Progressive Meshes

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Progressive Meshes

- Motivations
- For Surfaces: Progressive Triangular Meshes
  - Connectivity
  - Geometry
- For Solids: Progressive Tetrahedral Meshes

Complex Meshes

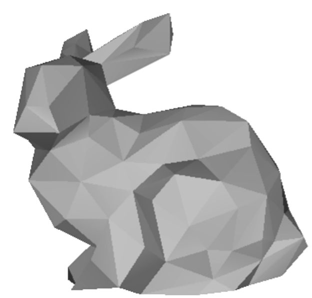
<u>Challenges:</u>
- Expensive to store, transmit, render, and edit

Level of Detail

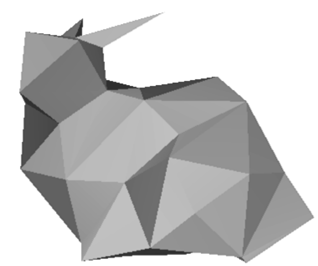
- Decreasing the complexity of a 3D object representation
  - as it moves away from the viewer
  - or based on other metrics (object importance, eye-space position…)
- Applied on geometry, texture, material…

69,451 faces

2,502 faces



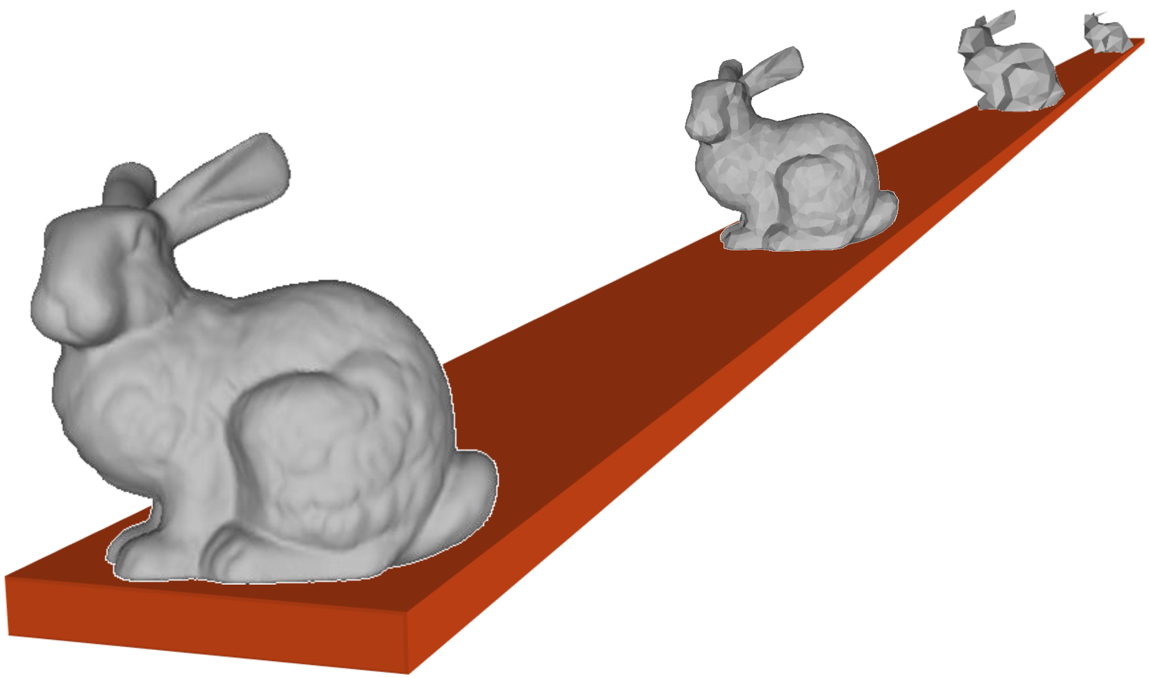
251 polys



76 polys

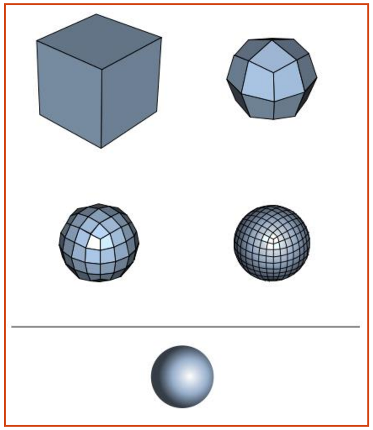
Level of Detail

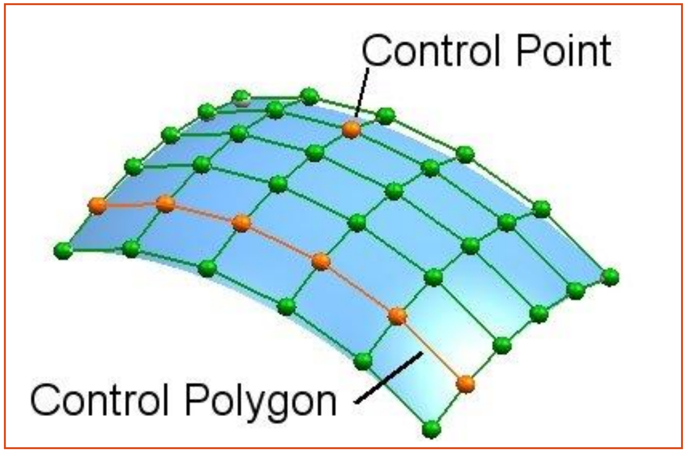
- Distant objects use coarser LODs:

