Reference List for 15-464 / 15-664 Feb 20, 2019

The first thing we did was talk through MiniProject2. One possible focus of this second project is to explore cloth simulation.

A description of how to do basic spring-mass cloth is given on this page:

http://www.cs.cmu.edu/~15464-s13/assignments/assignment3/assignment%203%20description.htm

Many cloth simulation systems are based on this central idea. If you really want to get a spring mass cloth simulation right, my favorite reference is this one. Features to look into include (1) how collisions (including self collisions) are handled by applying impulses to the cloth particles so that these collisions are never allowed to happen and (2) how impulses are similarly applied for "strain limiting" so that the cloth never stretches beyond a desired amount.

Bridson R, Fedkiw R, Anderson J. Robust treatment of collisions, contact and friction for cloth animation. ACM Transactions on Graphics (ToG). 2002 Jul 1;21(3):594-603. http://dl.acm.org/citation.cfm?id=566623

When trying to implement good looking and efficient cloth, collision response is important. I mentioned that this paper contains a good clear description of how to handle the penalty method for contact, including friction.

Yamane, Katsu, and Yoshihiko Nakamura. "Stable penalty-based model of frictional contacts." In *Proceedings 2006 IEEE International Conference on Robotics and Automation, 2006. ICRA 2006.*, pp. 1904-1909. IEEE, 2006. https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=1641984

You can find a description of how to handle rigid body contact using impulses here:

Guendelman E, Bridson R, Fedkiw R. Nonconvex rigid bodies with stacking. In ACM Transactions on Graphics (TOG) 2003 Jul 27 (Vol. 22, No. 3, pp. 871-878). ACM. https://graphics.stanford.edu/papers/rigid_bodies-sig03/

I mentioned the option of thinking about contact as solving a Linear Complementarity problem. If you are interested to learn more, my favorite paper at the moment for setting up and solving the Linear Complementarity Problem is this one:

Jain S, Liu CK. Controlling physics-based characters using soft contacts. In ACM Transactions on Graphics (TOG) 2011 Dec 12 (Vol. 30, No. 6, p. 163). ACM. http://dl.acm.org/citation.cfm?id=2024197

For advanced reading to take a look at solving the problem of many simultaneous contacts, take a look at this paper:

Kaufman, Danny M., Shinjiro Sueda, Doug L. James, and Dinesh K. Pai. "Staggered projections for frictional contact in multibody systems." In *ACM Transactions on Graphics (TOG)*, vol. 27, no. 5, p. 164. ACM, 2008. http://www.cs.ubc.ca/labs/sensorimotor/projects/sp_sigasia08/

Going back to cloth, one problem with spring mass systems is that it can be difficult to set parameters for realistic appearance and to illustrate the different properties of different types of cloth. These two papers attempt to set parameters by optimizing to fit measurements taken on actual cloth swatches.

Wang H, O'Brien JF, Ramamoorthi R. Data-driven elastic models for cloth: modeling and measurement. InACM Transactions on Graphics (TOG) 2011 Aug 7 (Vol. 30, No. 4, p. 71). ACM. http://graphics.berkeley.edu/papers/Wang-DDE-2011-08/

Bhat, Kiran S., Christopher D. Twigg, Jessica K. Hodgins, Pradeep K. Khosla, Zoran Popović, and Steven M. Seitz. "Estimating cloth simulation parameters from video." In *Proceedings of the 2003 ACM SIGGRAPH/Eurographics symposium on Computer animation*, pp. 37-51. Eurographics Association, 2003. http://graphics.cs.cmu.edu/projects/clothparameters/

This paper addresses perceptual issues, trying to understand how simulation parameters might map to perception of cloth properties.

Sigal, Leonid, Moshe Mahler, Spencer Diaz, Kyna McIntosh, Elizabeth Carter, Timothy Richards, and Jessica Hodgins. "A perceptual control space for garment simulation." *ACM Transactions on Graphics (TOG)* 34, no. 4 (2015): 117. https://dl.acm.org/citation.cfm?id=2766971

Getting a good looking simulation is difficult, yet there are quite a number of great systems out there. We looked at these two, both of which have source code available.

