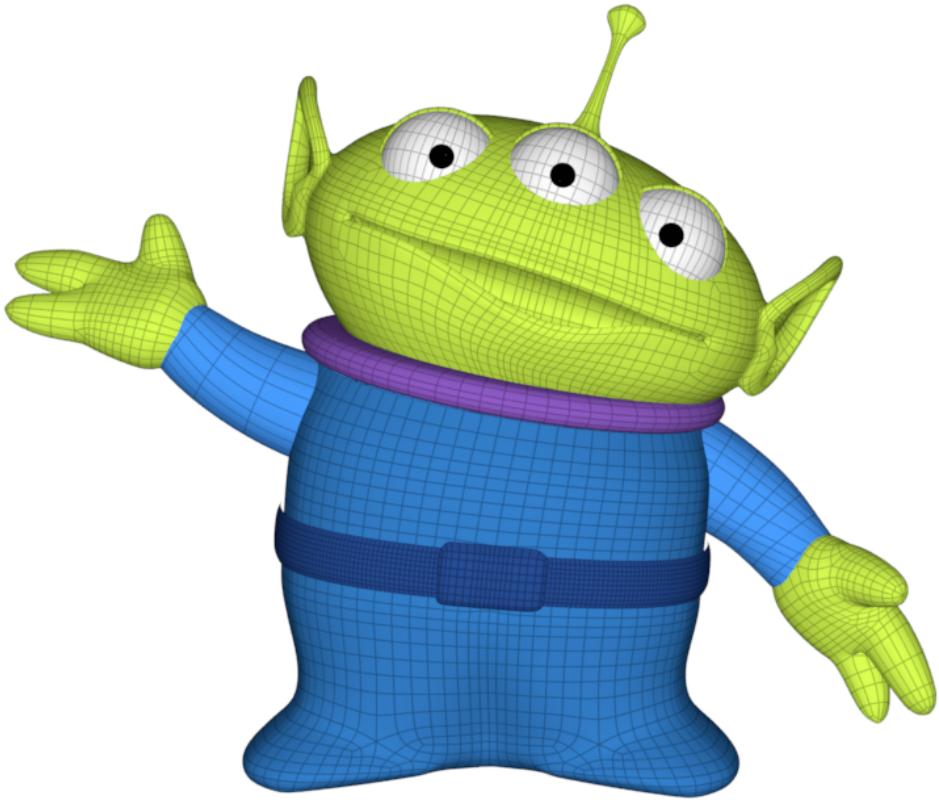
Subdivision Surfaces

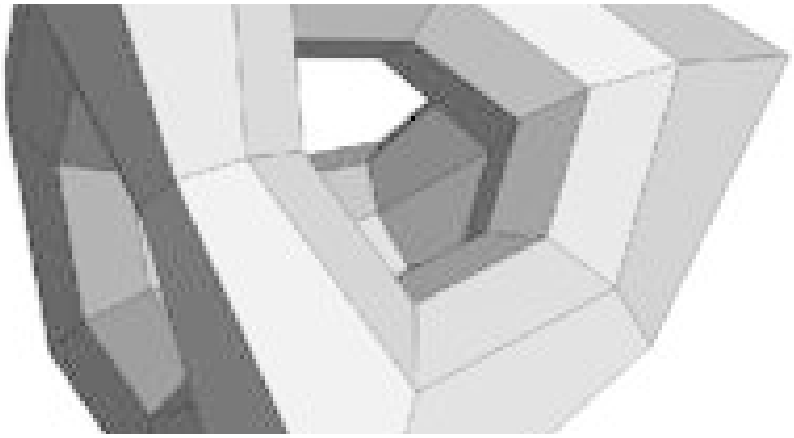


Introduction

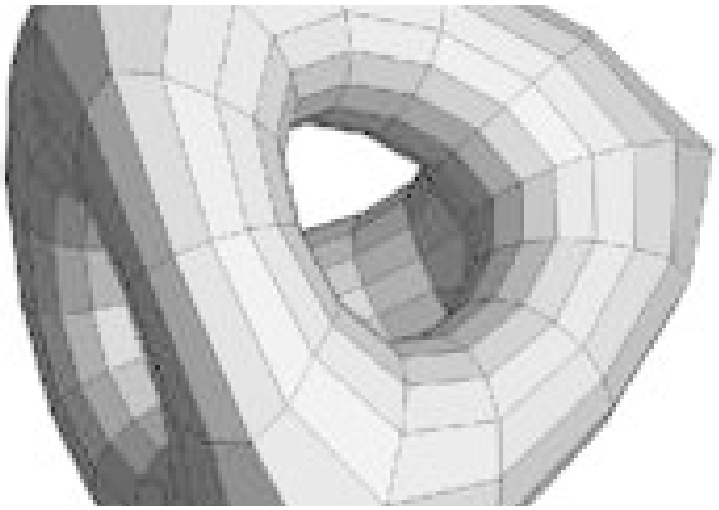
Subdivision surfaces are the most common way to model complex smooth geometry in RenderMan, and for good reasons: they guarantee the smoothness of a model and they impose very few topological constraints on the modeler.

A common way to approach a subdivision surface is to imagine a polygon mesh (the **control mesh**) which undergoes a local averaging (or smoothing) at every vertex, creating a new set of vertices which have a smoother appearance than the original mesh. One application of this averaging operator everywhere on a mesh is a single **subdivision step**. If we could take an infinite number of subdivision steps, eventually we will converge to a **limit surface** , which has a set of guaranteed smoothness properties depending on the type of subdivision being used.

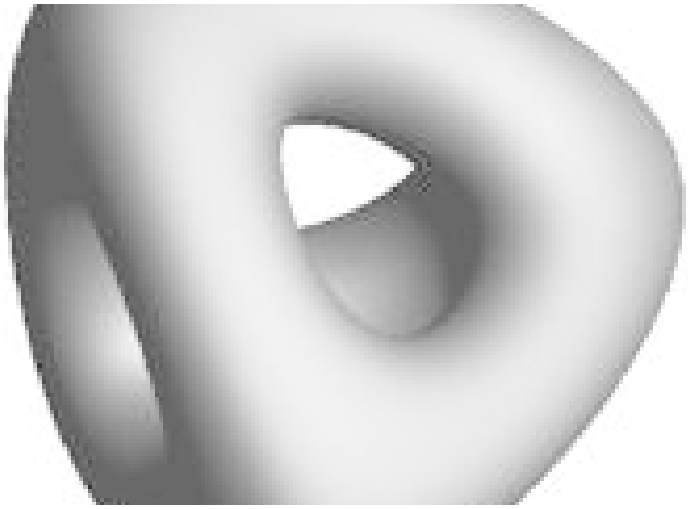
Control mesh



One level of subdivision



Two levels of subdivision



Limit surface

Like most other types of geometry, a subdivision mesh is described by its control mesh. Unlike NURBS, the control mesh is not confined to be rectangular, so in this respect, the control mesh is very similar to polygonal surface. But where polygonal surfaces require large numbers of points to appear smooth, a subdivision mesh's limit surface is guaranteed to be smooth - meaning that polygonal artifacts or faceting are never present, no matter how the surface animates, or how closely it is viewed.

Unlike many other renderers, RenderMan's implementation of subdivision surfaces does not apply a fixed number of subdivision steps to a polygonal mesh. Instead, it adaptively tessellates into micropolygons whose size is by default computed in term of pixels on the screen. Moreover, even if the micropolygons are large due to the micropolygon length setting, their vertices are computed directly from the limit surface for the highest accuracy.

Comparison with Polygons

A common question to consider when modeling assets is: should a polygonal asset be rendered as is, or should be it converted to a subdivision surface? If the asset is not smooth in nature (i.e. simple geometry with hard silhouettes), then polygons are probably all that are needed. If the asset is meant to be a smooth surface, then the tradeoffs become more complicated:

