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 – $\{\mathbf{v}_1, \ldots, \mathbf{v}_m\}$, 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

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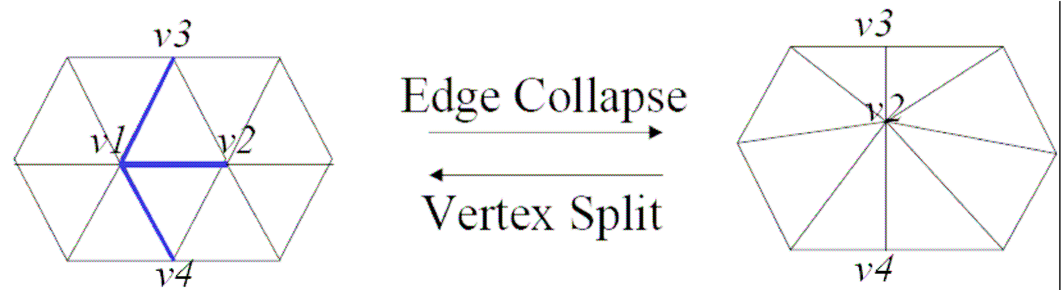
Algorithm in general

- Single transformation:



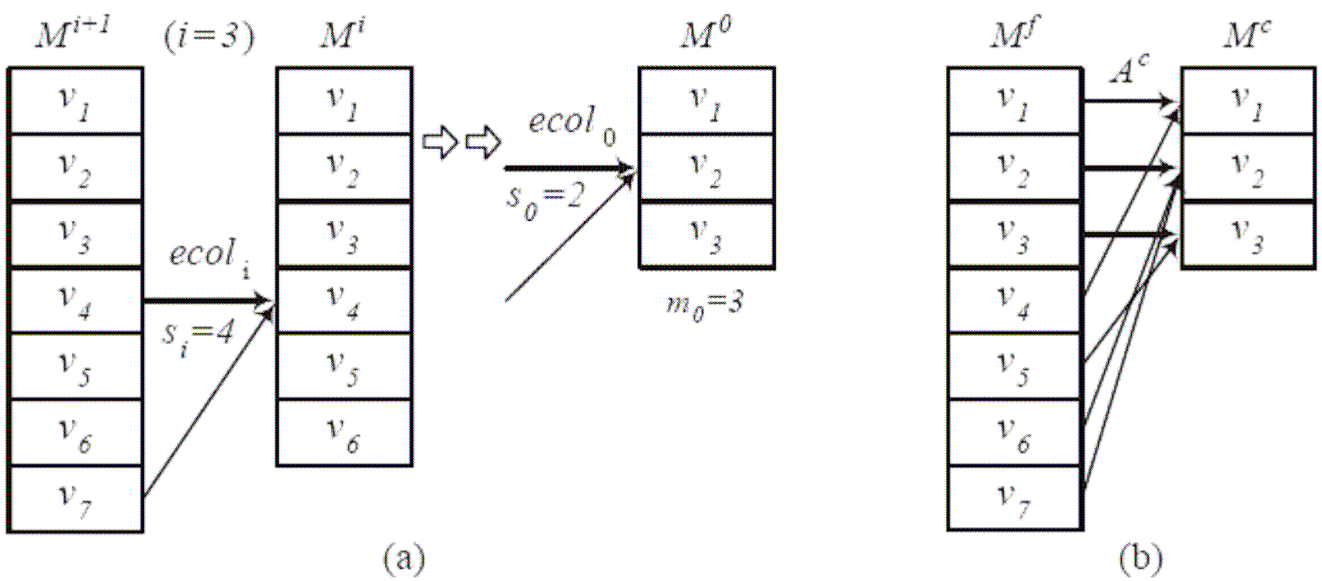


Figure 2: (a) Sequence of edge collapses; (b) Resulting vertex correspondence.

Algorithm in general

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

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

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

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

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

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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, $M^G(0) = M^{\boldsymbol{i}}$ and $M^G(1) = M^{\boldsymbol{i}+1}$
  - 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.

