

Progressive meshes

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Outline

- General concepts behind; motivations
- Algorithm description
 - Overview
 - Geomorphs
 - Selective refinement
- PM construction
 - Mesh simplification
 - Geometric attributes
 - Scalar attributes
 - Discontinuity curves
- Results

Motivations

- Highly detailed geometric models in computer graphics
- Complex meshes are expensive to store, transmit and render
- Problems:
 - Mesh simplification
 - LOD (Level-of Detail)
 - Progressive transmission
 - Mesh compression
 - Selective refinement

Some Concepts

- Assume triangular meshes
- Mesh representation, $M = (K, V, D, S)$
- Mesh geometry: (K, V)
 - K – mesh connectivity
 - $V = \{\mathbf{v}_1, \dots, \mathbf{v}_m\}$, set of vertex positions defining mesh
- Discrete attributes: D
 - Material identifier
 - Associates with faces $f = \{j, k, l\}$ in K
- Scalar attributes: S
 - Diffuse color, normal, texture coordinates
 - Associates with corners (v, f) of K

Algorithm in general

- Single transformation:

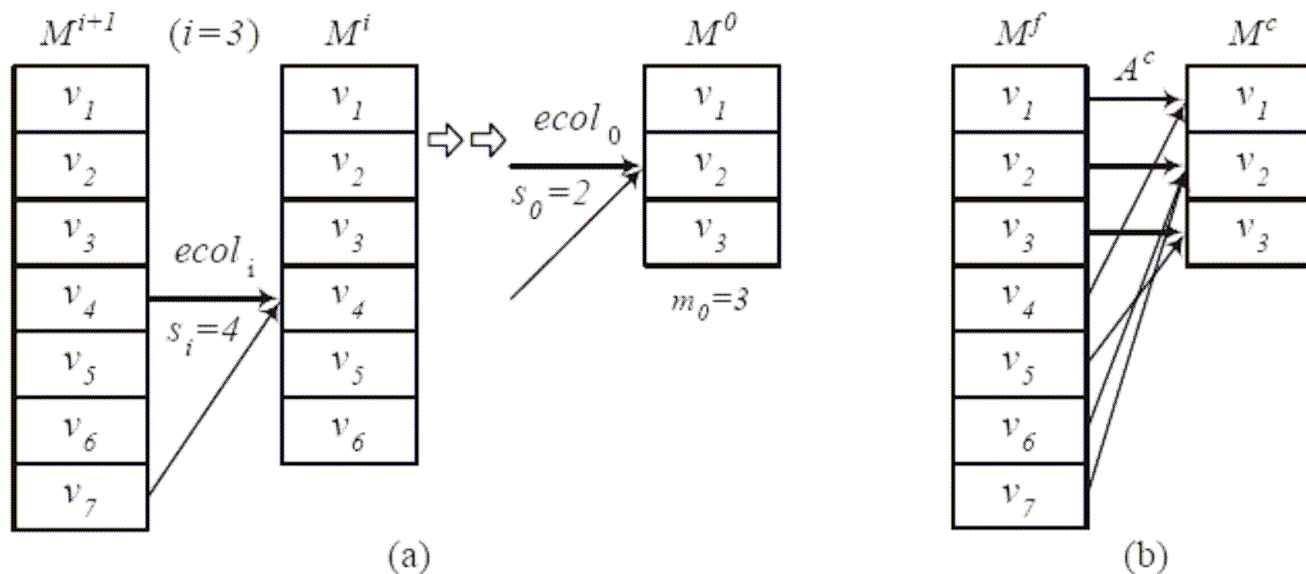
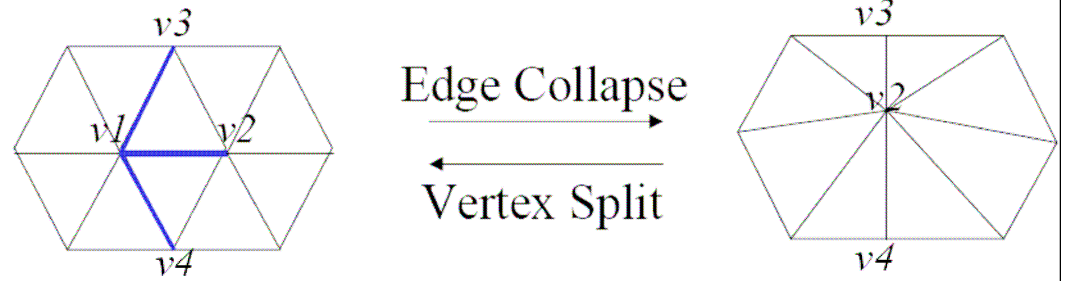