- The number of polygons that may be needed to represent a smooth surface may be significantly higher (and require more memory) than the equivalent subdivision mesh. In such cases, it is obvious that the subdivision mesh is the better representation.
- However, polygons are usually considerably cheaper if the renderer doesn't need to perform any subdivision. The renderer needs to retain extra memory on a subdivision surface in order to be able to perform subdivision. If the asset is significantly over-modeled to begin with, it may be the case that the limit surface may not differ significantly from the control mesh and the extra memory needed to perform the subdivision was wasted. In that case, the polygonal representation may suffice (i.e. it may be considered "smooth enough"). Note that the renderer tries very hard to mitigate cases where subdivision meshes are over-modeled by converting their underlying representation to what is essentially a polygonal representation up front in a "pre-tessellation" step, saving memory by discarding the subdivision data.
- Subdivision meshes have the ability to perform watertight dicing in order to close potential holes or cracks caused by displacement. In RenderMan, polygons cannot do this because they don't retain enough data.
- Subdivision meshes have some topological constraints; in particular, faces cannot have holes, and they cannot represent non-manifold surfaces (surfaces where an edge may be incident to more than two faces - imagine two cubes sharing a single edge). In practice, this is usually not a significant problem.

Features

Subdivision Schemes

RenderMan's implementation of subdivision meshes include two subdivision schemes:

- **Catmull-Clark** subdivision surfaces are the industry standard. It is a quadrilateral based subdivision scheme, and work best with control meshes that is comprised mostly of quads - any non-quad geometry is immediately converted to quadrilaterals on the very first subdivision step. They generally good for most situations and have no special concerns when it comes to texture filtering.
- **Loop** subdivision surfaces is a triangle based scheme, which is optimized for control meshes that are entirely triangles: they tend to require less memory than Catmull-Clark scheme. However, due to the nature of triangles, derivatives can be discontinuous from face to face, which may lead to texturing artifacts that require extra effort to solve.

Sharp Creases and Corners

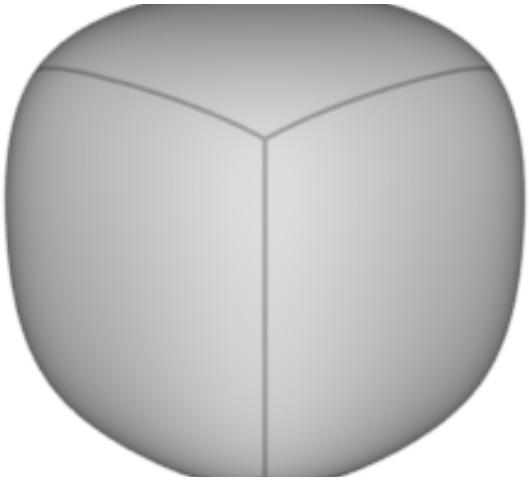
Not all geometry is smooth everywhere. In cases where a sharp feature needs to be preserved, an edge or vertex can be tagged as a **crease** or a **corner**. This means that near that feature, no actual subdivision will be applied, and the resulting limit surface will be unchanged from the control mesh.

Semi-sharp Creases and Corners

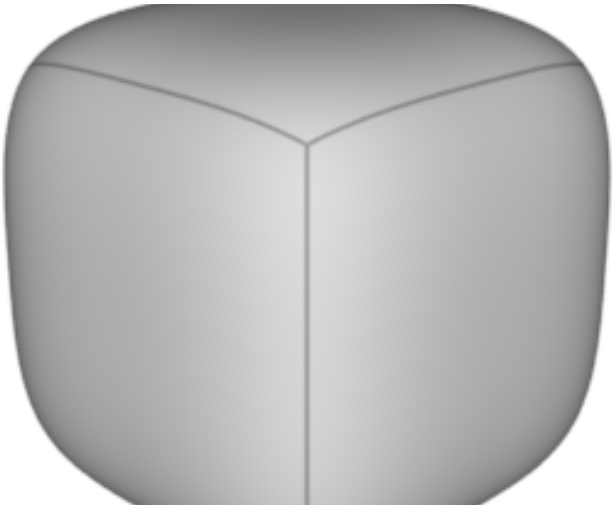
When approximating a smooth surface with polygons, it is common to apply a fillet operator onto a sharp edge in order to convert it into a rounded edge. Unfortunately, fillets tend to create many more polygons. This problem is somewhat mitigated by conversion of the polygon mesh into a subdivision surface: now, the smoothness of the surface is guaranteed; however, the size of the rounded edge is still determined by the size of the faces adjacent to the edge, and it may still prove necessary to introduce new faces into the model to control the size of the edge curve.

