CMSC 498M: Chapter 7b
Modeling - Level of Detail

Reading: (Not covered in our readings).
Overview:
- Static and Dynamic LOD
- Simplification Operators
- Error Evaluation
- Perceptual Criteria

Level of Detail for Polygonal Models

Level of detail (LOD):
- Flexible methods managing scene complexity.
- Also known as polygonal simplification, geometric simplification, mesh reduction, multiresolution modeling, ...
- A standard tool for balancing rendering speed with visual fidelity.

Basic Idea:
- Simplify the polygonal geometry of small or distant objects.

69,451 polys
2,502 polys
251 polys
76 polys

Courtesy Stanford 3D Scanning Repository
**Level of Detail**

**Distant** objects are rendered with **coarser** LODs.

---

**Static Levels of Detail**

**Static LOD:**
- Create LODs for each object **separately** through preprocessing.
- At run-time, **select** object's LOD by **distance** (or similar criterion).

**Advantages:**
- Easy to program—decouples simplification and rendering.
- LOD creation need **not** affected by real-time rendering issues.
- Simplifies run-time rendering—need only select LODs.
- Fits well with **modern graphics hardware:**
  - Easy to compile each LOD into triangle strips, display lists, etc.
  - Render much faster (3-5×) than unorganized polygons.

**Disadvantages:**
- Very large objects may simultaneously reside at **various** distances.
- Examples: Terrain fly-overs, volumetric isosurfaces, massive CAD models.
Dynamic Level of Detail

Dynamic LOD:
- Create data structure from which a desired level of detail can be extracted at run time.
- Improved granularity and control of detail.
- Can account for subtler aspects of rendering: lighting, viewing angle.
- Enables better overall fidelity.
- Enables drastic simplification of very large objects.

Design of Simplification

Simplification Operators

Error Evaluation

Perceptual Criteria
How To Simplify?

How to Simplify?
- Find a region of the mesh where a local simplification can be performed with a minimal impact on the object's geometry.
- Repeat this until desired degree of simplicity is achieved.

Simplification Operators: Possible local simplifications.
- Edge Collapse
- Vertex-Pair Collapse
- Triangle Collapse
- Cell Collapse
- Vertex Removal

Edge Collapse

Edge Collapse:
- Remove edge and merge endpoints at their midpoint.

Half-Edge Collapse:
- Collapse one endpoint into the other.
- Not symmetrical.
- Does not generate any new vertices.

Inverse Operator:
- Vertex split.
**Vertex-Pair Collapse**

**Vertex-Pair Collapse:**
- Can remove a "hole" in mesh.
- Useful for **topology simplifications**.

**Triangle Collapse**

**Triangle Collapse:**
- Collapse a single triangle from the mesh, replacing it with its centroid.
- Reduces height of the hierarchy.
- Topologically equivalent to two edge collapses.
Cell Collapse

Cell Collapse:
- Overlay a grid on top of the mesh.
- Collapse all vertices within each grid square to a single vertex.
- Simple to implement; robust; relatively poor visual quality.

Vertex Removal

Vertex Removal:
- Remove all triangles incident to the given vertex, forming a “hole”.
- Retriangulate the hole. (There are many possibilities).
- E.g., connect all to one vertex: Equivalent to half-edge collapse.
- Beware: Retriangulation is not generally possible. Ideally surrounding triangles nearly co-planar and form a convex ring.
### Design of Simplification

**Simplification Operators**

**Error Evaluation**

**Perceptual Criteria**

---

### Why Measure Error?

**Guide simplification process:**
- Making **better choices** produces better simplifications.

**Know quality of results:**
- Object-space error bounds describe quality.

**Know when to show a particular LOD:**
- Which LOD to achieve a desired screen-space error.

**Balance quality for large environments:**
- What error bound to achieve a desired polygon count.
Geometric Error Measures

Objectives:
- Promote accurate 3D shape preservation.
- Preserve screen-space shape:
  - Silhouettes.
  - Pixel coverage.

Error Metrics:
- Vertex-Vertex Distance.
- Vertex-Plane Distance.
- Point-Surface Distance.
- Surface-Surface Distance.

