Multiresolution Meshes

COS 526
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The Problem of Detail

Graphics systems are awash in model data
- very detailed CAD databases
- high-precision surface scans

Available resources are always constrained
- CPU, space, graphics speed, network bandwidth

We need economical models
- want the minimum level of detail (LOD) required
A Non-Economical Model

424,376 faces

60,000 faces

Automatic Surface Simplification
Automatic Surface Simplification

Produce approximations with fewer triangles
- should be as similar as possible to original
- want computationally efficient process

Need criteria for assessing similarity of models
- for display, visual similarity is the ultimate goal
- similarity of shape is often used instead
  $ generally easier to compute
  $ lends itself more to applications other than display

Simplification Methods

Manual preparation has been widely used
- skilled humans produce excellent results
- very labor intensive, and thus costly

Most common kinds of automatic methods
- vertex clustering
- vertex decimation
- iterative edge contraction
**Vertex Clustering**

Partition space into cells
- grids [Rossignac-Borrel], spheres [Low-Tan], octrees, ...

Merge all vertices within the same cell
- triangles with multiple corners in one cell will degenerate

**Vertex Decimation**

Starting with original model, iteratively
- rank vertices according to their importance
- select unimportant vertex, remove it, and retriangulate hole

A fairly common technique
- Schroeder et al, Soucy-Laurendeau, Klein et al, Campalini et al
Iterative Contraction

Contraction can operate on any set of vertices
- edges (or vertex pairs) are most common, faces also used

Starting with the original model, iteratively
- rank all edges with some cost metric
- contract minimum cost edge
- update edge costs

Edge Contraction

A single edge contraction \((v_1, v_2) \rightarrow v'\) is performed by
- moving \(v_1\) and \(v_2\) to position \(v'\)
- replacing all occurrences of \(v_2\) with \(v_1\)
- removing \(v_2\) and all degenerate triangles
Iterative Edge Contraction

Currently the most popular technique
- Hoppe, Garland–Heckbert, Lindstrom-Turk, Ronfard-Rossignac, Guéziec, and several others
- simpler operation than vertex removal
- well-defined on any simplicial complex

Also induces hierarchy on the surface
- a very important by-product
- enables several multiresolution applications

Cost Metrics for Contraction

Simple heuristics
- edge length, dihedral angle, surrounding area, ...

Sample distances to original surface
- projection to closest point [Hoppe]
- restricted projection [Soucy–Laurendeau, Klein et al, Campalini et al]

Alternative characterization of error
- quadric error metrics [Garland–Heckbert]
- local volume preservation [Lindstrom–Turk]
Can Also Consider Attributes

Mesh for solution

Radiosity solution

50,761 faces

10,000 faces
Levels of Detail (LODs)

- distance from viewer?
- close
- far

10,000 2,000 1,000 500 250

LODs are NOT the Whole Answer

- Switching discrete LODs causes popping
- Want continuous change in detail
- Cannot choose single LOD sometimes
- May need different amounts of detail on same surface

Garland
Hoppe
Need Multiresolution Meshes

Encode wide range of levels of detail
- extract appropriate approximations at run time
- must have low overhead
  - space consumed by representation
  - cost of changing level of detail while rendering
- can be generated via simplification process

Progressive Mesh

Encode continuous detail as sequence of edge collapses

$ecol(v_s, v_t, v'_s)$
**Simplification Process**

\[ M = M^n \rightarrow M^{1.75} \rightarrow M^1 \rightarrow M^0 \]

**Invertible!**

Vertex split transformation:

\[ \text{attributes} \]

\[ \text{vspl}(v_s, v_I, v_r, v'_s, v'_I, \ldots) \]
**Reconstruction Process**

\[ M^0 \rightarrow M^1 \rightarrow \cdots \rightarrow M^{1.75} \rightarrow \cdots \rightarrow M^n = \hat{M} \]

*progressive mesh (PM) representation*

**Multiresolution!**

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

\[ M^0 \rightarrow M^i \rightarrow \cdots \rightarrow M^n = \hat{M} \]

200K faces/sec! 100K faces/sec! (166 MHz Pentium)
Simplification/Reconstruction

Progressive Transmission

Transmit records progressively:

- time

\[ M^0 \rightarrow vspl_0 \rightarrow vspl_1 \rightarrow vspl_n \]

Receiver displays:

\[ M^0 \rightarrow M^i \rightarrow \hat{M} \]

(\sim\text{progressive JPEG})
Progressive Transmission

Hoppe
Selective refinement

(e.g. view frustum)

Smooth Transitions
Smooth Transitions

Mesh Compression

Encoding of vspl records:
- connectivity: ~ good triangle strips
- attributes: excellent delta-encoding

Record deltas:
1. $V'_t - V_s$
2. $V'_s - V_s$
3. ...

vspl($V_s, V_l, V_r, V'_s, V'_t, ...$)

Mesh Compression

Hoppe

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Mesh Compression

Hoppe
Applications Beyond Display

Other important applications are appearing

- surface editing [Guskov et al 99]
- surface morphing [Lee et al 99]
- multiresolution radiosity [Willmott et al 99]

Still others seem promising

- hierarchical bounding volumes
- object matching
- shape analysis / feature extraction

Progressive Mesh Summary

- single resolution
- continuous-resolution
- smooth LOD
- space-efficient
- progressive
Other Multiresolution Meshes

More flexibility
- PM’s imply dependency on all earlier contractions
- but non-overlapping contractions may be independent

Vertex Hierarchies

Encode simplification operations in tree
- Subtrees are independent of one another
- Cut through tree defines a mesh
- Move cut up/down to simplify/refine

Xia96, Hoppe97, Luebke97
View-Dependent Progressive Mesh

View-Dependent Progressive Mesh
Multiresolution Mesh Summary

Representations are available to support
- progressive transmission
- adaptive refinement
- compression

But limitations remain
- on-line costs not suitable for all applications
- interacting multiresolution objects largely ignored
- model may not fit in memory
- topological simplification still hard

Acknowledgements

Slides by
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- Hugues Hoppe