Soft Articulated Body Simulation with Fast Contact Handling

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The Challenge

Fast contact handling of soft articulated bodies is a computationally challenging problem, in part due to complex interplay between skeletal and surface deformation. We present a fast, novel algorithm based on a layered representation for articulated bodies that enables physically-plausible simulation of animated characters with a high-resolution deformable skin in real time. Our algorithm gracefully captures the dynamic skeleton-skin interplay through a novel formulation of elastic deformation in the pose space of the skinned surface.

Our approach for simulating soft characters with contact constraints constitutes perhaps the first unified framework for real-time modeling of skeletal deformations, surface deformation due to contact, and their interplay on object surfaces with thousands of degrees of freedom. We are able to achieve interactive simulation rates on models with challenging contact configurations as illustrated in Fig. 2.

The Approach

Our algorithm builds upon a conceptually simple, effective, and commonly used *layered representation* for soft characters in computer animation, which is essentially an integration of articulated body dynamics and skinning with displacement

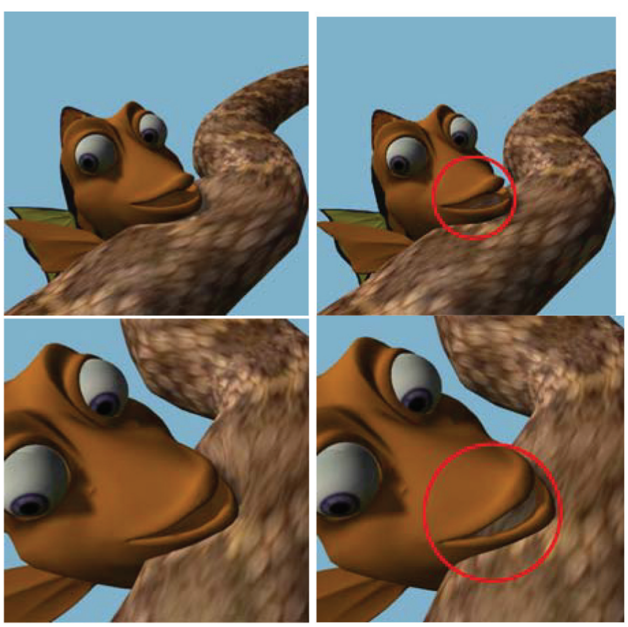

Figure 2: Contact Constraints. Left column: The fish touches the body of the snake, creating global response and skin deformations. Right column: We turn off local skin deformations to show the importance of handling both global and surface response. Notice the highlighted interpenetrations, clearly visible through the fish's mouth.

Highlights

- **Novel formulation of elastic deformation in pose space enabling natural handling of interplay between skin and skeleton**
- **Efficient and scalable computation of articulated body dynamics with contact and skin deformation. Reduction of runtime complexity from $O(mkn)$ to $O(m+k+n)$.**
  (m contacts, k bones, n surface points)

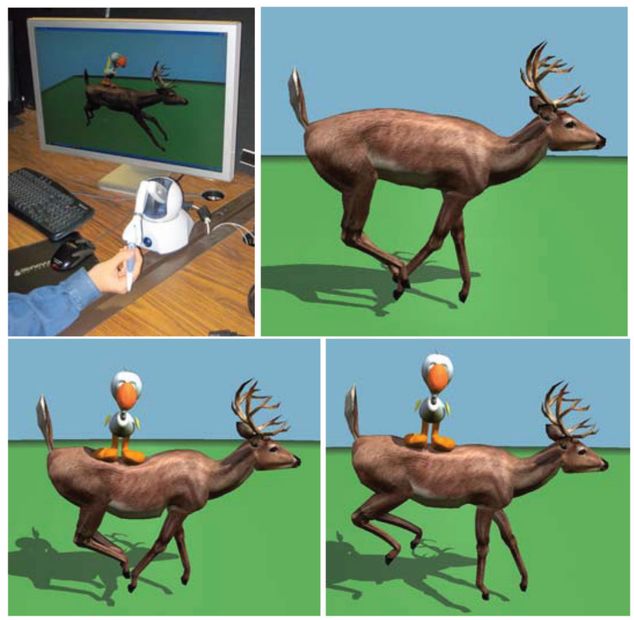

Figure 1: Interactive Deformation of an Articulated Deer. The deer, consisting of 34 bones and 2755 deformable surface vertices is being deformed interactively (almost 10 fps on average) by a rigid bird model. The interplay between small-scale contact deformations and the skeletal contact response is successfully captured.