Screen-space Geometric Error

Screen-space error:
- What is the number of image pixels covered by a triangle of diameter $\varepsilon$ in object space?
- Let:
  - $w$: width of the view frustum
  - $d$: image plane width
  - $r$: distance to the image plane
  - $\theta$: field-of-view angle.

\[
p = \frac{\varepsilon r}{w} = \frac{\varepsilon r}{2d \tan \frac{\theta}{2}}
\]
Screen-space Error Threshold

Nodes chosen by projected area:
- User sets desired screen-space size threshold.
- Nodes that are larger than threshold are unfolded.

Illumination-Dependent Detail

Regions of high illumination variation are refined.
- 8192 triangles
- 537 triangles
Silhouette Preservation

Retain more detail near silhouettes:
- Human visual system is very sensitive to edges.
- A silhouette node supports triangles on the visual contour.
- Use tighter screen-space thresholds when examining silhouette nodes.

Design of Simplification

Simplification Operators

Error Evaluation

Perceptual Criteria
Switching LOD

Primary LOD selection criteria:
- Distance or Size
- Velocity
- Eccentricity
- Depth of Field

Additional LOD constraints:
- Fixed-frame rate schedulers (reactive or predictive)
- Hysteresis (switching lag)
- Priority schemes
- Alpha-blended transitions (fading regions)
- Geomorph transitions (morph geometry)

Distance LOD

Distance LOD:
- Select resolution based upon the distance between an element and the viewer, i.e. coarser resolution for distant geometry.

Features:
- Simple to calculate (3-D Euclidean distance).
- Scale dependent.
- Resolution dependent.
- Field-of-view dependent.
Size LOD

Size LOD:
- Select resolution based upon the projected screen size (or area) of an element. Objects appear smaller as they move further away.

Features:
- Requires 3-D → 2-D projection.
- Scale invariant.
- Resolution invariant.
- Field-of-view invariant.

Computation:
- Bounding spheres or ellipsoids used instead of boxes as more efficient to calculate projected extent.

Eccentricity LOD

Eccentricity LOD:
- Resolution is selected based on the degree to which an element exists in the visual periphery.
- Humans can resolve less detail in their peripheral field due to:
  - More retinal photoreceptors (rods/cones) near fovea.
  - Retinal and cortical cell receptive field sizes increases linearly with eccentricity.
  - 80% of cortical cells devoted to central 10° of vision.
- Use eye-tracking system to track user's gaze or assume user looking towards center of display.
Velocity LOD

Velocity LOD:
- Resolution based upon the angular velocity of an element across the visual field, i.e. faster moving objects appear in lower resolution.
- Humans can resolve less spatial detail in objects moving across the retina, causing objects to blur as they move/rotate, or the user’s gaze moves.
- It is believed visual information for small features are destroyed by the process of integrating stimulus energy over time.
- Without eye-tracking technology, assume angular velocity across display device.

Depth of Field LOD

Depth-of-Field LOD:
- Resolution of element depends on the depth of field focus of the user’s eyes, i.e. objects outside the fusional area appear in lower detail.
- Under binocular vision, both eyes converge on object at certain distance in order to focus retinal image.
- Panum’s fusional area: Objects in this region appear in focus. (Physiologically measured.) Objects in front or behind are out of focus.
- Must track both eyes accurately to evaluate convergence distance, or assume focus on central object.
Vermeer
"Officer and Laughing Girl", 1658-60

120 x 135 degrees FOV
No eccentricity blurring
No velocity blurring

Vermeer
"Officer and Laughing Girl", 1658-60

120 x 135 degrees FOV
Eccentricity blurring
No velocity blurring
Visual Perception Software

Vermeer
"Officer and Laughing Girl", 1658-60

120 x 135 degrees FOV
Eccentricity blurring
Velocity = 60 deg/s

Chapter 7, Slide 29
Copyright © David Mount and Amitabh Varshney

Summary

Summary:
- Static and Dynamic LOD
- Simplification Operators
- Error Evaluation
- Perceptual Criteria

What's Next?
- Modeling and animation

Chapter 7, Slide 30
Copyright © David Mount and Amitabh Varshney