Figure 2: (a) Sequence of edge collapses; (b) Resulting vertex correspondence.

Algorithm in general

- Simplify $\hat{M}=M^n$ into M^0 through the sequence of successive transformations:

$$(\hat{M}=M^n) \xrightarrow{ecol_{n-1}} \dots \xrightarrow{ecol_1} M^1 \xrightarrow{ecol_0} M^0 .$$

- Edge collapse is invertible, thus can represent \hat{M} as M^0 and a sequence of n *split* records:

$$M^0 \xrightarrow{vsplit_0} M^1 \xrightarrow{vsplit_1} \dots \xrightarrow{vsplit_{n-1}} (M^n = \hat{M}) \Big|$$

- Progressive mesh representation (PM): $(M^0, \{vsplit_0, \dots, vsplit_{n-1}\}) \Big|$

Geomorphs

- Smooth visual transition between two meshes: $M^i \xrightarrow{vsplit_i} M^{i+1}$
- Construct geomorph $M^G(\alpha)$ with $0 \leq \alpha \leq 1$, such that, $M^G(0) = M^i$ and $M^G(1) = M^{i+1}$
 - Vertex positions interpolated between the two.
- Can be constructed between any two meshes of the same PM representation:
 - There is a unique sequence of *ecol* transformation for each vertex between the two meshes.

Selective refinement

- Detail added to the model only in desired areas
 - For example a view frustum
- When refining the mesh only perform *vsplit* for those vertices
 - That are present in the current mesh together with it's neighbours
 - If it's neighbourhood is within the refinement area

Mesh simplification

- Energy metric to measure the accuracy of the simplified mesh:
 - $E(M) = E_{dist}(M) + E_{spring}(M) + E_{scalar}(M) + E_{disc}(M)$

were:

- $E_{dist}(M)$ is a total square distance of the points to the mesh
- $E_{spring}(M)$ is regularizing term that corresponds to placing a spring of rest length 0 and tension k on each edge of the mesh
- $E_{scalar}(M)$ measures the accuracy of the scalar attributes
- $E_{disc}(M)$ measures the accuracy of the discontinuity curves

Mesh simplification

- Priority queue of edge collapses:
 - For each edge based on the estimated ΔE
 - Transformation at the front of the queue first (lowest ΔE)
 - Energy cost and priority of the edges in the neighbourhood of last transformation are updated at each iteration
 - Perform as many transformations as needed to get to the final mesh
 - Continuous-resolution family of meshes created

E_{dist} (Surface geometry)

- Sample a list of points from the original mesh (at least all of the vertices)
- $E_{\text{dist}}(M) = d^2(\mathbf{x}_i, \phi_V(|K|)) = \min_{\mathbf{b}_i \in |K|} \|\mathbf{x}_i - \phi_V(\mathbf{b}_i)\|^2$
- Minimization problem
- Optimizing a position of the new \mathbf{x}_i vertex
- \mathbf{b}_i – parameterization of the projection of \mathbf{x}_i on the mesh

E_{spring} (Surface geometry)

$$E_{\text{spring}}(M) = \sum k \|v_j - v_k\|^2$$

- Is most important when few points project on the neighbourhood of faces
- k – a function of the ratio of the number of points to the number of faces in the neighbourhood
- Influence decreases as mesh becomes simpler

