Under the Scalpel - ILM's Digital Flesh Workflows

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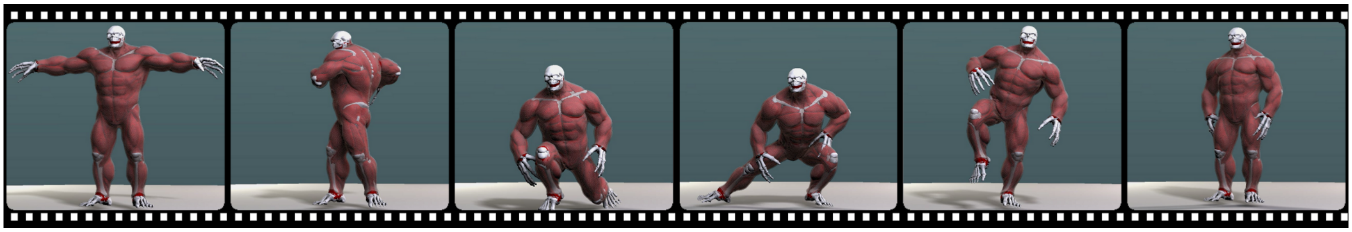

Figure 1: *Industrial Light Magic. All rights reserved. (c)*

1 Introduction

Every year, Industrial Light Magic is tasked with creating an immense spectrum of realistic character work. From the Hulk to dinosaurs, this work requires physiologically accurate, yet flexible, robust, and efficient muscle simulation techniques. Older methods often used an elaborate and expensive jiggle deformation systems that required a high amount of maintenance and post corrective work. However, on Jurassic World and Avengers: Age of Ultron, we sought to exhibit the anatomical connective network of tissue matrices. Our methods of tangential and volumetric tensegrity simulations enabled us to achieve a high resolution of simulated results, down to striations and veins of the muscle, previously unachievable.

ILM s deformable model simulation is accomplished through the use of tetrahedral spring mass models.These models can be solved using linear connective forces, and/or finite element forces. ILM relies on the PhysBAM simulation system, developed through Stanford University, to simulate a majority of the deformable models. PhysBAM provides for the ability to manipulate the simulation properties of tetrahedral nodes through the use of volumetric areas and animation envelopes, and implements algorithms used in the modeling of highly deformable, nonlinear, incompressible solids.

2 Technique

Muscle Solve: In order to simulate the elastic properties of connective tissue between the skeleton and the muscle, we use Stiction to dynamically attach the tetrahedral muscles to the skeletal structure. Flex data comes in the form of curves from animation performance and skeletal metering. When flexed or under load, tetrahedral springs stiffen and directional material properties harden. We solve muscle-to-muscle interaction with two-way coupled dynamic repulsions. Then, we cluster all our granular muscles into major muscle groups and use the processed flex data to drive shape detail of the muscles striated states and vein properties when under load. This final post process not only lets us exhibit these surface details, but also allows us to better manage and optimize the LSV rasterization of our musculo-skeletal simulation into collision objects for our fascia and and flesh solves.

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Fascia Solve: Fascia, also called connective tissue, forms a body-wide network that provides structural support, protection, shock absorption and elastic recoil. Fascial tissue exhibits a great diversity of characteristics, ranging from stiff cable-like structures such as tendons to supple sheets such as the superficial fascia under the skin. In order to physically represent the tangential tensional network of the fascia geometry we use our proprietary application, Zeno, to generate the Delaunay triangulated surface. The fascia is an adaptive tangential tensegrity model that assists and complements our musculo-skeletal solve. We use biphasic springs to adaptively model the compressional and tensive material of the deep fascia in coordination with the flexing properties of the surrounding muscle tissue. The motivation of our fascial flow comes through the use of blend shapes driven from our flex data. The fascia mesh is ultimately simulated by projecting the vertices down their normal to the targeted LSV collision surfaces produced by our musculo-skeletal solve. The normal projection provides a goal weight for the solve to reach and binds the fascia to the closest point on the targeted LSV collision surfaces.

Flesh Solve: In our final process, we use our tetrahedral flesh mesh to represent the cutaneous connective tissue from fascia to dermis. The flesh mesh consists of two layers: an inner layer that is topologically identical and dynamically connected to our fascia and an outer layer that represents the renderable dermis.The greater the distance between fascia and dermis the more fatty the tissue and the higher the mass. Likewise, in areas with lower distances, less mass is applied. By referencing MRI and CT data, we determine the thickness of the cutaneous tissue to assure a physically accurate simulation. Using Zeno we build a tetrahedral model of polygons to simulate the tensegrity of the cutaneous tissue, know as the flesh mesh. Simulating the volumetric structure of the the flesh mesh yields the cutaneous connection of the fascia and dermis that are underscored with self collisions and user-defined mass, stiffness, and frictional material properties. The result of this solve produces a renderable surface that exhibits the physiological properties of real skin.