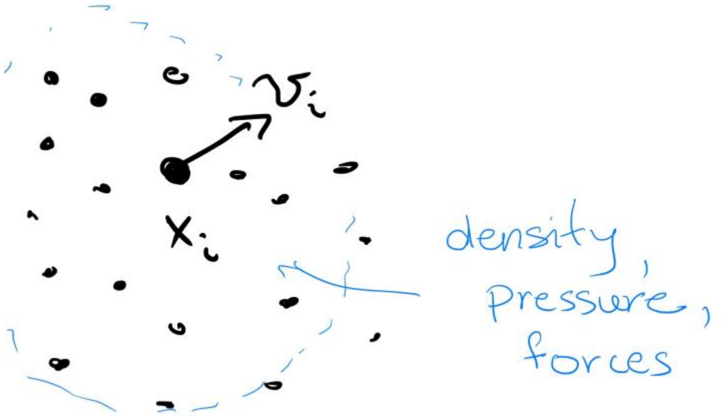
Um, Kiwon, Xiangyu Hu, and Nils Thuerey. "Liquid splash modeling with neural networks." In *Computer Graphics Forum*, vol. 37, no. 8, pp. 171-182. 2018. https://ge.in.tum.de/publications/2018-mlflip-um/

The following pages contain whiteboard notes from our class.

Navier-Stokes for SPH

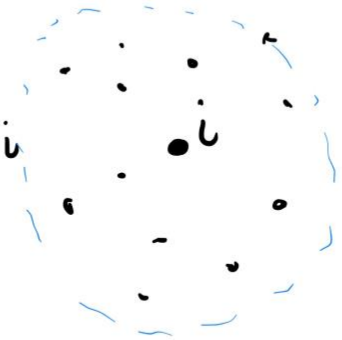
Smoothed Particle Hydrodynamics

$$\underbrace{\frac{dv_i}{dt}}_{\text{particle acceleration}} = \underbrace{-\frac{1}{\rho_i}\nabla p_i}_{\text{pressure gradient}} + \underbrace{\nu\nabla^2 v_i}_{\text{viscosity}} + \underbrace{\frac{F_i^{\text{OTHER}}}{m_i}}_{\text{e.g., gravity}}$$



SPH Solver

- find all neighbors j of particle i



- for each particle i
    - ✓ compute density ρ_i
    - ✓ compute pressure p_i
    - ✓ compute forces F_i

      pressure gradient, gravity, viscosity, …
    - update x_i and v_i

      $$v_i(t+\Delta t) = v_i(t) + \Delta t \, F_i(t)/m_i$$

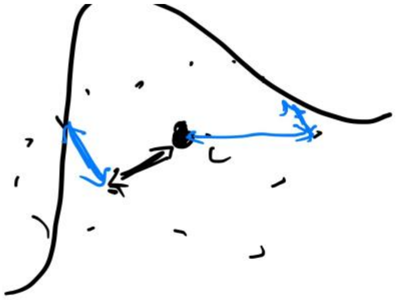
      $$x_i(t+\Delta t) = x_i(t) + \Delta t \, v_i(t+\Delta t)$$

advection

Density

$$\boxed{\rho_i = \sum_j m_j \underline{W_{ij}}}$$

Kernel



Pressure

$$\boxed{p_i = K\left(\left(\frac{\rho_i}{\rho_0}\right)^7 - 1\right)}\Bigg\}$$

State Equation

SESPH

Stiffness
(affects pressure
gradient forces)

rest
density

$$F_i^{PRESSURE} = -\frac{m_i}{\rho_i}\underline{\nabla p_i}$$

<u>symmetrical</u> SPH approximation

$$-m_i \sum_j m_j \underline{\left(\frac{p_i}{\rho_i^2} + \frac{p_j}{\rho_j^2}\right)} \underline{\nabla} W_{ij}$$

gradient of kernel

$$F_i^{VISCOSITY} = m_i \nu \underline{\nabla^2} v_i$$

$$F_i^{GRAVITY} = m_i g$$

$$\underline{F_i} = F_i^{PRESSURE} + F_i^{VISCOSITY} + F_i^{GRAVITY}$$

What Kernel

2D:

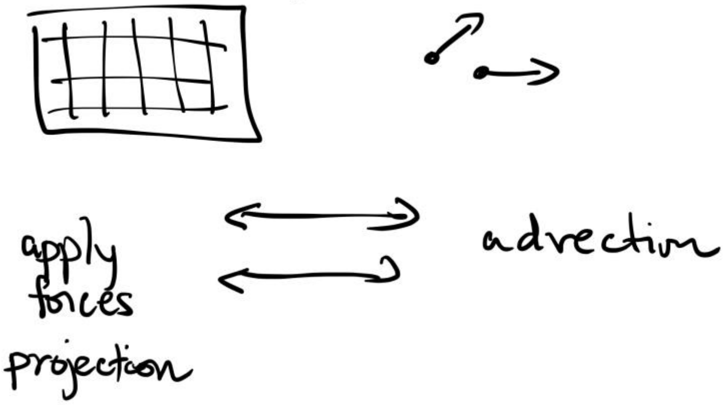
$$\boxed{W(q) = \frac{5}{14\pi h^2} \begin{cases} (2-q)^3 - 4(1-q)^3 & 0 \le q \le 1 \\ (2-q)^3 & 1 \le q \le 2 \\ 0 & q \ge 2 \end{cases}}$$

$$q = \frac{\| x_i - x_j \|}{h}$$

standard distance

$\nabla W(q)$ $\nabla^2 W$ given or calculate once

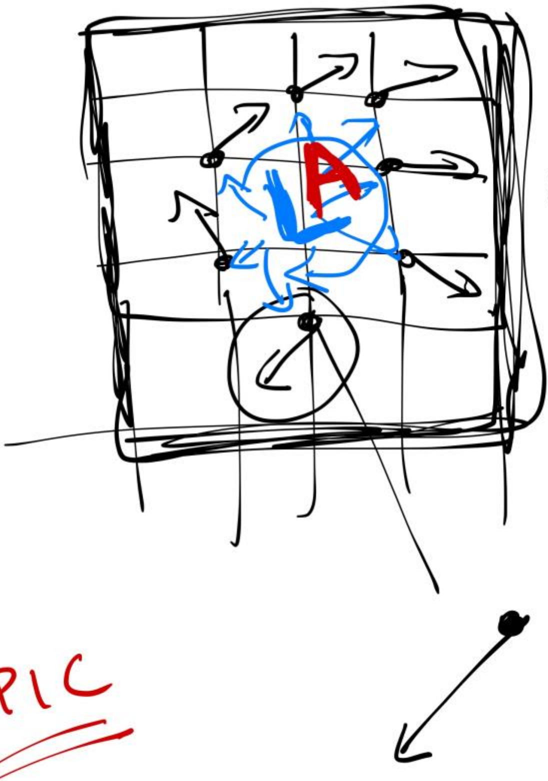
PIC, FLIP, APIC



PIC : transferred everything → too dissipative

FLIP: transferred changes → too noisy

APIC: tranferring affine information ...???



$x_i, v_i, \underline{\underline{L_i}}$

A_i

APIC