Advisor’s report on PhD study progress and dissertation thesis of

RNDr. Petr Kadlecek

PhD study progress

Petr was introduced to me by Jaroslav Krivanek at HiVisComp 2013, because Petr was motivated by his successful previous research in haptics (with 2 publications) and wanted to focus his PhD studies on physics-based simulation methods for computer animation. Because Jaroslav's research focused mainly on rendering, he asked me to co-advise Petr. Petr rose to the occasion and joined our research group at the University of Utah in 2015 and proactively connected not only with other PhD students in our group, but also with experts in other departments, in particular the 3D scanning lab at the J. W. Marriott Library (named after a Utah philanthropist who founded the well-known hotel chain) and the Department of Radiology, which enabled us to acquire MRI head scans used in Petr's research. Petr also remotely but actively collaborated with our colleagues and co-authors from EPFL, Switzerland and even hosted Alex Ichim's visit to Utah. Thanks to his connections, expertise and willingness to help others, Petr helped other PhD students at Utah almost as a second advisor. This also earned him co-authorship on Dimitar Dinev's 2020 publication, even though it's not part of Petr's thesis.

Dissertation thesis

The topic of Petr's thesis is physics-based simulation of anatomical models for applications in computer animation. Anatomical models have been used in film, visual effects (VFX) and games, but only in forward simulation, where the users must specify 3D geometry of bones, muscles etc., physical simulation parameters and kinematic motion of the bones and the forward simulator computes the motion of the soft tissues. Crafting the inputs to forward simulators that produces the desired results requires significant experience which gave rise to specialized job positions such as Creature Technical Directors. Petr's thesis focuses on the complementary problem of inverse simulation, whose goal is to effectively automate some of the work traditionally done by Creature TDs. In inverse simulation, we provide data how the simulation outputs should ideally look like, and the inverse simulator optimizes an anatomical model and simulation parameters automatically.

Petr dived into several important inverse simulation topics, starting with full body characters. The difficult aspect in this case is large skeletal motion, such as the shoulders which have a significant range of motion -- and the surrounding soft tissues must deform appropriately in all poses. Petr led the implementation and experimentation effort which resulted in his first ACM TOG publication (2016). Its main contribution was successful demonstration of general full-body inverse simulation, which required solving un-anticipated challenges such as degeneracies in the standard method for computing the deformation gradient (this problem does not exist in forward simulation where the rest pose is fixed).

In parallel, we've been approached by our colleagues from EPFL who created the FaceShift startup (which was acquired by Apple and formed the basis of ARKit). Our vision was to create advanced facial animation by combining traditional data-driven blendshape methods with physics-based simulation. Petr offered his expertise and code and worked closely with an EPFL PhD student Alex Ichim towards the next publication on inverse simulation for faces. In this case, the challenge is to achieve sufficient precision to explain the details of facial expressions. A small error on e.g., the bicep bulge usually goes unnoticed, but a small error in e.g., a smile often leads to "uncanny" results. Petr and Alex came up with a novel activation mechanism for human facial expressions that achieves higher precision than previous methods and retains compatibility with blendshape-based methods (which also means the method is compatible with standard face trackers, such as ARKit).

When Alex graduated, Petr continued on his own to push the realism of physics-based facial animation even further. To this end, he obtained MRI scans of his own head and learned the underlying medical imaging techniques to process the data. While not novel research, this contributed by Petr's professional growth and breadth of expertise. Because MRI scans are impractical for capturing facial expressions, Petr augmented the data with surface 3D scans and proposed a clever idea of varying the directions of gravity, which was found to create significant variations in the sagging of facial tissues. Petr combined this novel dataset with improved physics-based models (e.g., included pre-strain) and obtained the world's most accurate physics-based face expression model learned from data.

Conclusion

Completion of Petr's thesis was delayed by a combination of external factors, but his ideas and results have been very well received by the computer graphics community and even some experts in other areas, in particular medical imaging and biomechanics. Petr's thesis shows that more advanced machine learning models incorporating the laws of physics may be possible, avoiding re-learning these laws from data. Future research directions are uncertain, but I am confident that Petr deserves the Ph.D. degree.

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