15-464 / 15-664 Reference List for Jan 29, 2020

We started with a brief review on the board of Jacobian based approaches to inverse kinematics taken from this paper, noting that these approaches have some limitations due to their iterative nature, slow speed, lack of repeatability, difficulty of selecting good parameters, and tendency to become "tangled up" for lengthy chains. However, they are widely used and considered "go-to" techniques for character IK:

Buss, Samuel R. "Introduction to inverse kinematics with jacobian transpose, pseudoinverse and damped least squares methods." *IEEE Journal of Robotics and Automation* 17 (2004): 1-19. http://web.cse.ohio-state.edu/~parent/classes/694A/Lectures/Material/IKsurvey.pdf

We showed an example of this in Monday's class that involved character posing with a two-level priority system, where the point which the user clicks and drags is given top priority as the IK target, and constraint points are satisfied as well as possible with secondary priority using projection into the nullspace. For details, have a look at this paper:

Yamane, Katsu, and Yoshihiko Nakamura. "Natural motion animation through constraining and deconstraining at will." *Visualization and Computer Graphics, IEEE Transactions on* 9, no. 3 (2003): 352-360. http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=1207443

The classic Jacobian based approach to IK has been parallelized to work quickly for many degree of freedom characters on a modern GPU. We took a brief look at this paper, which is also worth reading for one more description of the classic Jacobian based approach to inverse kinematics.

Harish P, Mahmudi M, Callennec BL, Boulic R. Parallel inverse kinematics for multithreaded architectures. ACM Transactions on Graphics (TOG). 2016 May 25;35(2):19. http://dl.acm.org/citation.cfm?id=2887740

However, in some applications, even faster results may be desired. For fast IK, CCD is the standby approach, as we saw on Monday.

Lander, Jeff. "Oh My God, I Inverted Kine!." *Game Developer Magazine* 9 (1998): 9-14. http://graphics.cs.cmu.edu/nsp/course/15464-s15/www/lectures/lec06/jlander_gamedev_sept98.pdf

Lander, Jeff. "Making kine more flexible." *Game Developer Magazine* 1, no. 15-22 (1998): 2. http://graphics.cs.cmu.edu/nsp/course/15464-s15/www/lectures/lec06/jlander_gamedev_nov98.pdf

However, CCD can create artifacts such as the end effector curling in on itself. The following approach is also very fast and in the same style, but seems to create more visually pleasing and consistent results under some circumstances.

Aristidou, Andreas, and Joan Lasenby. "FABRIK: a fast, iterative solver for the inverse kinematics problem." *Graphical Models* 73, no. 5 (2011): 243-260.
http://www.andreasaristidou.com/FABRIK.html
https://www.youtube.com/watch?v=tN6RQ4yrNPU

You can see from the other papers listed on the same webpage that the authors have made this model work for humanoid characters, using heuristics to reconstruct full body character poses from a few markers or end effector trajectories.
https://www.youtube.com/watch?v=wjn19jBzJCE

The following classic IK paper points out that using iterative approaches does not really make sense if we only want the final pose. Why not pose the problem as a more general optimization problem and let one of the vast library of solvers out there do the work of finding an answer? I think this is an important idea that we should consider any time we are about to choose or implement an IK algorithm.

Zhao, Jianmin, and Norman I. Badler. "Inverse kinematics positioning using nonlinear programming for highly articulated figures." *ACM Transactions on Graphics (TOG)* 13, no. 4 (1994): 313-336.
http://ai.stanford.edu/~latombe/cs99k/2000/badler.pdf

Inverse kinematics is possible even when you have only a mesh and no skeleton at all. We took a look at the following paper, which is the classic paper on this topic. The second offers suggestions for improvements.

