Multiresolution Meshes

COS 526
Tom Funkhouser, Fall 2016
Slides by Guskov, Praun, Sweldens, etc.
Motivation

Huge meshes are difficult to

• render
• store
• transmit
• edit

→ Multiresolution Meshes!

[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

\( ecol(v_s, v_t, v'_s) \)

\( M^N \quad ecol_0 \quad ecol_1 \quad ecol_{i-1} \quad ecol_{n-1} \)
Progressive Mesh

Simplification process

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

ecol_{n-1} \rightarrow ecol_i \rightarrow 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

 прогрессивная сеть (PM) представление
Progressive Mesh

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

$M^0 \xrightarrow{\text{vspl}_0} \text{vspl}_1 \xrightarrow{\text{vspl}_{i-1}} \text{vspl}_{r-1}$

$M^i$

3,478 faces?

3,478
Progressive Mesh

LOD 0.000  #Faces 48

Hoppe
Progressive Mesh

Hoppe
Progressive Mesh

Benefits/Applications:

- Progressive transmission
- Surface compression
- Selective refinement
Progressive Transmission

Transmit records progressively:

Receiver displays:

\( M^0 \)

\( M^i \)

\( \hat{M} \)

\( \sim \) progressive JPEG
Progressive Transmission

Details added while user is browsing.

[Certain et al.]
Progressive Transmission
Mesh Compression

Lossy compression
Mesh Compression

Lossless compression
Mesh Compression

Encoding of vspl records:

- connectivity: ~ good triangle strips
- attributes: excellent delta-encoding

Record deltas:

\( V'_t - V_s \)
\( V'_s - V_s \)
\( ... \)
Selective Refinement (VDPM)

Refine mesh adaptively based on viewpoint

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

\[ \hat{M} \]

- single resolution

\[ V \quad F \]

lossless

\[ PM \]

- continuous-resolution
- smooth LOD
- space-efficient
- progressive

\[ M^0 \quad \text{vspl} \]
Multiresolution Meshes

Irregular

Semi-regular

Completely regular

[Hoppe]
Semi-Regular Mesh

Arbitrary base mesh + refinement via subdivision

[Hoppe]
Multiresolution Analysis

original
mapping
remesh

Irregular
Regular

domain

[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 $M$) \(\rightarrow\) (partition) \(\rightarrow\) (domain mesh $K$)

[Lounsberry et al.]
Multiresolution Analysis

Step 2: construct parameterization

- Map each face of domain mesh to corresponding triangular region
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

planar triangle

triangular region

[Lounsberry et al.]
Multiresolution Analysis

Step 3: remesh

- Regular subdivision

[Hoppe]
Multiresolution Representation

Wavelet representation

\[ \text{base shape } M^0 \]

\[ + \]

\[ \text{sum of local correction terms} \]

(\text{wavelet terms})
Multiresolution Representation

$\downarrow$ downsample

$\downarrow$ predict/subdivide

$\downarrow$ details/wavelets

[Guskov et al.]
Multiresolution Representation

Burt-Adelson pyramid

$F$ [Guskov et al.]

$n$ vertices $\rightarrow$ coarsen $\rightarrow$ subtract $\rightarrow$ subdivide $\rightarrow$ details $\rightarrow$ $n-1$ vertices
Multiresolution Representation

[wavelets]

[wavelets]

[wavelets]

[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


- 26K 4 bits/v
- 15K 2.5 bits/v

[Refs: 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
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.)
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