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February 20, 2023

To whom it may concern

Report on the Ph.D. thesis „Inverse Anatomical Modeling and Simulation of Virtual Humans" by Petr Kadleček

Developing realistic virtual characters is one of the long-standing grand challenges in Computer Graphics. Virtual characters have numerous applications in areas such as visual effects, communication, fashion, medicine, fitness, and AI-driven assistants. For all these applications, person-specific animatable virtual models are required. Unfortunately, obtaining such models is usually highly challenging and labor-intensive, requiring artists in the loop. One aspect that makes the problem extremely difficult is the so-called uncanny valley effect: Imperfect replicas result in uncanny and negative emotional responses of viewers, which are trained since childhood to recognize subtle facial expressions. Therefore, new computational models and efficient representations that allow obtaining high-quality models from sparse data are of outermost importance. A natural and promising approach to address this problem, as proposed in this work, is to develop anatomically-inspired models, and acquire their parameters from real-world scans.

Petr Kadleček has become one of the experts in the field of physics-based virtual human animation and modeling. He has developed methods and systems that explore differentiable forward simulation in combination with general optimization techniques to address inverse anatomical modeling problems. A big advantage of this approach, compared to pure data-driven approaches, is that these models can generalize to unseen scenarios, for example allowing the virtual character to make a handstand and thereby changing the direction of gravity .

Petr Kadleček's algorithms build on generic finite element approaches and material models which are theoretically well founded in continuum mechanics, and motivated by human anatomy. The underlying representations are carefully chosen to be sufficiently expressive, while still allowing to be fitted to a relatively small amount of data. These generic schemes are applied to inverse modeling of the human bodies and faces. The thesis is based on two technical papers that were published in ACM Transactions on Graphics, the most prestigious journal in the field, and one paper published in the the ACM proceedings of Computer Graphics and Interactive Techniques.

Petr Kadleček's thesis starts with introducing and motivating the problem in Chater 1. In Chapter 2 he thoroughly introduces the notation and fundamental concepts for simulating soft tissues, the finite element method, material models and integration schemes. It also discusses performance aspects and strategies for efficiently computing solutions. The following chapters consistently build on the introduced problem formation and notation.

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Chapter 3 introduces the topic of solving inverse problems. It familiarizes the reader with general techniques such as inverse kinematics, the adjoint method, and equilibrium constraint method that will be applied in the following Chapters to solve application-specific problems.

Building on Chapter 2 and Chapter 3, Chapter 4 investigates inverse human body modeling. It presents a method to reconstruct a personalized volumetric physics-based human body model, by solving a challenging non-linear optimization problem including bone parameters, joint angles, rest pose, and muscle growth. A core technical contribution is how this problem is solved robustly. This is achieved through clever regularization, including a novel symmetric as-rigid-as-possible energy formulation. The thesis also illustrates how this model can be used for animation. The contribution clearly extends the state of the art, with the closest work probably being anatomy transfer by Dicko et al. and its extensions.

Chapter 5 subsequently focuses on the face. It presents two approaches, motivated by different types of potentially available input data. The first part builds on facial surface scans. It adapts a template model that includes rigid bone structures, active muscle tissue, and passive tissue to the surface scans, yielding a volumetric simulation model of the face. While following a similar mechanism as in Chapter 4, one highlight is the automatic estimation of muscle fibre directions. The second part illustrates how model parameters can be estimated from MRI scans, exploiting the effect of gravity. The reconstructed models look very convincing and demonstrate that the proposed technique works. The applicability of the models is demonstrated in several use cases, such as applying inertia, interaction with external forces and objects, simulating muscle paralysis, and other face modifications.

Finally, the Chapter Conclusion summarizes the three presented frameworks from the perspectives of simulation, optimization, and animation, and raises challenges such as model genelization and modeling level of detail.

Overall, Kadleček's dissertation contains several contributions that advance the state of the art. Kadleček's results include novel insights in inverse modeling and optimization of anatomically-based virtual humans. With his contributions he expanded the boundary of virtual characters, opening up novel paths for facial and body animation. His algorithms and system implementations also compel with tangibly practical applications. Petr Kadleček has published and presented his work at well-established, peer-reviewed top journals in the field. The thesis is well written and meets a balance between technical discussions and illustrations, making it attractive to read for both experts and non-expert readers. His work has already gained attention in the research community. I am also very confident that his work will keep inspiring follow-up work of independent research groups.

In summary, I am happy to report that Petr Kadleček has made significant novel contributions to the field. The thesis clearly proves the authors ability for creative scientific work. I believe the thesis is of high quality. I recommend that the faculty of mathematics and physics at Charles University accepts Petr Kadleček's thesis without reservation.

Respectfully,

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