Reference List 15-464 / 15-664 Feb 1, 2023

We started class by looking at a couple of recent papers that use machine learning to tackle the problems of rigging and skinning.

Xu, Zhan, Yang Zhou, Evangelos Kalogerakis, Chris Landreth, and Karan Singh. "RigNet: neural rigging for articulated characters." *ACM Transactions on Graphics (TOG)* 39, no. 4 (2020): 58-1.
https://zhan-xu.github.io/rig-net/

Li, Peizhuo, Kfir Aberman, Rana Hanocka, Libin Liu, Olga Sorkine-Hornung, and Baoquan Chen. "Learning skeletal articulations with neural blend shapes." *ACM Transactions on Graphics (TOG)* 40, no. 4 (2021): 1-15.
https://peizhuoli.github.io/neural-blend-shapes/

I mentioned that skinning research can be divided into three categories: physics based, example based, and geometry based.

We then had a quick look at geometry based methods for skinning, which are widely used in production, specifically Linear Blend Skinning (LBS) and Dual Quaternion Skinning (DQS).

This SIGGRAPH 2014 course contains a great deal of useful information, including details about these techniques.

Alec Jacobson, Zhigang Deng, Ladislav Kavan, J. P. Lewis.
Skinning: Real-time Shape Deformation
SIGGRAPH Course, 2014.

Linear blend skinning (LBS) and its problems are described in the first section of the SIGGRAPH course notes. There is a nice description of the candy wrapper effect.

Much research has focused on maintaining the speed and ease of use of LBS and removing the artifacts. I showed a video from this paper, which uses dual quaternion blending to remove twisting artifacts:

Kavan, Ladislav, Steven Collins, Jiří Žára, and Carol O'Sullivan. "Geometric skinning with approximate dual quaternion blending." *ACM Transactions on Graphics (TOG)* 27, no. 4 (2008): 105.
http://dl.acm.org/citation.cfm?id=1409627
https://www.youtube.com/watch?v=LUOJccOZfWQ

We then began to talk about quaternions, following this reference:
https://www.essentialmath.com/GDC2013/GDC13_quaternions_final.pdf

You may also want to refer back to the 15-462/15-662 course materials on the topic, e.g.,:
http://15462.courses.cs.cmu.edu/spring2019/lecture/3Drotate

What do we absolutely need to know?

- How to represent a rotation as a quaternion (page 43 of GDC slides)
- What does a given quaternion mean (i.e., in terms of axis and angle of rotation)
- How do we use a quaternion to accomplish a rotation? (page 44 of GDC slides)

However, if you are interested in geometric intuition, take a look at the relationship between quaternion rotation and Rodrigues formula (page 24 / 45 of GDC slides). The slide deck also outlines a matrix representation of quaternions, discussing the analogy of each constant matrix to a different complex number, if you find that more insightful!

I also really like this paper for talking about the mathematics of 3D rotations, especially the use of the 3D exponential map to avoid using the 4D quaternion representation for things like angle displacements and incremental rotations.

Grassia, F. Sebastian. "Practical parameterization of rotations using the exponential map." *Journal of graphics tools* 3, no. 3 (1998): 29-48.
http://www.cs.cmu.edu/afs/cs.cmu.edu/user/spiff/www/moedit99/expmap.pdf

The rest of the references in this document cover things not really discussed in class.

If you are interested in learning more about dual quaternions, this paper is one of many overview / tutorials which explain the idea:

Leclercq, Guillaume, Philippe Lefèvre, and Gunnar Blohm. "3D kinematics using dual quaternions: theory and applications in neuroscience." Frontiers in behavioral neuroscience 7 (2013): 7.
https://www.frontiersin.org/articles/10.3389/fnbeh.2013.00007/full

Here are a couple of other useful references. The first explains how linear interpolation for quaternions differs from proper spherical interpolation.
http://number-none.com/product/Hacking%20Quaternions/

The second gives a little bit of an introduction to what dual quaternions are and why they are useful (e.g., see the section on Dual Quaternion as a Rigid Transform).
http://simonstechblog.blogspot.com/2011/11/dual-quaternion.html

For example-based approaches, we talked very very briefly about pose-space deformation (an example-based approach). Here is the classic paper on this topic.

Lewis, John P., Matt Cordner, and Nickson Fong. "Pose space deformation: a unified approach to shape interpolation and skeleton-driven deformation." In *Proceedings of the 27th annual conference on Computer graphics and interactive techniques*, pp. 165-172. 2000.
https://dl.acm.org/doi/10.1145/344779.344862
https://www.youtube.com/watch?v=XPxRftplwJM

Caging is a geometry-based approach that provides the animator with relatively sparse handles to control shape:

Corda, Fabrizio, Jean-Marc Thiery, Marco Livesu, Enrico Puppo, Tamy Boubekeur, and Riccardo Scateni. "Real-Time Deformation with Coupled Cages and Skeletons." In *Computer Graphics Forum*, vol. 39, no. 6, pp. 19-32. 2020.
http://pers.ge.imati.cnr.it/livesu/papers/CTLPBS20/CTLPBS20.html

Here are two examples of physics-based approaches. Physics based approaches are designed to capture effects such as skin jiggle that result from dynamic motions and impacts that cannot be captured from static pose alone.

Kim, Meekyoung, Gerard Pons-Moll, Sergi Pujades, Seungbae Bang, Jinwook Kim, Michael J. Black, and Sung-Hee Lee. "Data-driven physics for human soft tissue animation." ACM Transactions on Graphics (TOG) 36, no. 4 (2017): 1-12.
https://ps.is.tuebingen.mpg.de/publications/meekyoung-siggraph

Mukai, Tomohiko, and Shigeru Kuriyama. "Efficient dynamic skinning with low-rank helper bone controllers." ACM Transactions on Graphics (TOG) 35, no. 4 (2016): 1-11. https://mukai-lab.org/publications/siggraph2016/

Here are two additional papers that use example-based techniques. Remember that example based techniques are based on the principle that the correct weights may not be constant over the pose space and the way to get good results is to fix up and store numerous artist generated (or captured) examples at different poses and blend between them.

A classic example based approach from the Max Plank group that I mentioned is given here:

Loper, Matthew, Naureen Mahmood, Javier Romero, Gerard Pons-Moll, and Michael J. Black. "SMPL: A skinned multi-person linear model." ACM transactions on graphics (TOG) 34, no. 6 (2015): 1-16. https://smpl.is.tue.mpg.de/

The question also came up in class as to whether it is important to model the underlying anatomy to obtain good skinning results. This paper shows one example of the idea:

Ali-Hamadi, Dicko, Tiantian Liu, Benjamin Gilles, Ladislav Kavan, François Faure, Olivier Palombi, and Marie-Paule Cani. "Anatomy transfer." ACM Transactions on Graphics (TOG) 32, no. 6 (2013): 1-8.
https://dl.acm.org/doi/abs/10.1145/2508363.2508415