To mitigate this problem, RenderMan's implementation of subdivision surfaces allow for edge and vertices to be tagged as **semi-sharp** creases and corners, respectively. Tagging an edge as a semi-sharp crease means that the resulting limit surface near the edge will be somewhere in between where it would have been if it had been tagged as a fully sharp crease (i.e. the control mesh) and where it would normally have ended up as a fully smooth surface. The example below shows the subdivision mesh resulting from a cube control hull, with various crease strengths applied.

No creases



Crease strength 0.5



Crease strength 1

Crease strength 2

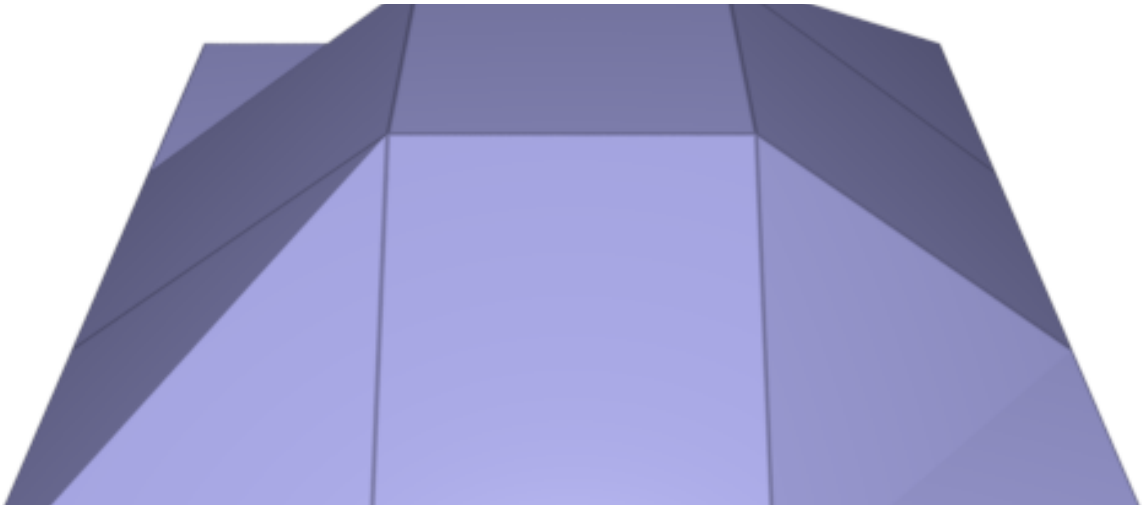
Watertight Dicing

A benefit of using subdivision meshes over polygon meshes is that the topological data needed to perform subdivision is also useful for guaranteeing that the surface will remain watertight, no matter what happens in the displacement. In particular, if the faces immediately adjacent to a shared edge compute a different displacement result, on a polygon mesh a crack will likely appear as the faces pull apart. While this seems like an obvious thing to avoid, in practice it may not be easy to do so particularly when using a complicated texture asset derived from PTex or a UDIM based workflow. If a subdivision mesh is used instead of a polygon mesh, with watertight dicing enabled, the renderer can ensure that no cracks will appear at face boundaries.

⚠ Watertight dicing can be significantly slower than regular dicing and lengthen the Time to First Pixel (TTFP).

