Multiresolution Meshes

COS 526
Tom Funkhouser, Fall 2014

Slides by Guskov, Praun, Sweldens, etc.
Multiresolution Meshes

Huge meshes are difficult to
• render
• store
• transmit
• edit

Multiresolution is crucial

[Guskov et al.]
Multiresolution Meshes

Irregular  Semi-regular  Completely regular

[Hoppe]
Multiresolution Meshes

Irregular

Semi-regular

Completely regular

[Hoppe]
Irregular Multiresolution Meshes

Encode mesh simplification operations in tree

- Cut through tree defines a mesh
- Move cut up/down to simplify/refine

Xia96, Hoppe97, Luebke97
Progressive Mesh

Encode continuous detail as sequence of edge collapses

\[ \text{encode}(v_s, v_t, v'_s) \]

Slide by Hoppe
Progressive Mesh

Simplification process

$\hat{M} = M^n \rightarrow M^{175} \rightarrow M^1 \rightarrow M^0$

$\text{ecol}_{n-1} \rightarrow \text{ecol}_i \rightarrow \text{ecol}_0$
Progressive Mesh

Inversion is possible with vertex split transformation

\[ \text{vspl}(v_s, v_l, v_r, v'_s, v'_t, \ldots) \]
Progressive Mesh

Reconstruction process

\[ M^0 \xrightarrow{\text{vspl}_0} M^1 \xrightarrow{\text{vspl}_i} M^{175} \xrightarrow{\text{vspl}_{n-1}} M^n \]

progressive mesh (PM) representation
Progressive Mesh

From PM, extract $M_i$ of any desired complexity (this is multiresolution)

$M^0 \xrightarrow{vspl_0} vspl_1 \xrightarrow{vspl_i} vspl_{i-1} \xrightarrow{vspl_{n-1}} M_i$

3,478 faces?
Progressive Mesh

LOD  0.000  #Faces  48

Hoppe
Progressive Mesh
Progressive Mesh

Benefits/Applications:

- Progressive transmission
- Surface compression
- Selective refinement
Transmit records progressively:

Receiver displays:

$\hat{M}$

($\sim$ progressive JPEG)
Progressive Transmission

Details added while user is browsing.

[Certain et al.]
Progressive Transmission

LOD 0.000
#Faces 598
Mesh Compression

Lossy compression
Mesh Compression

Lossless compression
Mesh Compression

Encoding of \textit{vspl} records:
- connectivity: \textasciitilde good triangle strips
- attributes: excellent delta-encoding

Record deltas:
- \(v_t' - v_s\)
- \(v_s' - v_s\)
- \(\ldots\)
Selective Refinement (VDPM)

Refine mesh adaptively based on viewpoint

(e.g. view frustum)
Selective Refinement (VDPM)
Selective Refinement (VDPM)
Progressive Mesh Summary

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

Irregular  Semi-regular  Completely regular
Semi-Regular Mesh

Arbitrary base mesh + refinement via subdivision

[Hoppe]
Multiresolution Analysis

original

mapping

remesh

Irregular

domain

Regular

[Guskov et al.]
Multiresolution Analysis

step 1: construct a simple domain mesh $K$
step 2: construct a parametrization $r$ of $M$ over $K$
step 3: remesh
Multiresolution Analysis

Step 1: construct simple base domain

- topological type of $K = \text{topological type of } M$
- small number of triangular regions
- smooth and straight boundaries

mesh $M$ \hspace{2cm} partition \hspace{2cm} domain mesh $K$

[Lounsberry et al.]
Multiresolution Analysis

Step 2: construct parameterization

- Map each face of domain mesh to corresponding triangular region

[Local map] [Lounsberry et al.]
Multiresolution Analysis

Step 2: construct parameterization

- Map each face of domain mesh to corresponding triangular region
- Local maps must agree on boundaries and introduce small distortions → harmonic maps
Multiresolution Analysis

Step 3: remesh

- Regular subdivision

[Hoppe]
Multiresolution Representation

Wavelet representation

\[
\text{base shape } M^0 \\
+ \\
\text{sum of local correction terms (wavelet terms)}
\]

[Lounsberry et al.]
Multiresolution Representation

- **downsample**
- **predict/subdivide**
- **details/wavelets**

[Guskov et al.]
Multiresolution Representation

Burt-Adelson pyramid

$n$ vertices $\xrightarrow{\text{coarsen}} \text{subdivide} \xrightarrow{} n-1$ vertices