Sumner, Robert W., Matthias Zwicker, Craig Gotsman, and Jovan Popović. "Mesh-based inverse kinematics." In *ACM Transactions on Graphics (TOG)*, vol. 24, no. 3, pp. 488-495. ACM, 2005.
http://people.csail.mit.edu/sumner/research/meshik/

Wampler K. Fast and reliable example-based mesh IK for stylized deformations. ACM Transactions on Graphics (TOG). 2016 Nov 11;35(6):235.
http://dl.acm.org/citation.cfm?id=2982433

If you are interested in reading further, you may want to take a look at the following references, which we did not get to in class, but which all offer interesting twists on inverse kinematics.

The following paper covers posing using lines of action and has been used as a final project topic in this class.

Guay, Martin, Marie-Paule Cani, and Rémi Ronfard. "The line of action: an intuitive interface for expressive character posing." *ACM Transactions on Graphics (TOG)* 32, no. 6 (2013): 205.
https://dl.acm.org/citation.cfm?id=2508397
https://www.youtube.com/watch?v=QgrQuBwlbSE

This paper creates poses from silhouette drawings. You may check whether their software is available online to try out.

Bessmeltsev M, Vining N, Sheffer A. Gesture3D: posing 3D characters via gesture drawings. ACM Transactions on Graphics (TOG). 2016 Nov 11;35(6):165. http://dl.acm.org/citation.cfm?id=2980240
https://www.youtube.com/watch?v=8C3uZOXLBIA

This paper which adds physics cleanup to motions in an interactive keyframing setup.

Rabbani, Amir H., and Paul G. Kry. "PhysIK: Physically Plausible and Intuitive Keyframing." In *Graphics Interface*, pp. 153-161. 2016. https://dl.acm.org/citation.cfm?id=3076161
https://www.youtube.com/watch?v=UmwAR4wnYIM

.. and this paper uses anatomical constraints for IK for the human hand.

Aristidou, Andreas. "Hand tracking with physiological constraints." *The Visual Computer* 34, no. 2 (2018): 213-228. https://link.springer.com/article/10.1007/s00371-016-1327-8
https://www.youtube.com/watch?v=ajSU_oOAido

This paper uses machine learning techniques to model human motion with the goal of constructing very realistic looking motions from a few “handles” or “pins.”

Huang, Jing, Qi Wang, Marco Fratarcangeli, Ke Yan, and Catherine Pelachaud. "Multi-Variate Gaussian-Based Inverse Kinematics." In *Computer Graphics Forum*, vol. 36, no. 8, pp. 418-428. 2017.
https://onlinelibrary.wiley.com/doi/full/10.1111/cgf.13089
http://www.cse.chalmers.se/~marcof/publication/cgf2017/

This paper has a similar goal

Holden, Daniel, Jun Saito, and Taku Komura. "A deep learning framework for character motion synthesis and editing." *ACM Transactions on Graphics (TOG)* 35, no. 4 (2016): 138.
https://dl.acm.org/citation.cfm?id=2925975
https://www.youtube.com/watch?v=urf-AAIwNYk

And this one allows you to move around in an “emotion space.”

Aristidou, Andreas, Qiong Zeng, Efstathios Stavrakis, KangKang Yin, Daniel Cohen-Or, Yiorgos Chrysanthou, and Baoquan Chen. "Emotion control of unstructured dance movements."
In *Proceedings of the ACM SIGGRAPH/Eurographics Symposium on Computer Animation*, p. 9. ACM, 2017. https://dl.acm.org/citation.cfm?id=3099566
https://www.youtube.com/watch?v=dkrMOQel8rU

You may also be interested in this paper, which allows puppeteering non-humanlike characters using your entire body. This one has been the topic of a final project for this class. The students brought in a Kinect and let us try it out.

Seol Y, O'Sullivan C, Lee J. Creature features: online motion puppetry for non-human characters. InProceedings of the 12th ACM SIGGRAPH/Eurographics Symposium on Computer Animation 2013 Jul 19 (pp. 213-221). ACM. http://dl.acm.org/citation.cfm?id=2485903