

Level of Detail Techniques



15-462 Computer Graphics
School of Computer Science

Feb 17, 2004

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1

Announcements

- Mobile animation assignment due tonight
 - Any questions?
- Reminders
 - Turn OFF writing images
 - Turn in README file
 - Description of shadow algorithm
 - Extra credit features

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2

CG Performance goals

- Frame rate
 - Beyond a certain point, it doesn't add any perceptual difference to the viewer
- Resolution
 - 1600 x 1200 is pretty good for most purposes
- Scene complexity
 - Can always increase

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Some acceleration algorithms

- Spatial data structures
 - Bounding volume hierarchies (BVH)
 - BSP trees, octrees, scene graphs
- Culling techniques
 - Backface culling
 - Occlusion culling
 - View frustum culling
- Level of detail
 - Deal with object complexity

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Trade-offs



- Why not wait for better hardware?
 - Object complexity will always catch up

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Very large models

- Boeing 777
 - 132,500 unique parts
 - 3,000,000 fasteners
 - 500 million polygons
- Digital Michelangelo
 - Stanford University
 - Michelangelo's David
 - 56 million polygons



Stanford University

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Hardware rendering speeds

- More polygons in your scene
 - More detailed objects/scenery
 - Visually richer
- Must stay within hardware allocations for real-time rendering
 - nVidia Quadro FX 3000 - Workstation class
 - 80 million lit and textured triangles/second
 - nVidia GeForce FX series - Desktop class
 - ~30 million triangles/second
 - ATI Radeon 9800 XT - Desktop class
 - ~25 million triangles/second

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Level of detail in a nutshell

- Allow objects to be represented with different numbers of polygons
- Use fewer polygons for distant objects
 - Less visual contribution
- Use more polygons for near objects
 - More visual contribution

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A little history

- Ideas first introduced in 1976
 - James Clark, “Hierarchical Geometric Models for Visible Surface Algorithms”
- Flight simulators
 - Hand made LOD's
 - Cost-effective

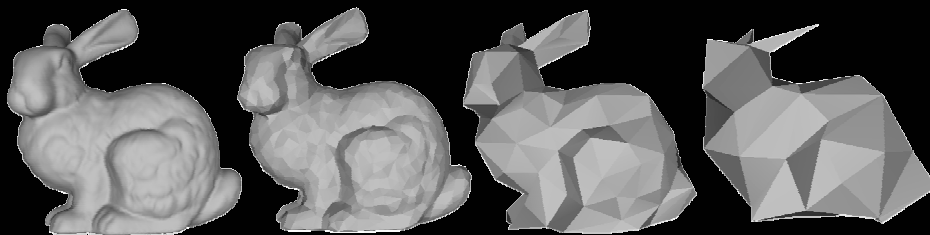


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9

Bunny example



69,451

2,502

251

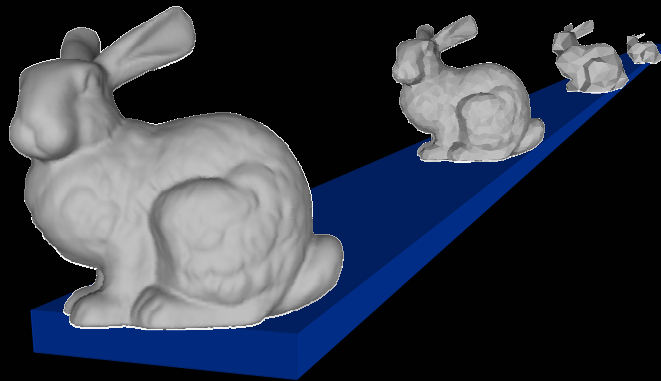
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10

Bunny example II



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LOD Frameworks - I

- Discrete (1976)
 - Create fixed object representations offline
 - Select the right one at runtime
- Advantages
 - Easy to program
 - Fits modern graphics hardware well
- Disadvantages
 - Difficult to perform *large* simplifications

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12

LOD Frameworks - II

- Continuous (1996)
 - Create a data structure
 - encode a *continuous* spectrum of detail
 - Select as required at run-time
- Advantages
 - Better granularity -> better fidelity
 - LOD specified exactly
 - Frees up polygons for other objects, better resource utilization

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LOD Frameworks - III

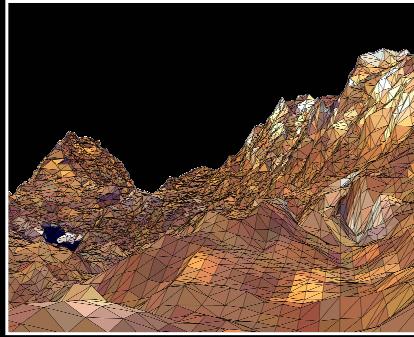
- View-dependent (1997)
 - Extend continuous LOD
 - Use current view parameters to dynamically select best representation *for the current view*
- Advantages
 - Good for complex models, representing physically large objects
 - E.g. Isosurfaces from medical visualization results

