

Realistic Eye Motion Using Procedural Geometric Methods

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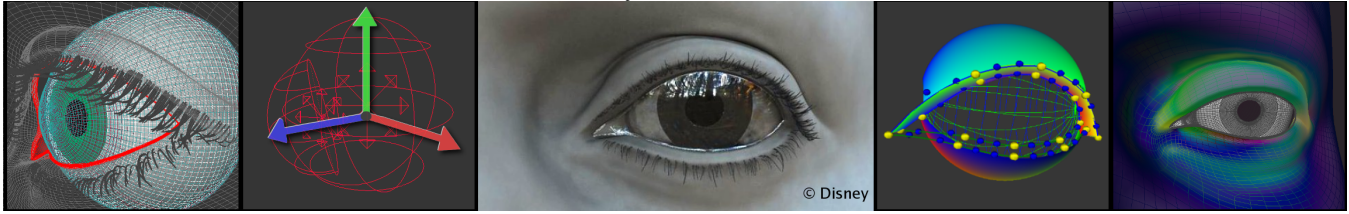


Figure 1: (a) Model (b) primitives, coordinate system, quadrants (c) gray-scale render (d) spherical coordinate skinning (e) vertex gaze weights

For late-breaking R&D on the upcoming Disney film *King of the Elves*, we have embarked upon an adventure called the Realistic Eye Initiative; to investigate realistic procedural methods for one of the most important aspects of a digital character's face – the eyes. We will leap beyond the simple spheres of previous Disney films, into fantastic, striking realism. Using an anatomically motivated approach, our method to produce realistic convincing deformations of the skin and flesh surrounding the eye is unique, not only due to the novel approaches employed, but also because our method is entirely procedural, based on geometric analysis and packaged into a production friendly, compact, efficient mathematical apparatus in the form of a single black-box deformer that can be easily applied onto any digital creature's face.

1 Spherical Coordinate Lid Skinning

The movement of the lid skin over the eye ball is the most significant motion that occurs during a blink. To simulate this skin deformation, we use *transformation-propagation*. The deformation basis function is given by internally computed spline patches. The patches are defined by a curvature-continuous blend between key shapes that include a neutral shape (obtained by least-squares fitting of spline patches into the original eye opening) and user-defined closed, surprised, and intermediate shapes.

Once the patches are in place, we define a smooth vector field of displacements $\mathbf{D}(\mathbf{x})$ on the eye-lid skin as follows. First, attachment weights are set on the skin region directly driven by the patches. Next, vertex weights are computed to define a pulling area that smoothly follows the attachment. Finally, $\mathbf{D}(\mathbf{x})$ is set to zero outside of the pulling and attachment regions.

In the pulling region of $\mathbf{D}(\mathbf{x})$ we require nearly perfect harmonic behaviors (i.e. $\Delta \mathbf{D}(\mathbf{x}) = \mathbf{0}$); in addition our resulting surface should maintain the curvature defined by the sum of the eye ball radius and thickness of the skin. This requires solving a differential equation that defines $\mathbf{D}(\mathbf{x})$ for the pulled vertices. Instead of solving Poisson's equation with special conditions, which would make computations too expensive for interactive use, we introduce a novel, fast relaxation scheme. The essence of this scheme is Laplacian smoothing based on spherical coordinates. The system of spherical coordinates is defined by the location and orientation of the eye ball \mathbf{E} ; constructing the map function $\mathbf{S}(\mathbf{x}, \mathbf{E})$ converts \mathbf{x} to local spherical coordinates. We define the Laplacian operator as

$$\Delta \mathbf{D}(\mathbf{S}(\mathbf{x}, \mathbf{E})) = \left(\frac{\partial^2}{\partial S^2(\mathbf{x}, \mathbf{E})_u} + \frac{\partial^2}{\partial S^2(\mathbf{x}, \mathbf{E})_v} + \frac{\partial^2}{\partial S^2(\mathbf{x}, \mathbf{E})_{\text{radius}}} \right) \cdot \mathbf{D}(\mathbf{S}(\mathbf{x}, \mathbf{E}))$$

We are guaranteed convergence of the smoothing iterations to a surface with vertices equidistant from the eye's center while direct manipulation of the radius component gives us exact control over curvature.

2 Procedurally Unfolding Skin Wrinkles

Another blink-driven deformation is the unfolding of wrinkles between the lower brow and the lids. To make this appear natural, we allow the pace of the unfolding to be independent from the gross motion of the blink. The actual unfold is done using anisotropic relaxation along the blink's primary direction.

3 Driven Wrinkles and Lid Pressure

As the lids blink, the skin uncompresses and unfolds into a smooth, relaxed spherical coordinate space. Thus, we interpolate new wrinkles and bulging that occur when the eye closes. When the spline surfaces meet at blink, a pressure value activates a bulge force perpendicular to blink direction. The blink also activates normal displaced wrinkles around the eye. Wrinkles and bulges have vertex weights, allowing subtle control over shape of wrinkle or flesh as it bulges or creases.

4 Shape Shifting based on Gaze Angle

A blink is only a portion of eye motion; flesh and skin around the eye reacts as look direction changes due to underlying anatomy. To mimic this effect we implement three additive layers to cause skin reaction to the eye's gaze angle: a flesh layer, a driven lid progression layer and a shape shifting layer.

First, the coordinate system of the eye is stored and a bind is computed. The inverse parent matrix ensures deformation only occurs from changes in local eye space. The eye coordinate system is then decomposed and quaternions are used to extract rotations, initially removing twist from the eye matrix. Subtle diffuse weighting is computed, radiating from the eye center. Weighted skinning is then applied for a smooth fleshy effect when the eye looks around.

Next, to apply driven lid progression, we extract side looking rotation and build a matrix that only represents upward and downward motion. The sign of the lid motion is set by alignment of the bind Y-axis and run-time Z-axis (the look vector). An additive weighted binding is applied, and the transition seamlessly blends when the eye is neutral and also fades off entirely as the blink occurs.

Finally, the shape shifting effect is applied. In order to achieve subtle almond shaped deformations, the eye coordinate system is partitioned into six gaze quadrants: up, down, and diagonally 45° on left/right, up/down sides. As the eye's look vector aligns with a gaze quadrant, a weighted transformation causes the skin to change shape.

5 Cornea / Sclera Collision Primitives

The anatomical domed like nature of our cornea requires skin-to-eyeball collision and sliding interaction. This is achieved using fast sphere primitives fitted to the dome of the cornea/sclera mesh, instead of complex polygons. A fast radius test detects lid intersection, and a smooth non-dynamic weighted collision is applied, pushing the lid back onto the limit of the primitive with control over magnitude and attenuation, resulting in a smooth, convincing sclera/corneal bulge sliding beneath the lids.

6 Future and Planned Work

We're currently extending this procedural deformation system with a layered compression based wrinkle algorithm, skin and flesh simulation to resolve self collisions, and better automatic weight generation using heat diffusion. Future R&D is also slated for rendering: areas to research here are novel eye reflectance models, corneal refraction-distortion texture un-warping, and procedural iris generation using texture synthesis and Markov Random Fields.