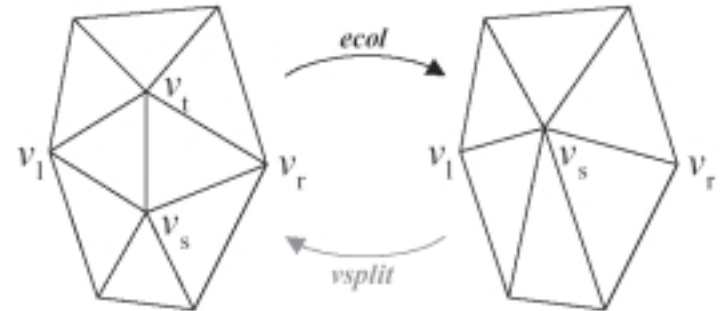
E_{scalar} (Scalar attributes)

$$E_{\text{scalar}}(\underline{V}) = (c_{\text{scalar}})^2 \sum_i \|\underline{\mathbf{x}}_i - \phi_{\underline{V}}(\mathbf{b}_i)\|^2$$

- were
 - $\underline{\mathbf{v}}_j \in \mathbf{R}^d$ are scalar attributes
 - c_{scalar} is a constant assigning relative weight between the scalar attributes E_{scalar} and geometric E_{dist} errors

E_{disc} (Discontinuity curves)

- Preserve topologically and geometrically

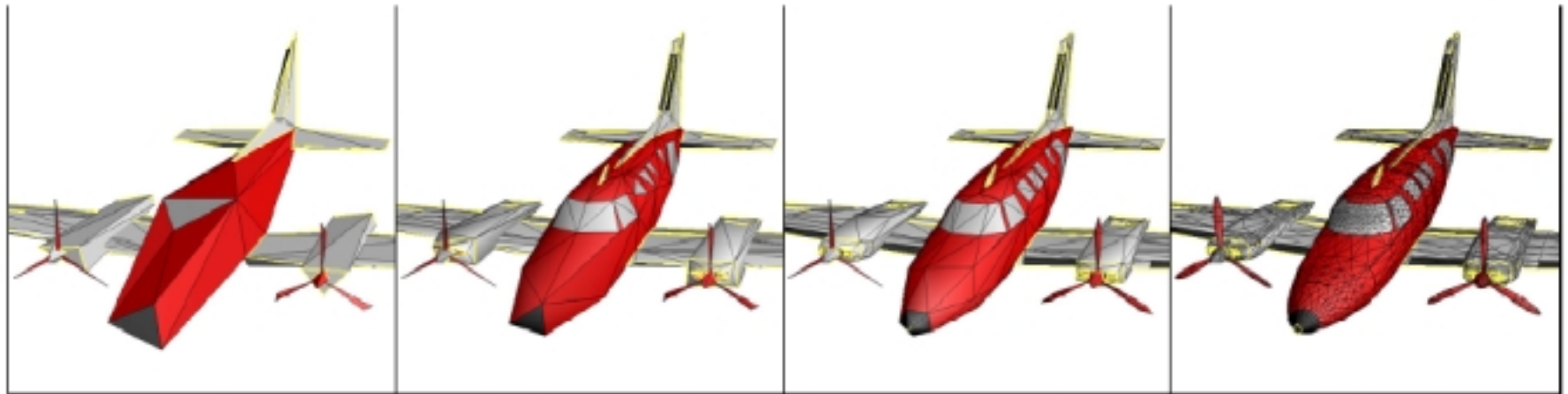


- $\text{sharp}(v_s, v_l)$ and $\text{sharp}(v_l, v_r)$, or
 - $\text{sharp}(v_s, v_r)$ and $\text{sharp}(v_l, v_r)$, or
 - $\#\text{sharp}(v_s) \geq 1$ and $\#\text{sharp}(v_l) \geq 1$ and not $\text{sharp}(v_s, v_l)$, or
 - $\#\text{sharp}(v_s) \geq 3$ and $\#\text{sharp}(v_l) \geq 3$ and $\text{sharp}(v_s, v_l)$, or
 - $\text{sharp}(v_s, v_l)$ and $\#\text{sharp}(v_s) = 1$ and $\#\text{sharp}(v_l) \neq 2$, or
 - $\text{sharp}(v_s, v_l)$ and $\#\text{sharp}(v_l) = 1$ and $\#\text{sharp}(v_s) \neq 2$.
- Collapsing an edge that modifies the topology of the discontinuity curves is either disallowed or penalized