Umetani, Nobuyuki, Danny M. Kaufman, Takeo Igarashi, and Eitan Grinspun. "Sensitive couture for interactive garment modeling and editing." *ACM Trans. Graph.* 30, no. 4 (2011): 90-1. http://www.cs.columbia.edu/cg/SC/

Narain, Rahul, Armin Samii, and James F. O'Brien. "Adaptive anisotropic remeshing for cloth simulation." *ACM transactions on graphics (TOG)* 31, no. 6 (2012): 152. http://graphics.berkeley.edu/resources/ARCSim/

This paper used ArcSim in a data-driven technique which used precomputation to get real-time display of clothing simulation.

Kim, Doyub, Woojong Koh, Rahul Narain, Kayvon Fatahalian, Adrien Treuille, and James F. O'Brien. "Near-exhaustive precomputation of secondary cloth effects." *ACM Transactions on Graphics (TOG)* 32, no. 4 (2013): 87. http://graphics.cs.cmu.edu/projects/exhaustivecloth/

This paper pioneered simulating cloth at the yarn level.

Kaldor, Jonathan M., Doug L. James, and Steve Marschner. "Simulating knitted cloth at the yarn level." In *ACM Transactions on Graphics (TOG)*, vol. 27, no. 3, p. 65. ACM, 2008. https://www.cs.cornell.edu/~srm/publications/SG08-knit.html

Here is a recent paper building on this work.

Leaf, Jonathan, Rundong Wu, Eston Schweickart, Doug L. James, and Steve Marschner. "Interactive design of periodic yarn-level cloth patterns." In *SIGGRAPH Asia 2018 Technical Papers*, p. 202. ACM, 2018. https://graphics.stanford.edu/projects/yarnsim/

Part of the innovation is putting some of the simulation onto the GPU to make the process more interactive. We took a quick look at this paper which also explores GPU programming to speed cloth simulation:

Tang, Min, Zhongyuan Liu, Ruofeng Tong, and Dinesh Manocha. "I-cloth: incremental collision handling for GPU-based interactive cloth simulation." In *SIGGRAPH Asia 2018 Technical Papers*, p. 204. ACM, 2018. https://dl.acm.org/citation.cfm?id=3275005

We quickly looked at this paper which tries to get contact friction right.

Li, Jie, Gilles Daviet, Rahul Narain, Florence Bertails-Descoubes, Matthew Overby, George E. Brown, and Laurence Boissieux. "An implicit frictional contact solver for adaptive cloth simulation." *ACM Transactions on Graphics (TOG)* 37, no. 4 (2018): 52. http://www-users.cselabs.umn.edu/~lixx4611/contact_friction.html

A paper that builds on Sensitive Couture for a more interesting range of patterns.

Minchen Li, Alla Sheffer, Eitan Grinspun, and Nicholas Vining. 2018. Foldsketch: enriching garments with physically reproducible folds. *ACM Trans. Graph.* 37, 4, Article 133 (July 2018). http://www.cs.ubc.ca/labs/imager/tr/2018/FoldSketch/

And finally, a paper that represents cloth simulation as an optimization problem timestep by timestep and uses a common multiresolution technique (Multigrid) to solve it efficiently.

Wang, Zhendong, Longhua Wu, Marco Fratarcangeli, Min Tang, and Huamin Wang. "Parallel Multigrid for Nonlinear Cloth Simulation." In *Computer Graphics Forum*, vol. 37, no. 7, pp. 131-141. 2018. http://www.cse.chalmers.se/~marcof/publication/pg2018/

Simulators, again:

- Bullet http://bulletphysics.org/wordpress/ and you may find this SIGGRAPH course of interest: http://bulletphysics.org/siggraph2011/michael_siggraph2011.pdf
- Karen Liu's RTQL8 http://www.cc.gatech.edu/~karenliu/RTQL8.html and the valuable writeups available on that web page if you want to learn more about the dynamics of articulated characters and how these simulators are written.

- Karen Liu's DART http://dartsim.github.io/index.html which is a follow-on to RTQL8.
- Emo Todorov's MuJoCo http://www.mujoco.org/ which was developed at least partially with the goal of doing optimization of motions that include many contacts.
- Box2D http://box2d.org/about/ which does very well with 2D simulations
- Gazebo http://gazebosim.org/ which has options for using different simulation engines
- FleX https://developer.nvidia.com/flex which is entirely particle based.
- I also mentioned ARCSim and Sensitive Couture for cloth simulation
  http://graphics.berkeley.edu/resources/ARCSim/
  http://www.cs.columbia.edu/cg/SC/