Flesh, Flab, and Fascia Simulation on Zootopia

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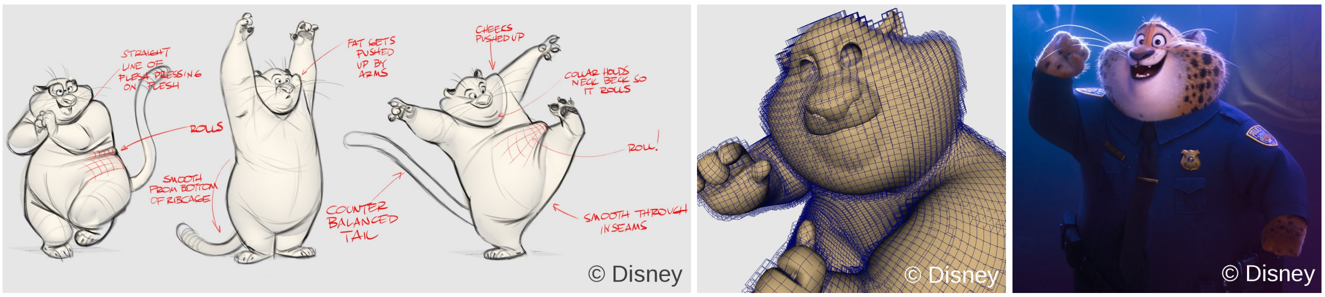

Figure 1: *Visual development, simulation grid and final render of Clawhauser. Characters on* Zootopia *achieved specific art direction while incorporating physical simulation.*

Abstract

We present the latest character simulation techniques developed for Disney's *Zootopia*. In this film, we created herds of anthropomorphic mammals whose art direction called for the subtle, detailed motion distinctive to the real animal world coupled with the stylized, non-physical aesthetics characteristic of animated feature films. This required a strong partnership between technology and production to productize our flesh simulation research to meet the unique challenges of this show. Our techniques scaled from several hero characters to many secondary and tertiary characters, and also accommodated two characters with special requirements.

Keywords: flesh simulation, elastic deformation

Concepts: •**Computing methodologies** → **Physical simulation;**

1 Aesthetic and Production Goals

One of the main goals on *Zootopia* was to capture the distinctive qualities of each animal species. With characters that are bipedal and anthropomorphic, it was particularly important that they remain convincingly animal, and not look like a person in an animal suit. We also had to convey the vast range of character sizes, from the smallest rodent to the largest elephant. We used flesh simulation on all of the massive characters. This helped to give them a sense of weight. Flesh simulation adds details such as self-collision, volume preservation and jiggle that make the characters feel more alive. At the same time, we still had to be able to achieve art direction, often in the form of draw-overs from a traditional 2D animator. For us, the goal of simulation is not photorealism, but increased visual quality in service to a stylized animation aesthetic.

From a production perspective, it was important to have a process that allowed setting up a character simulation quickly. A complete flesh simulation rig for a new character type could be created and tuned in a day. The simulator also had to be robust to allow the widespread use of flesh simulation across many characters and shots. These aesthetic and production considerations led to a different approach to flesh simulation than that typically used in visual effects, such as [Comer et al. 2015].

2 From Research to Production

Our volumetric grid-based flesh simulator PhysGrid, based on [McAdams et al. 2011], was used extensively for the first time on *Zootopia*. Significant development effort was invested to transform PhysGrid from a research project into a production tool. This included optimizations from the lowest level to high level algorithms. We implemented SIMD vectorization and improved the parallelism of the code. We carefully minimized data movement by fusing together previously separate parallel computation kernels. At a higher level, switching from backward Euler time integration to the generalized-alpha method allowed us to take only a single time step per frame without suffering from undesirable numerical damping.

Much of our effort was focused on making the simulator more art-directable and artist-friendly. It is common for flesh simulators to operate on tetrahedral meshes, which can be tedious to generate. Our simulator avoids the need to generate a tetrahedral mesh by embedding the surface mesh in a grid. However, in the original implementation, level sets were used extensively. We replaced the use of level sets with methods that operate directly on triangle meshes, eliminating all intermediate translation steps and the need to tune any meshing or rasterization-related parameters.

We also refined the way simulation parameters are exposed to make them more intuitive. This included adopting more descriptive and less technical names for physical parameters, logically ordering and grouping parameters, normalizing all parameter units to a common range, and ensuring resolution-independence. The artist can paint maps for physical parameters on the surface, which are diffused into

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the volume with a Laplacian solve. For more control, additional paint surfaces can be positioned inside the volume.

