Toward Real-Time Continuous System Simulation for Interactive Environments

Doug L. James
Department of Computer Science, The Robotics Institute
Carnegie Mellon University
5000 Forbes Avenue, Pittsburgh, PA, 15213
djames@cs.cmu.edu, (412)-268-5505
http://www.ri.cmu.edu/people/james_doug.html

Motivation

Algorithms for real-time simulation of continuous physical systems, such as realistic deformable objects, are an important research frontier for the building of complex interactive virtual environments. Many applications stand to benefit including biomedical simulation, virtual assembly (and destructive disassembly), haptic rendering, robotic manipulation, character animation, and virtual training.

Progress on Data-Driven Simulation

Our simulation approaches exploit precomputation to build efficient data-driven representations of physical systems. Interactive simulation algorithms are based on the fast linear superposition of precomputed quantities, such as Green's functions [2, 3, 1], vibrational modes [4], or other statistical quantities [5]. There are numerous benefits of the data-driven approach to physical modeling.

Output-Sensitive Simulation: Data-driven models permit high-speed simulation using output-sensitive algorithms, i.e., *random simulation*. This allows a subset of the model to be exclusively simulated at a lower cost. For example, it is possible to simulate just the model's boundary (see Fig. 1), or easily answer a global query on the system.

Figure 1: *Interactive deformable characters* [2, 4]

Haptic Force-Feedback: Output-sensitive data-driven simulation is ideal for haptic force-feedback (see Fig. 2). It enables algorithms for *fast constraint handling*, and contact forces may be computed exclusively, and therefore efficiently at high rates, even on modest computing platforms.

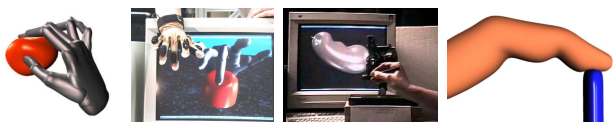

Figure 2: *Haptic force-feedback and contact simulation* [3, 1]

Multiresolution Data Models and Algorithms: Multiresolution techniques aid in generating efficient representations of large precomputed data-driven models. Also, multiresolution fast-summation algorithms can accelerate simulation speeds by controlling the amount of information managed by the data-driven constraint solver.

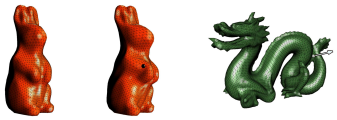

Figure 3: *Multiresolution deformable models* [1]

Synthesis on Programmable Graphics Hardware: Another benefit of output-sensitive synthesis is that deformed triangles can be computed independently on SIMD hardware. Several of our physical models [4, 5] are synthesizable on commodity programmable graphics hardware at virtually no cost to the main CPU.

Figure 4: *FEM simulation on graphics hardware* [4, 5]

Reality-Based Modeling: Finally, data-driven representations of physical systems can also be estimated from real world measurements using reality-based modeling techniques (see Pai et al. [6]).

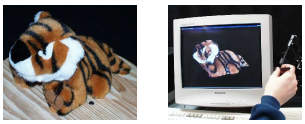

Figure 5: *Reality-based modeling* [6]

References and Collaborators

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[4] Doug L. James and Dinesh K. Pai. DyRT: Dynamic Response Textures for Real Time Deformation Simulation with Graphics Hardware. In *SIGGRAPH 2002 Conference Proceedings*, Annual Conference Series. ACM SIGGRAPH, Addison Wesley, 2002.

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[6] Dinesh K. Pai, Kees van den Doel, Doug L. James, Jochen Lang, John E. Lloyd, Joshua L. Richmond, and Som H. Yau. Scanning Physical Interaction Behavior of 3D Objects. In *SIGGRAPH 2001 Conference Proceedings*. ACM SIGGRAPH, 2001.