corrections. The importance of handling both global and surface response is shown in Fig. 1. The algorithm takes advantage of a fast, approximate, *image-space collision detection* algorithm for articulated characters.

Our algorithm overcomes the computational bottlenecks due to contacts using the key results shown in the *highlights* box. The key to our efficient approach is an implicit constraint-based collision handling approach that exploits the layered representation to enable efficient, approximate yet robust matrix condensation. We first present the *condensation of skeleton dynamics*, which allows for $O(k+n)$ update of collision-free dynamics in practice. Then we present the condensation of

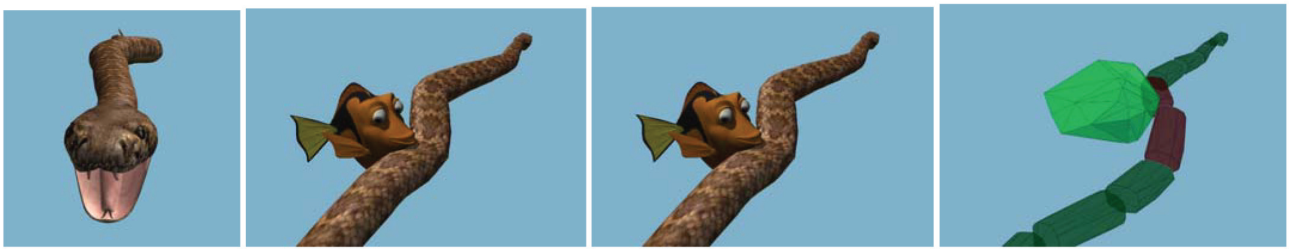

Figure 3: Skeletal Deformations of a Soft Snake. Simulation sequence with a fish touching the snake, showing the global deformation of the snake. The last image shows the proxies for collision detection.

contact constraints and *anticipation of skeleton response*, which allow for $O(m+k+n)$ update of contact-consistent dynamics in practice.

Results

In Figures 2 and 3, we show two examples of simulations performed with our algorithm. The deer model in Figure 2 has 34 bones and 2755 skin nodes. The simulation was driven by a pre-recorded animation and by applying additional control forces on its bones. The simulation is interactive, with frame rates in the range of 6–9fps. By performing multiple benchmarks with different skin resolutions, we have shown that the runtime complexity of the simulations is $O(m+k+n)$ in practice. For the benchmark of the snake (16 bones and 3102 skin nodes, shown in Figure 3), the simulation runs at 7 fps with collisions, and 10 fps when there are no collisions. All the benchmarks were simulated on a 3.4 GHz Pentium-4 processor PC with an NVidia GeForce 7800GTX graphics card.

As demonstrated in the experiments, our method for simulating soft articulated characters handles contact constraints interactively while producing rich deformations on the skin. Compared to previous methods in the family of FEM-based methods, our layered representation enables us to exploit the decomposition of the deformation, leading to considerable benefits for fast collision handling. Therefore, we can handle both local skin and global skeletal response with approximate implicit integration more stably, robustly and efficiently than previous methods.

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Selected Publications

N. Galoppo, M.A. Otaduy, S. Tekin, M. Gross and M.C. Lin. "Soft Articulated Characters with Fast Contact Handling," *Proceedings of Eurographics*, Prague 2007.

N. Galoppo, M.A. Otaduy, S. Tekin, M. Gross and M.C. Lin. "Haptic Rendering of High-Resolution Deformable Objects," *12th International Conference on Human-Computer Interaction*, July 2007, Beijing, China.