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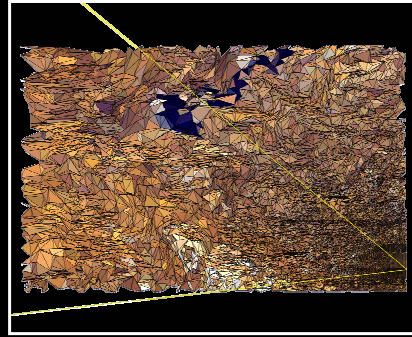
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View-dependent LOD



View from eyepoint



Bird's-eye view

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LOD Topics

- LOD Generation
 - Mesh simplification
- LOD Switching
 - Blending between simplified object representations
- LOD Selection
 - Deciding when to pick which representation

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LOD Generation

- Mesh simplification
- Low level techniques
 - Local simplification
 - Global simplification
 - More complicated algorithms
 - Fitting within LOD frameworks
 - Measuring error metrics

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Basic topology

- “Topology”
 - Structure of connected polygonal mesh
- “Genus”
 - Think number of holes in the object
 - Genus of a sphere? A torus? A pretzel?

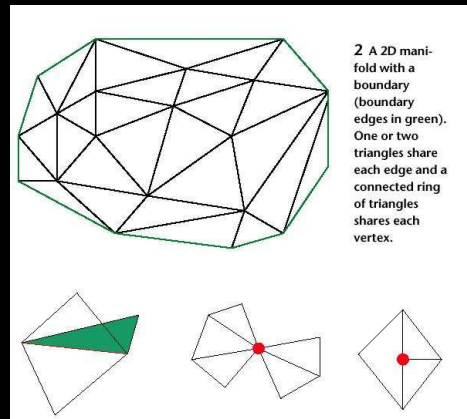
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More basic topology

- “Manifold”
 - Anyone?
 - Every edge shared by exactly 2 triangles
 - Every triangle shares an edge with exactly 3 neighboring triangles
- Mesh topology is an extensive field!



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Basic topology - relevance to LOD techniques

- Genus
 - Topology-preserving algorithms restrict over-simplification and retain manifold connectivity

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

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Basic topology - relevance to LOD techniques

- Manifold
 - Manifold meshes are well-behaved
 - Almost any simplification algorithm will work
- Disclaimer: Most algorithms operate on triangle meshes
 - Many triangulation algorithms around...

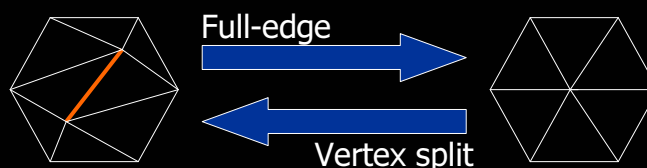
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Local simplification operators

- Full-edge collapse
 - Collapsed to a new vertex
- Side-effects
 - Mesh foldover
 - Topological inconsistency



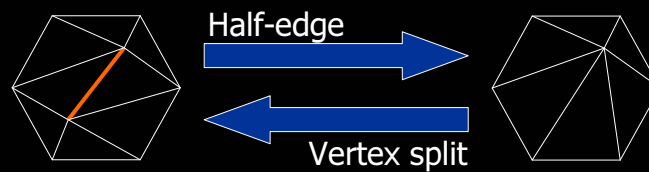
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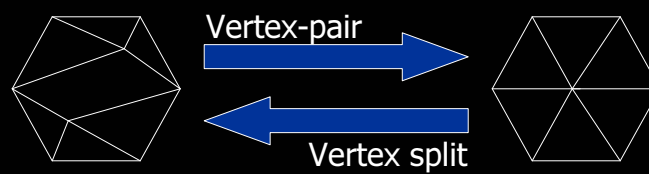
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Local simplification operators

- Half-edge collapse



- Vertex-pair collapse



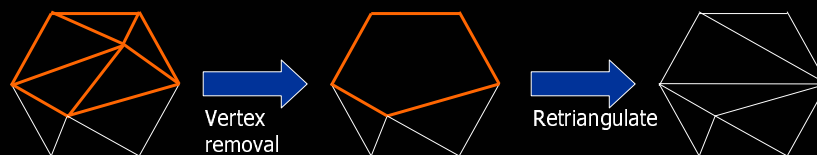
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Local simplification operators