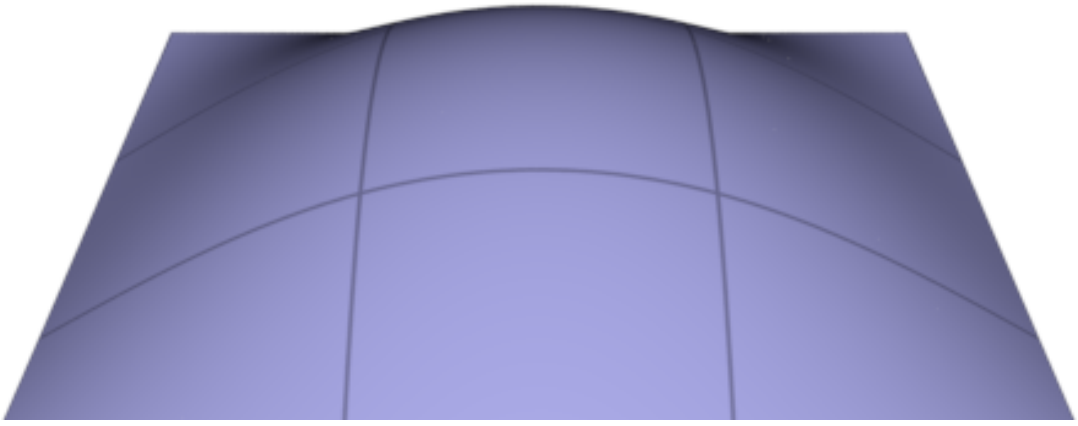
Boundary Interpolation

In order to provide the smoothest possible limit surface, the averaging behavior of a subdivision surface is such that the limit surface "pulls away" from the boundaries of the control mesh by default. This can be undesirable when dealing with non-closed meshes, especially those that need to connect seamlessly with other adjoining meshes. As a convenience, RenderMan provides **boundary interpolation rules** that allow this behavior to be overridden, allowing the surface to continue all the way to the boundary of the control mesh. Different rules allow for smooth or sharp **corners** (vertices which have exactly two incident edges). The example below shows the boundary interpolation rules applied to a simple 9 face control mesh.