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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)
- $E_{dist}(M) = d^2(\mathbf{x}_i, \phi_V(|K|)) = \min_{\mathbf{b}_i \in |K|} \|\mathbf{x}_i - \phi_V(\mathbf{b}_i)\|^2$
- Minimization problem
- Optimizing a position of the new x_i vertex
- b_i – parameterization of the projection of x_i on the mesh

E_{spring} (Surface geometry)

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

- 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

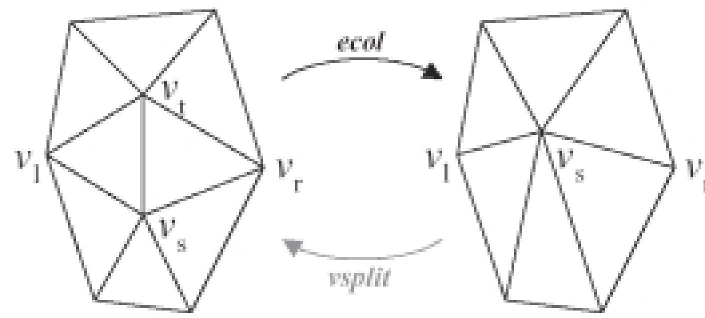
E_{scalar} (Scalar attributes)

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

- 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



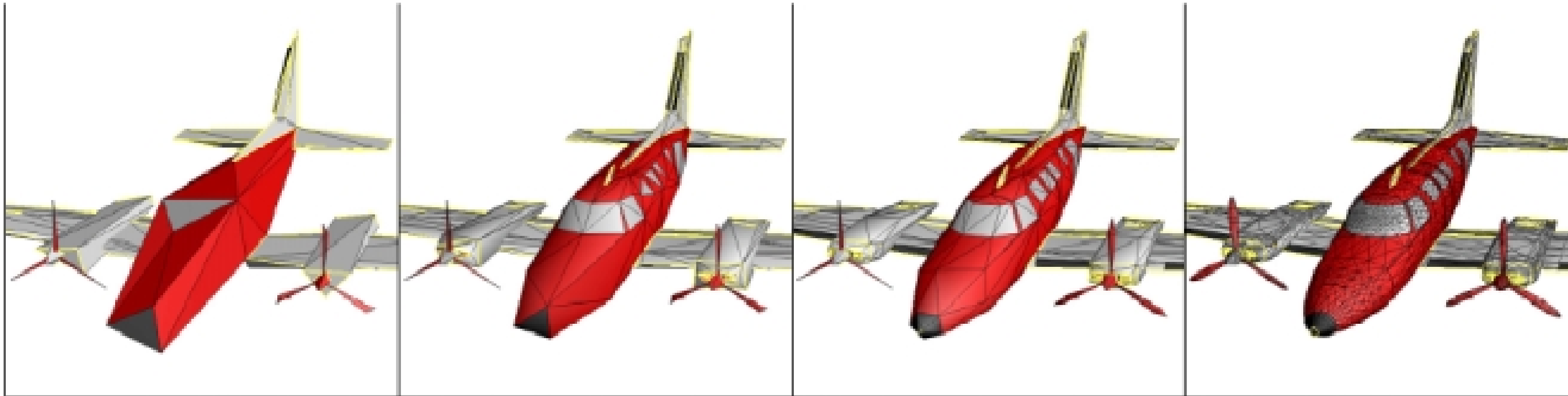
  - *sharp*(v_s, v_l) and *sharp*(v_t, v_l), or
  - *sharp*(v_s, v_r) and *sharp*(v_t, v_r), or
  - #*sharp*$(v_s) \geq 1$ and #*sharp*$(v_t) \geq 1$ and not *sharp*(v_s, v_t), or
  - #*sharp*$(v_s) \geq 3$ and #*sharp*$(v_t) \geq 3$ and *sharp*(v_s, v_t), or
  - *sharp*(v_s, v_t) and #*sharp*$(v_s) = 1$ and #*sharp*$(v_t) \neq 2$, or
  - *sharp*(v_s, v_t) and #*sharp*$(v_t) = 1$ and #*sharp*$(v_s) \neq 2$.

