Reference List for 15-464 / 15-664 Feb 19, 2020

These course notes are an excellent introduction to writing a physically based simulator:

Andrew Witkin and David Baraff, "Physically Based Modeling: Principles and Practice," Siggraph '97 Course notes. http://www.cs.cmu.edu/~baraff/sigcourse/

We talked about how to simulate particles and how to extend a particle simulation into a spring/mass cloth simulation. A photo of my handwritten note is included at the end of this document.

The integrator you choose can determine cloth behavior, and we talked about a variety of integrators to compare, including Euler, Implicit Euler, Symplectic Euler, Verlet, and RK4. (See notes at the bottom of this document for details.) It is possible to develop a fully implicit integrator for cloth, and that is the subject of this paper:

Baraff D, Witkin A. Large steps in cloth simulation. InProceedings of the 25th annual conference on Computer graphics and interactive techniques 1998 Jul 24 (pp. 43-54). ACM. http://dl.acm.org/citation.cfm?id=280821

This paper has a good practical discussion about different integrators and discusses the design decisions behind Maya nCloth, nParticle, etc.

Stam, Jos. "Nucleus: Towards a unified dynamics solver for computer graphics." In *Computer-Aided Design and Computer Graphics, 2009. CAD/Graphics' 09. 11th IEEE International Conference on*, pp. 1-11. IEEE, 2009. http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5246818

You can find a clear writeup about the spring mass system's behavior and a reminder for how to solve those differential equations here. Reading this paper may help you to set damping parameters in a correct proportion to how you set stiffnesses.

Allen, Brian F., and Petros Faloutsos. "Misconceptions of PD control in animation." In *Proceedings of the ACM SIGGRAPH/Eurographics Symposium on Computer Animation*, pp. 231-234. Eurographics Association, 2012. http://dl.acm.org/citation.cfm?id=2422389

We talked about this paper, which talks about particle simulation with constraints and Verlet integration in the context of simulating rag doll characters for the game Hitman.

Jakobsen, Thomas. "Advanced character physics." In Game Developers Conference, pp. 383-401. 2001. http://www.gotoandplay.it/_articles/2005/08/advCharPhysics.php

I also showed some videos from a constraint based cloth simulation system written by a CMU MS student. The writeup can be found here: http://www.cs.cmu.edu/~ytoh/stickyfingers.pdf

Videos can be seen here: http://www.kentoh.com/publications/

Finally, we reviewed the following paper for an overview of point based methods in general for simulation.

Macklin, Miles, Matthias Müller, Nuttapong Chentanez, and Tae-Yong Kim. "Unified particle physics for real-time applications." *ACM Transactions on Graphics (TOG)* 33, no. 4 (2014): 153. https://dl.acm.org/citation.cfm?id=2601152

Some Simulation References

Although we spent a good amount of time looking at the nuts and bolts of simulation systems today, you probably won't be in the situation of writing your own, except for specific research purposes. Fortunately, there are many good simulation engines out there. Here are some references to get you started. There are other references in the MiniProject2 handout, and you can always see what simulation plugins and built-in capabilities are available for your favorite animation environment (e.g., Unity, Houdini…).

Open Dynamics Engine http://www.ode.org/

Bullet Physics Library http://bulletphysics.org/wordpress/

Also check out this SIGGRAPH 2011 course: http://bulletphysics.org/siggraph2011/

Karen Liu's DART http://dartsim.github.io/

Emanuel Todorov's MuJoCo http://www.mujoco.org/

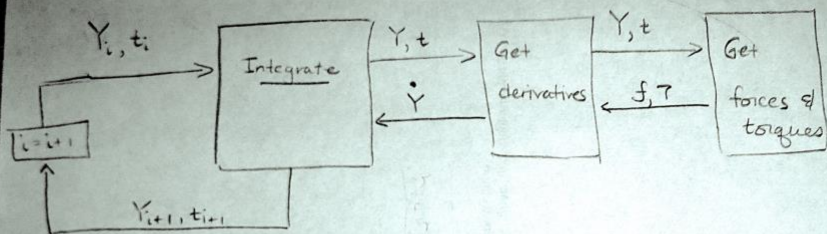
Box2D http://box2d.org/

Gazebo http://gazebosim.org/

Particle: $Y = \begin{bmatrix} x \\ v \end{bmatrix}$ $\dot{Y} = \begin{bmatrix} v \\ f/m \end{bmatrix}$

Rigid Body $Y = \begin{bmatrix} x \\ mv \\ R \\ I\omega \end{bmatrix}$ $\dot{Y} = \begin{bmatrix} v \\ f \\ \omega \times R \\ \tau \end{bmatrix}$

$\begin{bmatrix} x \\ mv \\ q \\ I\omega \end{bmatrix}$ $\begin{bmatrix} v \\ f \\ \frac{1}{2}\omega q \\ \tau \end{bmatrix}$



Euler

$$x_{i+1} = x_i + \Delta t\, v_i$$
$$v_{i+1} = v_i + \Delta t\,(f_i/m)$$

(Backward) Implicit Euler

$$x_{i+1} = x_i + \Delta t\, v_{i+1}$$
$$v_{i+1} = v_i + \Delta t\,(f_{i+1}/m)$$

Symplectic Euler

$$x_{i+1} = x_i + \Delta t\, v_{i+1}$$
$$v_{i+1} = v_i + \Delta t\,(f_i/m)$$

Verlet

$$x_{i+1} = 2x_i - x_{i-1} + \Delta t^2 \left(f_i/m\right)$$

RK4, Leapfrog

Example:

$f = -kx$ (spring)

$$x_{i+1} = x_i + \Delta t\, v_i + \frac{\Delta t^2}{m}\left(-k\, x_{i+1}\right)$$

$$x_{i+1}\left(1 + \frac{k}{m}\Delta t^2\right) = x_i + \Delta t\, v_i$$

$$x_{i+1} = \frac{x_i + \Delta t\, v_i}{\left(1 + k/m\, \Delta t^2\right)}$$

$$v_{i+1} = v_i + \Delta t\left(\frac{-k x_{i+1}}{m}\right)$$