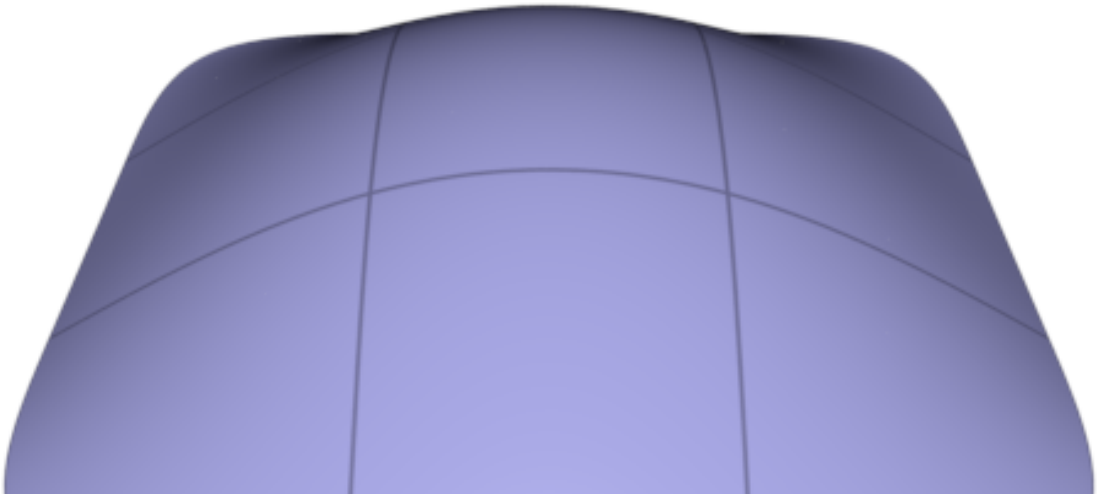


Control mesh

Subdivision mesh, no boundary interpolation

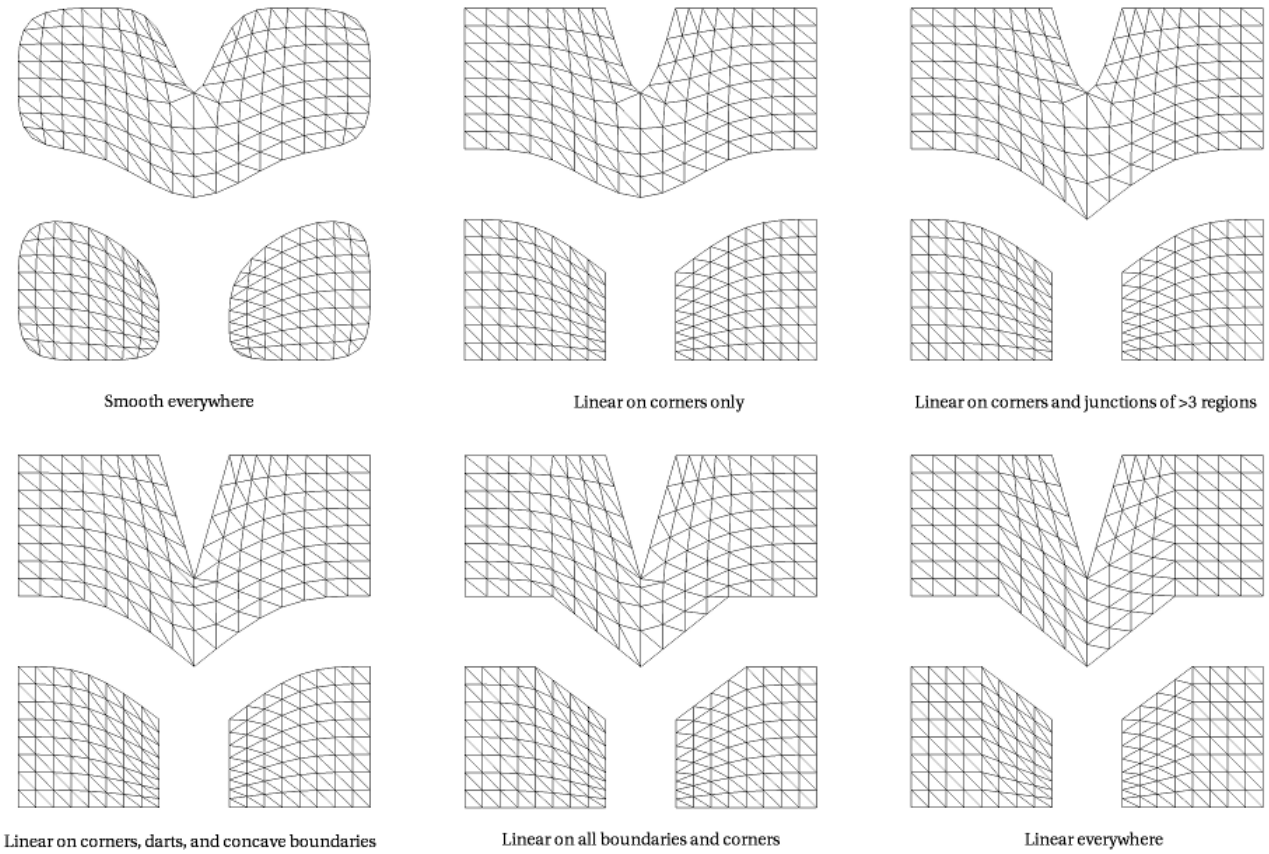


Subdivision mesh, boundary interpolate: edges and corners



Subdivision mesh, boundary interpolation: edges only

This idea of boundary interpolation can also be extended to the interpolation rules applied when dealing with data over the surface, most notably texture coordinates (in this context, RenderMan uses the term **facevarying boundary interpolation**). When dealing with the seams between disjoint UV regions, the renderer can use several different rules, trading off smoothness of the subdivided result away from the seams against the desire to interpolate the seams exactly. Note that no matter what rule is chosen, the UV texture map editor must also abide by the same rules, otherwise undesirable texturing artifacts will result. The following image demonstrates the different rules applied to a 4x4 grid of quads segmented into three UV regions.



The "interpolateboundary" tag controls how interpolation boundary face edges are interpolated. This tag has one optional integer argument and zero floating-point arguments. If the integer argument is not specified it is assumed to have a value of 1. A value of 0 specifies that no boundary interpolation behavior should occur (the default behavior when this tag is not specified). A value of 1 indicates that all the boundary edge-chains are sharp creases and that boundary vertices with exactly two incident edges are sharp corners. A value of 2 indicates that all the boundary edge-chains are sharp creases; boundary vertices are not affected.

Exceptions

The "RenderMan" default is 0, however, bridge products override this to be 1. This RenderMan default may be changed in the future.

Since Katana follows the RenderMan defaults, it is the sole bridge product to specify 0.