- Collapsing an edge that modifies the topology of the discontinuity curves is either disallowed or penalized

Summary

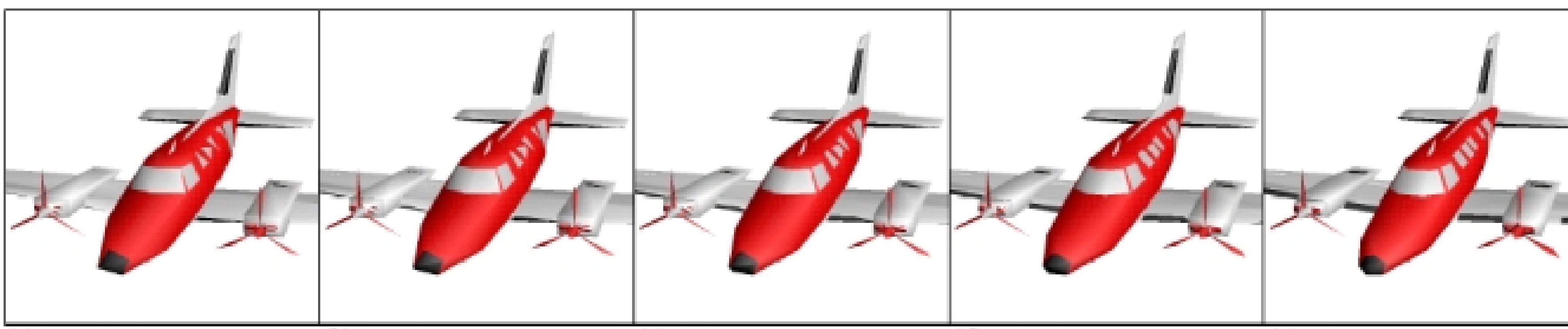
- Lossless representation
- Supports
  - Geomorphs
  - Progressive transmission
  - Compression
  - Selective refinement
  - Geometry and overall appearance of the mesh
    - Surface creases
    - Normals
    - Shading, radiosity
    - Color and texture mapping