- Vertex Removal
 - Completely remove a vertex
 - Including edges + triangles
 - Retriangulate the hole created
 - With fewer triangles



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Global simplification operators

- Volume processing
 - Idea: *voxelize* the input model
 - Simplify in the volumetric domain with local operators
 - Reconvert volumetric densities into triangle mesh
- Alpha-hull based simplification

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The bigger picture

- Assume errors are not a problem
- How do we apply these operators?
- Several options
 - Nonoptimizing
 - All operations in arbitrary order
 - Greedy
 - Lazy
 - Estimating
 - Independent
 - Interleaved

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Simplification frameworks

- Greedy
 - Bound error after each possible operation

```
for each possible operation op
    compute_cost(op)
    Q->insert(op)
while Q not empty
    op = Q->extract_min()
    apply_operator(op)
    for each neighbor operation i
        compute_cost(i)
        Q->change_key(i)
```

- Lazy: reduce # of calls to compute_cost()

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Simplification error metrics

- Guide and improve the simplification
- Measure the quality of the results
- Know when to show an LOD
- Balance quality across a large environment
 - Knapsack optimization problem
 - Hard!

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Types of error measurements

- Geometric
 - Hausdorff Distance
 - Mapping Distance
 - Screen-space error
- Attribute
 - Colors
 - Normals
 - Texture co-ordinates

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Sample distance algorithms

- Vertex-vertex distance
- Vertex-edge distance
- Surface-surface distance
- Vertex-surface distance

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TIFF (LZW) decompressor
are needed to see this picture.

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are needed to see this picture.

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Case study - progressive mesh

- Hugues Hoppe, Microsoft Research

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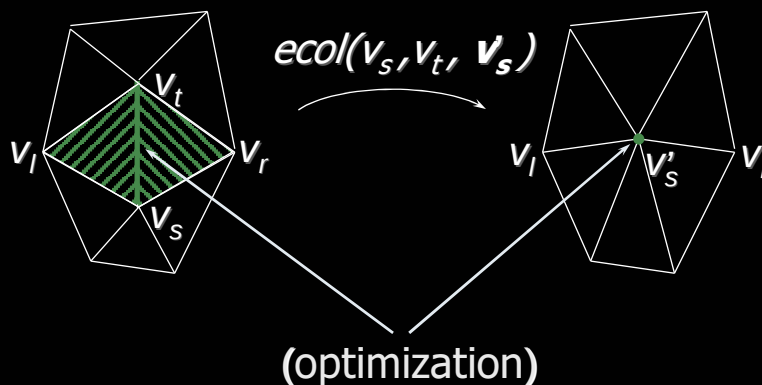
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Case Study - Progressive Mesh (Hugues Hoppe)

- Idea: Apply sequence of edge collapses

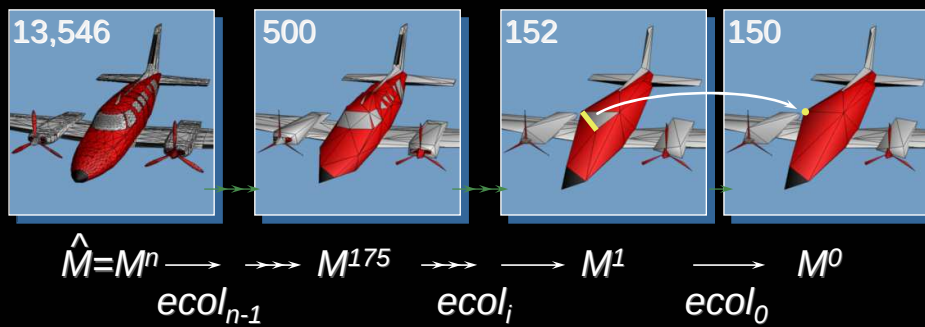


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32

Simplification process



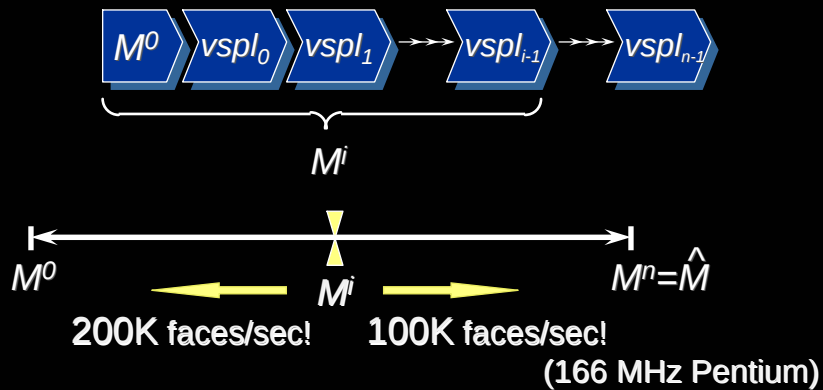
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Application: Continuous-resolution LOD

From PM, extract M^i of any desired complexity.



