Reference List 15-464 / 15-664 February 22, 2023

Today we spoke about contact and collision detection. We used the slide deck linked from the course web pages to direct the conversation and spoke about the following topics:

- Brief notes on collision detection
- Collision response
  - Impulse methods
  - Penalty methods
  - Constraint based methods

Witkin and Baraff's SIGGRAPH course notes are a great place to start for a basic introduction (and for how to derive the impulse calculation).

Andrew Witkin and David Baraff, Physically Based Modeling: Principles and Practice, Online SIGGRAPH 1997 Course Notes, 1997 https://www.cs.cmu.edu/~baraff/sigcourse/

The course textbook, if you already have it, also has a wealth of information that is useful for getting started:

Rick Parent. Computer Animation: Algorithms and Techniques, 3rd Edition. Chapter 7.4, September 2012

The go-to reference for fully understanding basic impulse based techniques is still Brian Mirtich's 1996 dissertation:

Brian Vincent Mirtich. Impulse-based Dynamic Simulation of Rigid Body Systems. UC Berkeley PhD thesis, Fall 1996
https://people.eecs.berkeley.edu/~jfc/mirtich/thesis/mirtichThesis.pdf

Penalty-based methods compute the contact forces based on the penetration depth and normal velocity of a pair of objects using linear or nonlinear spring-damper model. A classic implementation can be found here:

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/document/1641984

We talked about how to do the penalty method "right." Note that there is code available for this technique on the linked web page.

Hongyi Xu, Yili Zhao, and Jernej Barbič. Implicit multibody penalty-based distributed contact. IEEE transactions on visualization and computer graphics 20.9 (2014): 1266-1279. https://viterbi-web.usc.edu/~jbarbic/implicitContact/

Constraint-based methods compute constraint forces that are designed to cancel any external accelerations that would result in interpenetration. We talked about how the idea that you can either accelerate away or apply force but not both leads to a Linear Complementarity Problem.

The overall idea that we can solve this problem by applying forces to eliminate problematic accelerations is supported by the fact that the change in generalized acceleration of any character or multibody system, no matter how complex, is linearly related to the change in generalized forces applied to that system. I gave a quick glance at one of my favorite references which makes this point if you want to learn more:

Kokkevis, Evangelos. "Practical physics for articulated characters." In *Game Developers Conference*, vol. 2004. 2004. http://ubm-twvideo01.s3.amazonaws.com/o1/vault/gdc04/slides/practical_physics_for.pdf

These references can get you started with setting up, solving, and understanding constraint based systems:

https://www.toptal.com/game/video-game-physics-part-iii-constrained-rigid-body-simulation

Michael Bradley Cline, Rigid Body Simulation with Contact and Constraints. UBC Master thesis. 2002 https://open.library.ubc.ca/cIRcle/collections/ubctheses/831/items/1.0051676

David Baraff. Non-penetrating Rigid Body Simulation. Eurographics 1993 State of the Art Reports. https://www.cs.cmu.edu/~baraff/papers/eg93.pdf

The SIGGRAPH 2022 course on contact is here:

Andrews, Sheldon, Kenny Erleben, and Zachary Ferguson. "Contact and friction simulation for computer graphics." In *ACM SIGGRAPH 2022 Courses*, pp. 1-172. 2022. https://siggraphcontact.github.io/

The three recent papers which we did not have time to talk about are these:

Li, Minchen, Zachary Ferguson, Teseo Schneider, Timothy R. Langlois, Denis Zorin, Daniele Panozzo, Chenfanfu Jiang, and Danny M. Kaufman. "Incremental potential contact: intersection-and inversion-free, large-deformation dynamics." *ACM Trans. Graph.* 39, no. 4 (2020): 49. https://ipc-sim.github.io/

Ferguson, Zachary, Minchen Li, Teseo Schneider, Francisca Gil-Ureta, Timothy Langlois, Chenfanfu Jiang, Denis Zorin, Danny M. Kaufman, and Daniele Panozzo. "Intersection-free rigid body dynamics." *ACM Transactions on Graphics* 40, no. 4 (2021). https://ipc-sim.github.io/rigid-ipc/

Lan, Lei, Danny M. Kaufman, Minchen Li, Chenfanfu Jiang, and Yin Yang. "Affine body dynamics: Fast, stable & intersection-free simulation of stiff materials." *ACM Trans. Graph.* 41, no. 4 (2022). https://www.math.ucla.edu/~minchen/