Another major workflow improvement was the use of a method we dubbed the "body bone". Originally, we envisioned the simulation controlled by individual rigid bones that were rigged to follow the animation skeleton. However, artists found it difficult to predict how the size and placement of the bones would affect the simulation. Instead, we use a single deforming "bone" that consists of a copy of the body surface mesh, displaced inwards. The thickness between the body bone and the surface mesh controls how closely the simulation follows the animation. We carve out areas like large bellies to allow them them to jiggle more. To deform the body bone, it is bound to the rigged and animated body surface mesh. Initially, we used the iBind [Miller et al. 2009] technique for this. Later, we developed a binding technique that uses PhysGrid itself in a two pass solve. The first pass is a quasistatic solve for the body bone, performed by embedding it in the simulation grid and placing constraints at all of the vertices of the animated body surface mesh. The second pass is a dynamic solve for the simulation mesh, performed by placing constraints at the surface of the body bone.

3 Special Characters

The Clawhauser character, shown in Figure 1, posed a particular challenge because we wanted the benefits of simulation on his chubby cheeks, without sacrificing the ability to achieve specific art-directed shapes on the highly sensitive facial area. For example, the visual development in Figure 1 calls out the shapes of rolls of fat in particular poses. We developed a delta-based process that allows us to combine simulation with all of the artistic controls to which our artists are accustomed. First the character is rigged with procedural skinning such as dual-quaternion skinning. Then a quasistatic PhysGrid simulation is used to generate shapes that are applied using pose space deformation in pre-skinning space by inverting the deltas through the skinning deformer. Additional art-directed shapes are sculpted on top and applied using pose space deformation in post-skinning space. More detailed controls and deformers are layered on top. After animating the character using this rig, the output of the skinning deformer is used to drive a dynamic PhysGrid simulation using the body bone approach, bypassing all post-skinning deformers and art-directed shapes. Finally, the deltas between the full animation rig and the skinning deformer are applied on top of the simulation. The effect is to substitute a dynamic physical simulation for standard procedural skinning.

The characters in the film are anthropomorphic bipedal animals with a stylized aesthetic. However, at one point a jaguar "goes savage" and transitions to quadrapedalism. We emphasized the transformation by revealing a more defined creature-style anatomy. We were able to achieve this very different style with the same toolset developed for the other characters (Figure 2). For this style of character, we start by modeling anatomically-plausible bones and muscles. The bones are rigidly bound to the animation skeleton, while the muscles are bound to the animation mesh with iBind. The muscles automatically activate based on measured extension and compression. Secondary motion is procedurally added to the muscles based on the animation. Next, the muscles are combined into larger groups and remeshed before being simulated with PhysGrid to resolve collisions and preserve volume, creating bulges. The simulated muscles are wrapped with a tight cloth simulation to provide tangential sliding motion for the fascia layer. Finally, a second PhysGrid simulation is used on top for a layer of dermal fat. Although this character has more defined and dynamic anatomy, we still maintain our hallmark animation aesthetic.

4 Conclusion

For *Zootopia*, we have developed a novel flesh simulation workflow and technology that facilitates a simple and robust setup across most characters, while also accommodating special cases requiring higher levels of art direction or realism. This has allowed us to increase the richness of the motion and visual quality of the film while preserving our unique style based on traditional animation principles. Along the way, we learned lessons about what it takes to develop promising research into an artist-friendly and production-proven tool.

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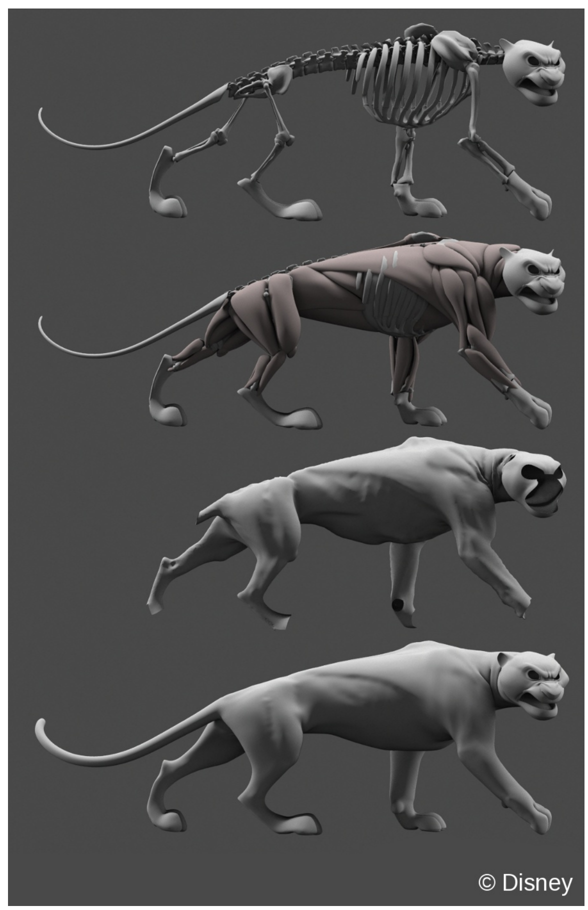

Figure 2: *Anatomy layers: bones, muscles, fascia and dermal fat.*