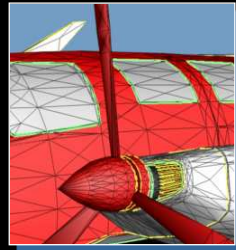
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How to select edge collapses?

- Preserve appearance:
 - geometric shape
 - scalar fields (e.g. color)
 - discontinuity curves



$$E = \sum_{\text{points}} \int_{\text{face areas}} (e_{\text{shape}} + e_{\text{scalars}}) dA + \sum_{\text{points}} \int_{\text{disc. edges}} (e_{\text{disc}}) dL$$

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Selecting edge collapses

- Greedy algorithm: always collapse edge resulting in smallest ΔE
- Simplification rates: ~ 30 faces/second
 - Off-line process
 - Could use simpler heuristics

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Applications for progressive mesh

- Smooth transitions
- Mesh compression
- Progressive transmission
- Continuous-resolution LOD
- Selective refinement

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LOD Switching

- Problems?
- Popping
 - Abrupt switch from one LOD to another
- LOD Switching needs to be seamless

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The obvious solution

- Anyone?
- Discrete Swap LOD's
 - Generate a lot of LOD's
 - Switch between them at specific distances
- Advantages
 - Pull indexed triangle strips directly from hardware

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The next obvious solution

- Anyone?
- Blend LOD's
 - Blend two different LOD's over a *short* period of time
- Disadvantages
 - Computational cost of blending two objects
 - Blending a 500 million polygon Boeing 777 down to 400 million polygons?

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40

Blending LOD's

- Might still be profitable
 - Short amount of time
 - Not all objects in a scene at the same time
 - E.g. could lose some objects while shifting
 - Use the extra time to compute blend
- How is the blend computed?
 - Any ideas?

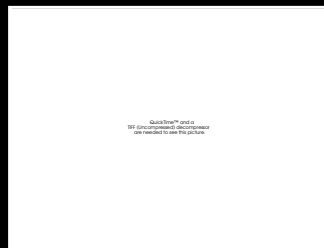
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41

Different LOD Switching

- Continuous schemes
 - Simply use data structure from Continuous LOD method
 - Select as required
- Geomorph LOD's
 - Used in the "Unreal" game engine
 - Geometrically interpolate between different object representations



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LOD Selection

- Many possible decisions for selection
 - Distance
 - Size
 - Priority
 - Hysteresis
 - Environmental Conditions
 - Perceptual Factors
- Potential Issues
 - What happens when the threshold distance gets toggled repeatedly?

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43

More algorithms

- Surface Simplification using Quadric Error Metrics, SIGGRAPH 1997
 - Michael Garland, Paul Heckbert
- Out-of-Core Compression for Gigantic Polygon Meshes, SIGGRAPH 2003
 - Martin Isenburg, Stefan Gumhold

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

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44

Gaming optimizations

- Mostly still use discrete approach
- Very popular for terrain representations
- Game environment issues
 - Constant frame rate
 - Low memory
 - Multiple instantiations
 - E.g. bots in “Halo”
 - Scalable platforms
 - Fill rate vs. Triangle rate
 - Average triangle size

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Unreal Tournament

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TIFF (Uncompressed) decompressor
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LOD in Games

- Take advantage of hardware
 - Perform as much offline processing as possible
- Eternal developer's nightmare!
 - Trying to develop next-generation graphics on yesterday's hardware
 - Push for better algorithms
- Inter-platform differences in vertex handling
 - PlayStation2, Xbox, GameCube

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Remember...

- LOD techniques are only one component of the larger real-time rendering picture...
 - Parallel rendering options
 - Culling, spatial data structures
- Questions?

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48

Libraries/Resources

- A lot of libraries around...
- Qslim (Garland + Heckbert)
 - Code available at:
 - <http://graphics.cs.uiuc.edu/~garland/software/qslim.html>
- ROAM (RT Optimally Adapting Meshes)
 - Code available at:
 - http://www.cognigraph.com/ROAM_homepage/
- See <http://lodbook.com/source/> for more details and full list

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49

References

- “Level of Detail for 3D Graphics”
 - David Luebke, Martin Reddy, Jonathan Cohen, Amitabh Varshney, Benjamin Watson, Robert Huebner
- “Real-Time Rendering”
 - Tomas Akenine Moller, Eric Haines

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50