Summary

- Lossless representation
- Supports
 - Geomorphs
 - Progressive transmission
 - Compression
 - Selective refinement
 - Geometry and overall appearance of the mesh
 - Surface creases
 - Normals
 - Shading, radiosity
 - Color and texture mapping

Results



(a) Base mesh M^0 (150 faces) (b) Mesh M^{175} (500 faces) (c) Mesh M^{425} (1,000 faces) (d) Original $\hat{M}=M^0$ (13,546 faces)

Figure 5: The PM representation of an arbitrary mesh \hat{M} captures a continuous-resolution family of approximating meshes $M^0 \dots M^n = \hat{M}$.



(a) $\alpha = 0.00$

(b) $\alpha = 0.25$

(c) $\alpha = 0.50$

(d) $\alpha = 0.75$

(e) $\alpha = 1.00$

Figure 6: Example of a geomorph $M^G(\alpha)$ defined between $M^G(0) \doteq M^{175}$ (with 500 faces) and $M^G(1) = M^{425}$ (with 1,000 faces).

Results

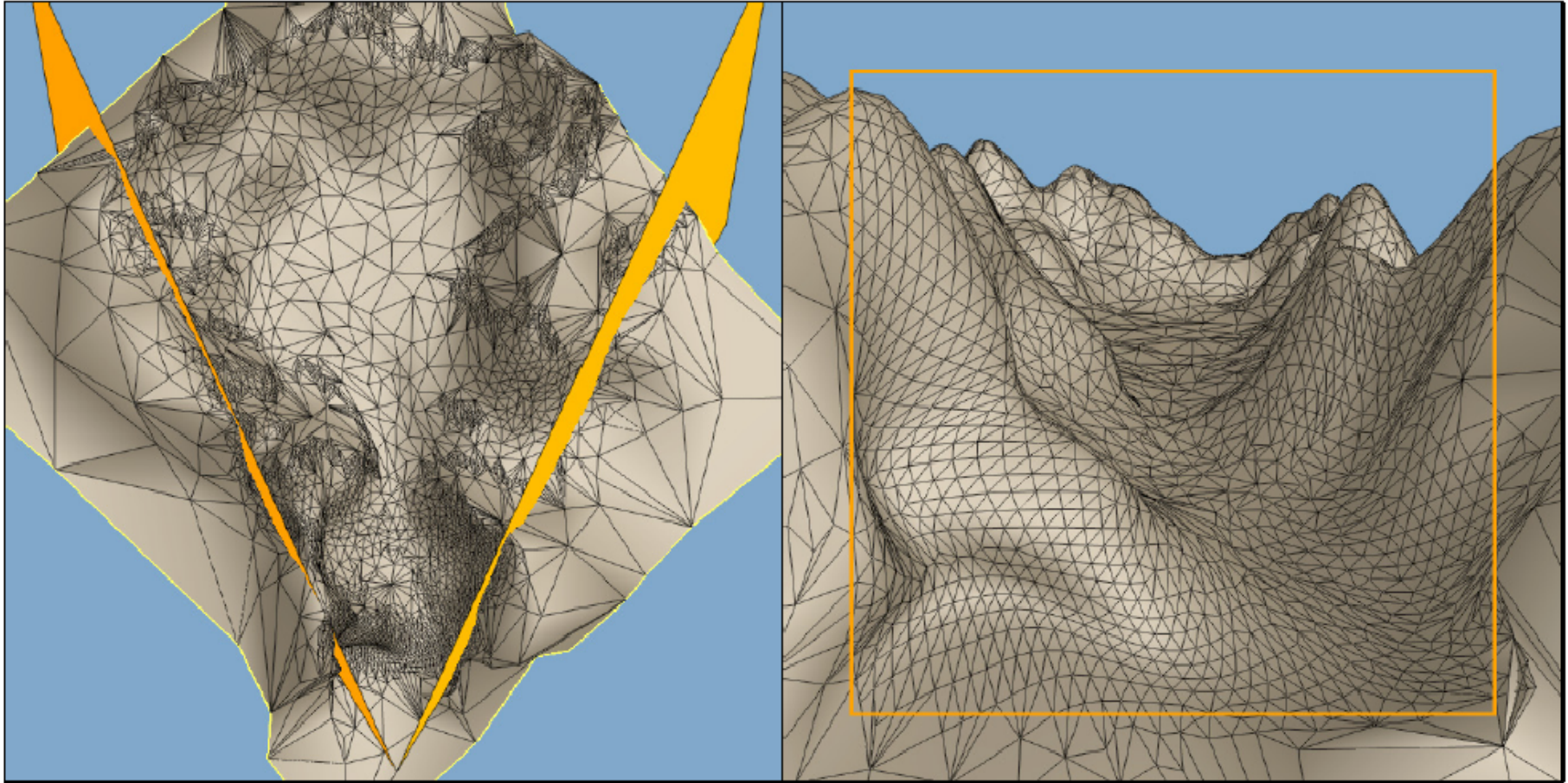
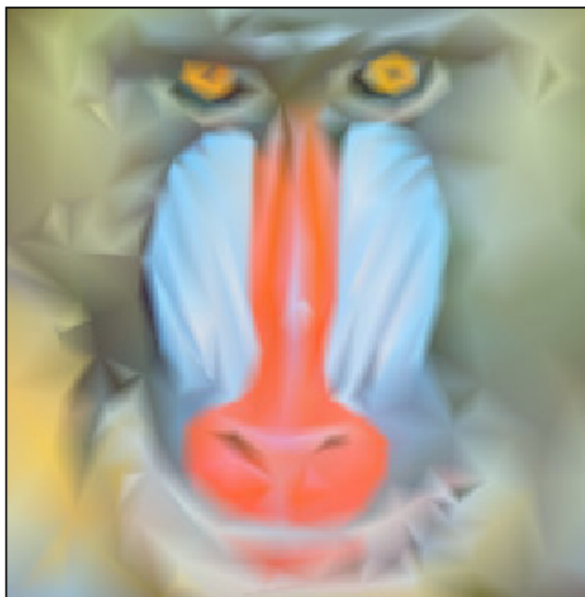