Results



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

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



(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

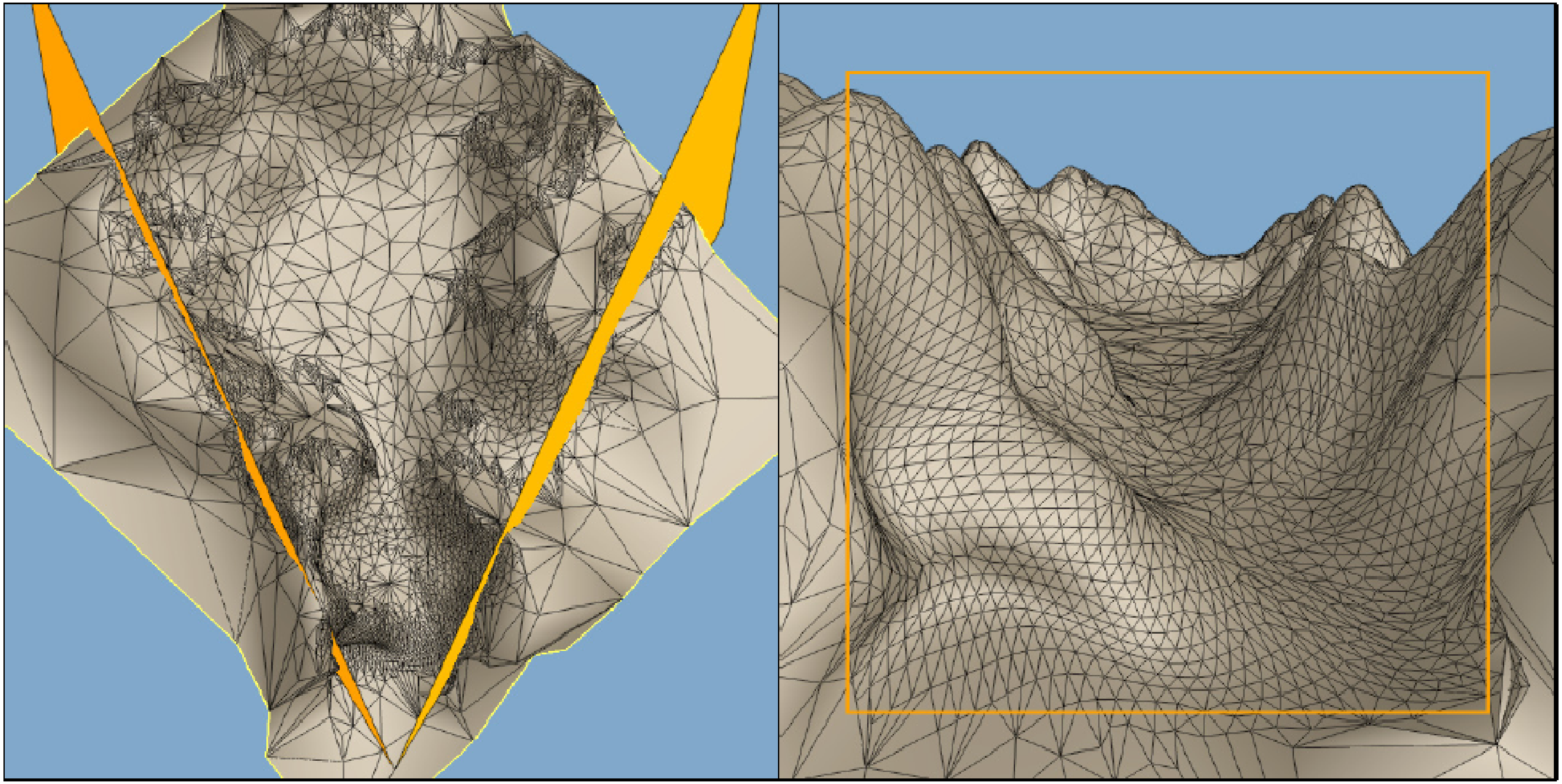
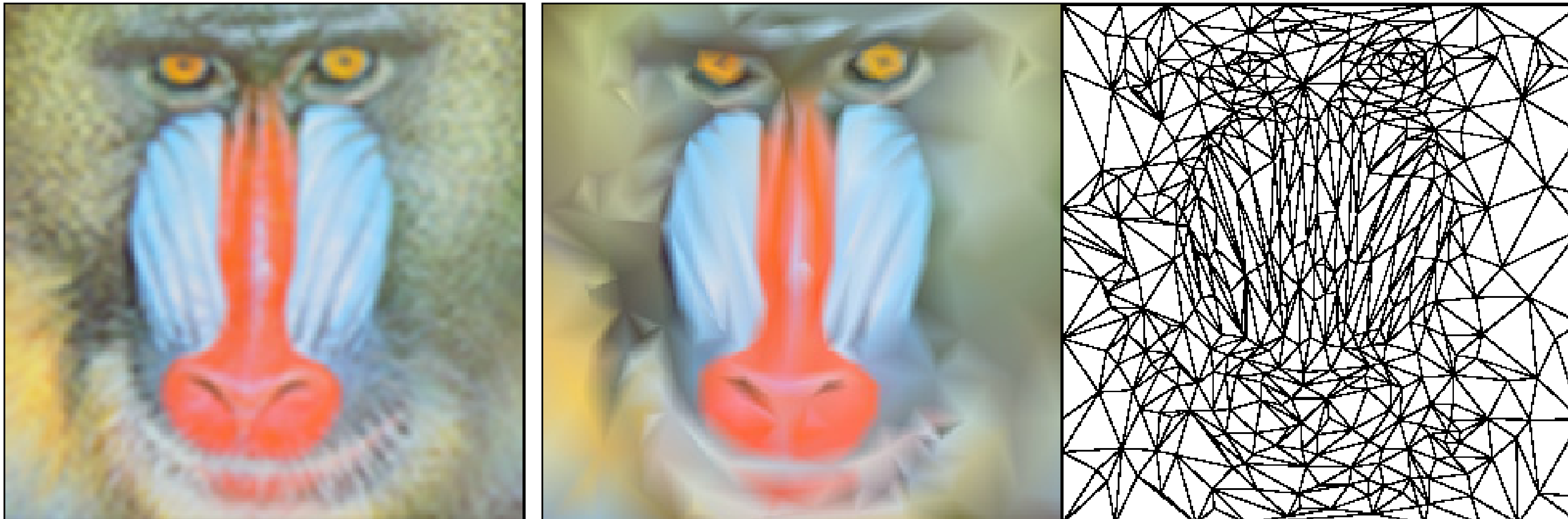


Figure 10: Selective refinement of a terrain mesh taking into account view frustum, silhouette regions, and projected screen size of faces (7,438 faces).