$n$ vertices $\xrightarrow{}$ details

[Guskov et al.]
Multiresolution Representation

[Image showing wavelets]

wavelets

[Reference: Guskov et al.]
Multiresolution Representation

Two scalar displacement \((t,n)\)

One scalar (normal mesh)

Normal Mesh

[Guskov et al.]
Multiresolution Representation

Normal mesh

[Guskov et al.]
Multiresolution Meshes

Applications:

- Adaptive remeshing
- Compression
- Filtering
- Editing
- Morphing
Adaptive Remeshing

[Guskov et al.]
Adaptive Remeshing

[Zorin et al.]
Adaptive Remeshing

Both 11K triangles

Uniform

Adaptive

[Zorin et al.]
Multiresolution Meshes

Applications:

- Adaptive remeshing
- **Compression**
- Filtering
- Editing
- Morphing
Mesh Compression

Effect of wavelet transform

- changes distribution of coefficients
  - almost all coefficients close to zero

3 scalars

Vertex coordinates

1 scalar

Wavelet coefficients

[Guskov et al.]
Mesh Compression

Fixed file size

Normal Meshes:

CPM:

[Guskov et al.]
Mesh Compression

[Image of 3D models and their respective compressed data sizes and bit rates.]

- 956B (4 bits/v)
- 2004B (4 bits/v)
- 4806B (4 bits/v)
- 26191B (4 bits/v)

- 1253B (2.5 bits/v)
- 2804B (2.5 bits/v)
- 6482B (2.5 bits/v)
- 14844B (2.5 bits/v)

[Guskov et al.]
Multiresolution Meshes

Applications:

- Adaptive remeshing
- Compression
- Filtering
- Editing
- Morphing
Multiresolution Mesh Processing

Smoothing

[Guskov et al.]
Multiresolution Mesh Processing

Enhancing

smoothed + 2 * (original - smoothed) = enhanced

[Guskov et al.]
Multiresolution Mesh Processing

Filtering

[Guskov et al.]
Multiresolution Meshes

Applications:

- Adaptive remeshing
- Compression
- Filtering
- Editing
- Morphing
Multiresolution Mesh Editing

Goal: edit surface with operations at various resolutions

[Guskov et al.]
Multiresolution Mesh Editing

When edit at fine resolution, update higher levels of multiresolution hierarchy

Input at level 3
Edit on level 3
Effect of edit on level 2

[Zorin et al.]
Multiresolution Mesh Editing

original    coarse    edit coarse    edit fine

[Guskov et al.]
Multiresolution Mesh Editing

[Guskov et al.]
Multiresolution Mesh Editing

[Zorin et al.]
Multiresolution Mesh Editing

[Zorin et al.]
Multiresolution Mesh Editing

[Zorin et al.]
Multiresolution Mesh Editing

[Zorin et al.]
Multiresolution Meshes

Applications:

- Adaptive remeshing
- Compression
- Filtering
- Editing
- Morphing
Multiresolution Mesh Morphing

Goal: interpolate surfaces

[Lee et al.]
Multiresolution Mesh Morphing

Common parameterization

- If two semi-regular meshes have the same base domain, then they share a common parameterization
Multiresolution Mesh Morphing

[Lee et al.]
Multiresolution Mesh Morphing

[Lee et al.]
Multiresolution Mesh Morphing

[Lee et al.]
Multiresolution Mesh Morphing

Multiresolution

- Can morph different multiresolution levels at different rates
Multiresolution Mesh Morphing

[Lee et al.]
Multiresolution Mesh Morphing

with Spatial Control

[Lee et al.]
Multiresolution Mesh Morphing

[Lee et al.]
Multiresolution Mesh Morphing

with Spatial Control

[Lee et al.]
Multiresolution Meshes

Irregular

Semi-regular

Completely regular

[Hoppe]
Completely Regular Mesh

Regular sampling of parameter domain

\[ [r, g, b] = [x, y, z] \]

Geometry Image
Multiresolution Meshes

Key ideas

- Multiresolution analysis provides parameterization
- Different resolutions represent different frequencies
- Can map operations in parameter domain to operations on mesh (e.g., smoothing, morphing, etc.)
Acknowledgements

Slides by

- Igor Guskov
- Wim Sweldens
- Peter Schroeder
- Denis Zorin
- Aaron Lee
- Emil Praun
- Michael Lounsberry
- Hugues Hoppe