Figure 10: Selective refinement of a terrain mesh taking into account view frustum, silhouette regions, and projected screen size of faces (7,438 faces).

Results



(a) \hat{M} (200 \times 200 vertices)



(b) Simplified mesh (400 vertices)

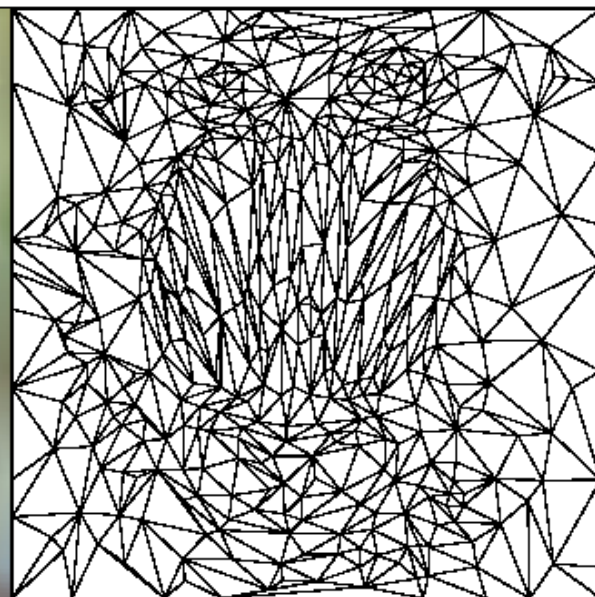


Figure 8: Demonstration of minimizing E_{scalar} : simplification of a mesh with trivial geometry (a square) but complex scalar attribute field. (\hat{M} is a mesh with regular connectivity whose vertex colors correspond to the pixels of an image.)

Results



Figure 11: Simplification of a radiosity solution; left: original mesh (150,983 faces); right: simplified mesh (10,000 faces).