Results



(a) $\hat{M}$ (200×200 vertices)

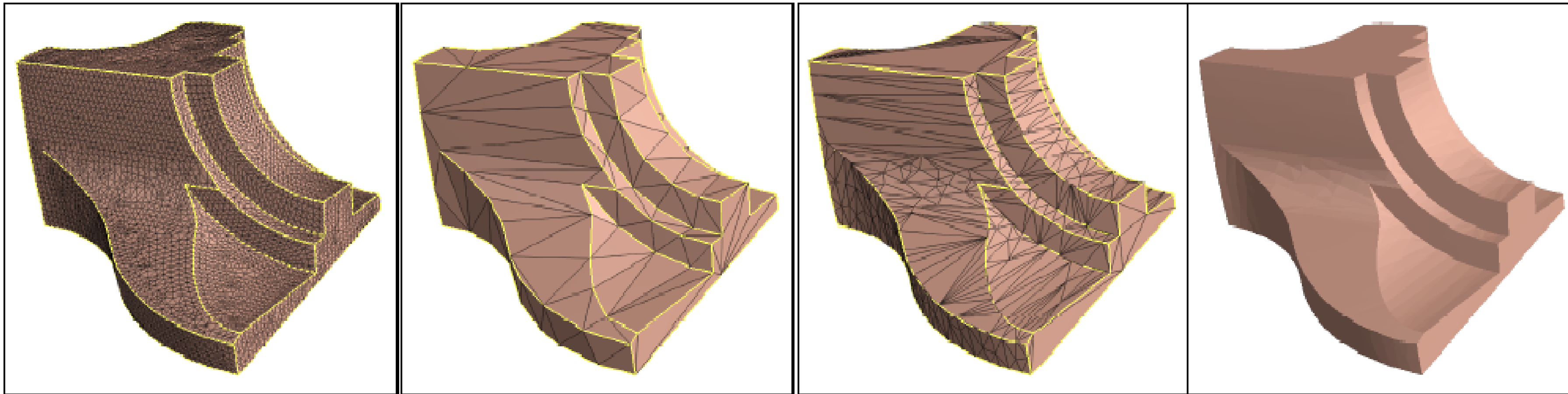
(b) Simplified mesh (400 vertices)

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.)

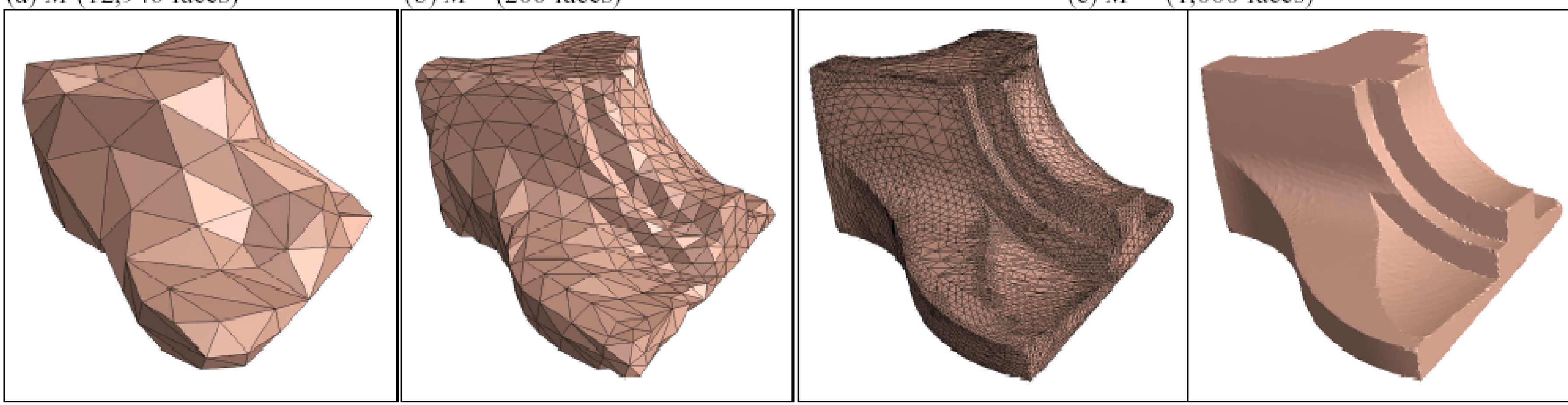
Results

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

Results



(a) $\hat{M}$ (12,946 faces) (b) M^{75} (200 faces) (c) M^{475} (1,000 faces)



(d) $\epsilon = 9.0$ (192 faces) (e) $\epsilon = 2.75$ (1,070 faces) (f) $\epsilon = 0.1$ (15,842 faces)

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.