Results

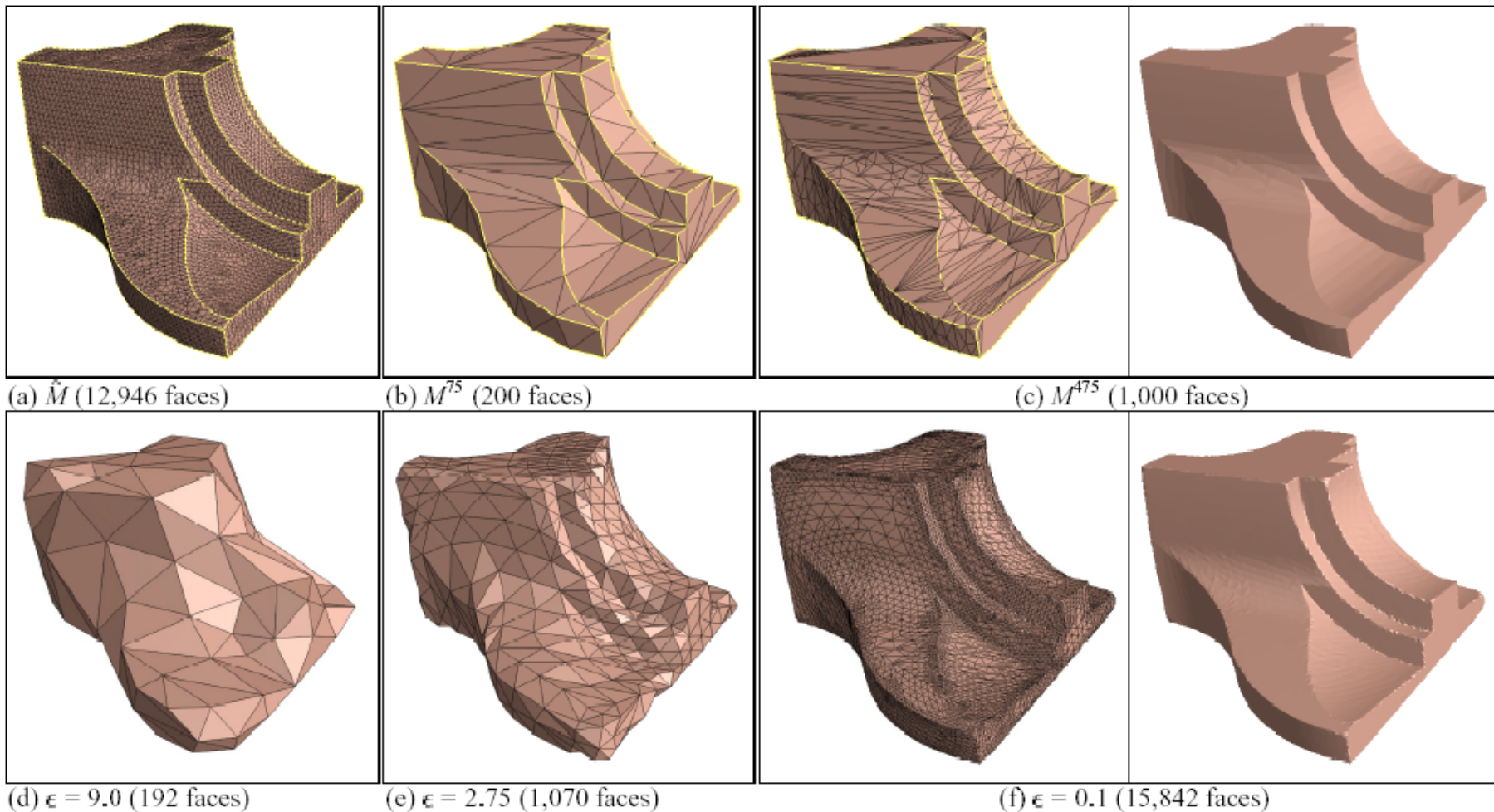


Figure 12: Approximations of a mesh \hat{M} using (b–c) the PM representation, and (d–f) the MRA scheme of Eck et al. [7]. As demonstrated, MRA cannot recover \hat{M} exactly, cannot deal effectively with surface creases, and produces approximating meshes of inferior quality.