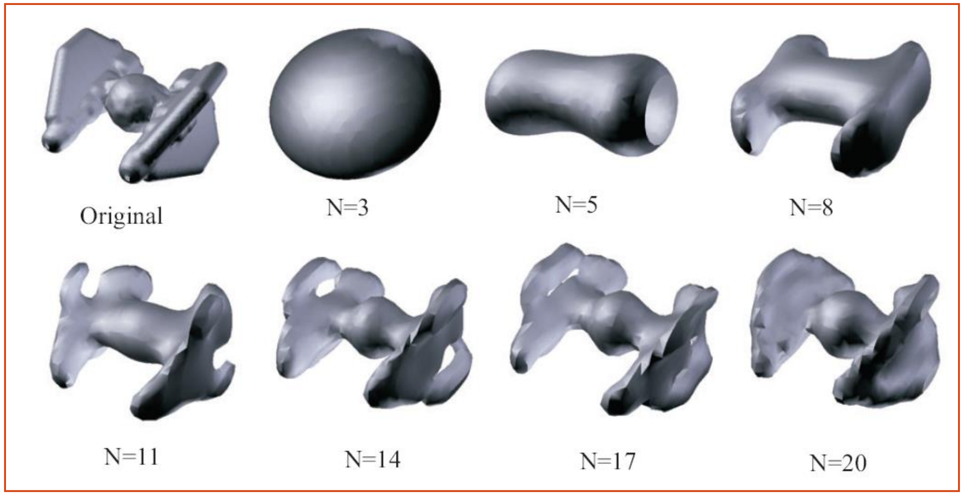


Multiresolutional Modeling, Processing and Analysis

- Subdivision Surface, splines, wavelets…
- Image pyramid…
- Quad/oct tree, BSP tree…





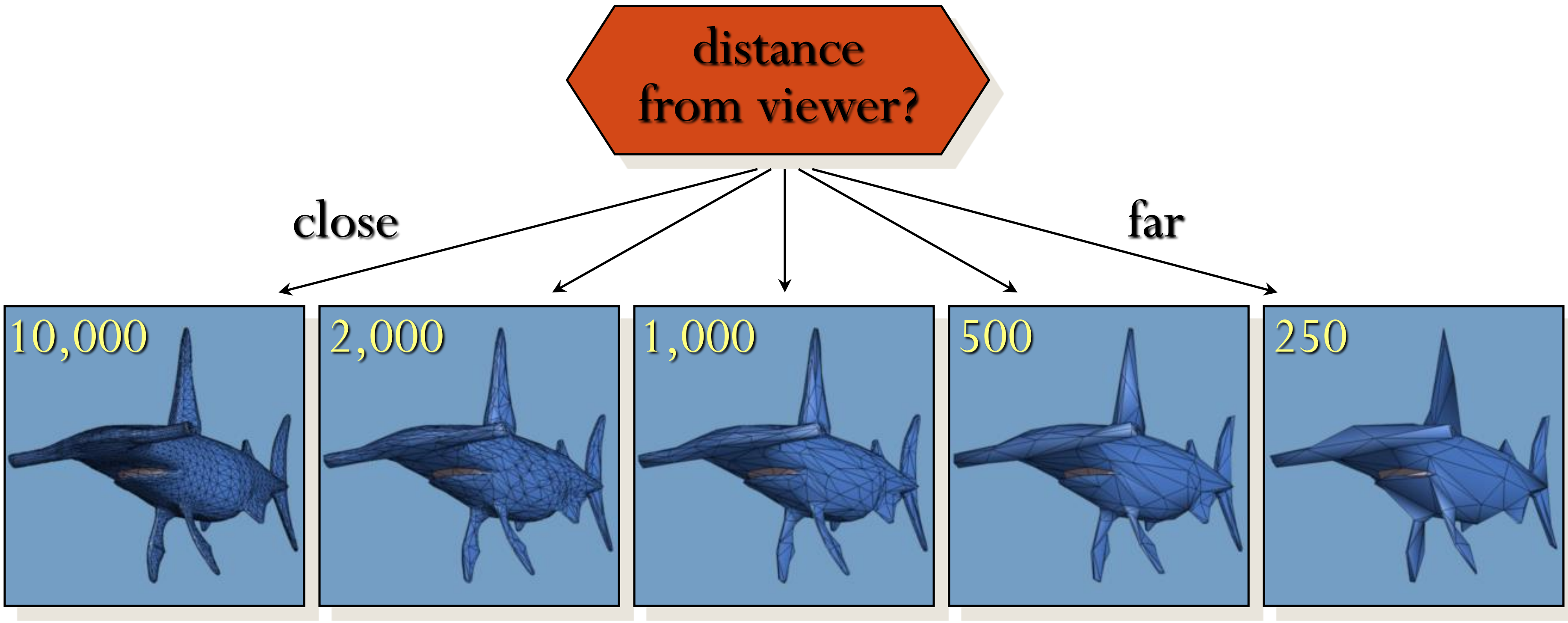


Motivations

- Applications of multiresolution techniques : Compression, Progressive transmission and display, Level-of-detail Control, Multiresolution editing…

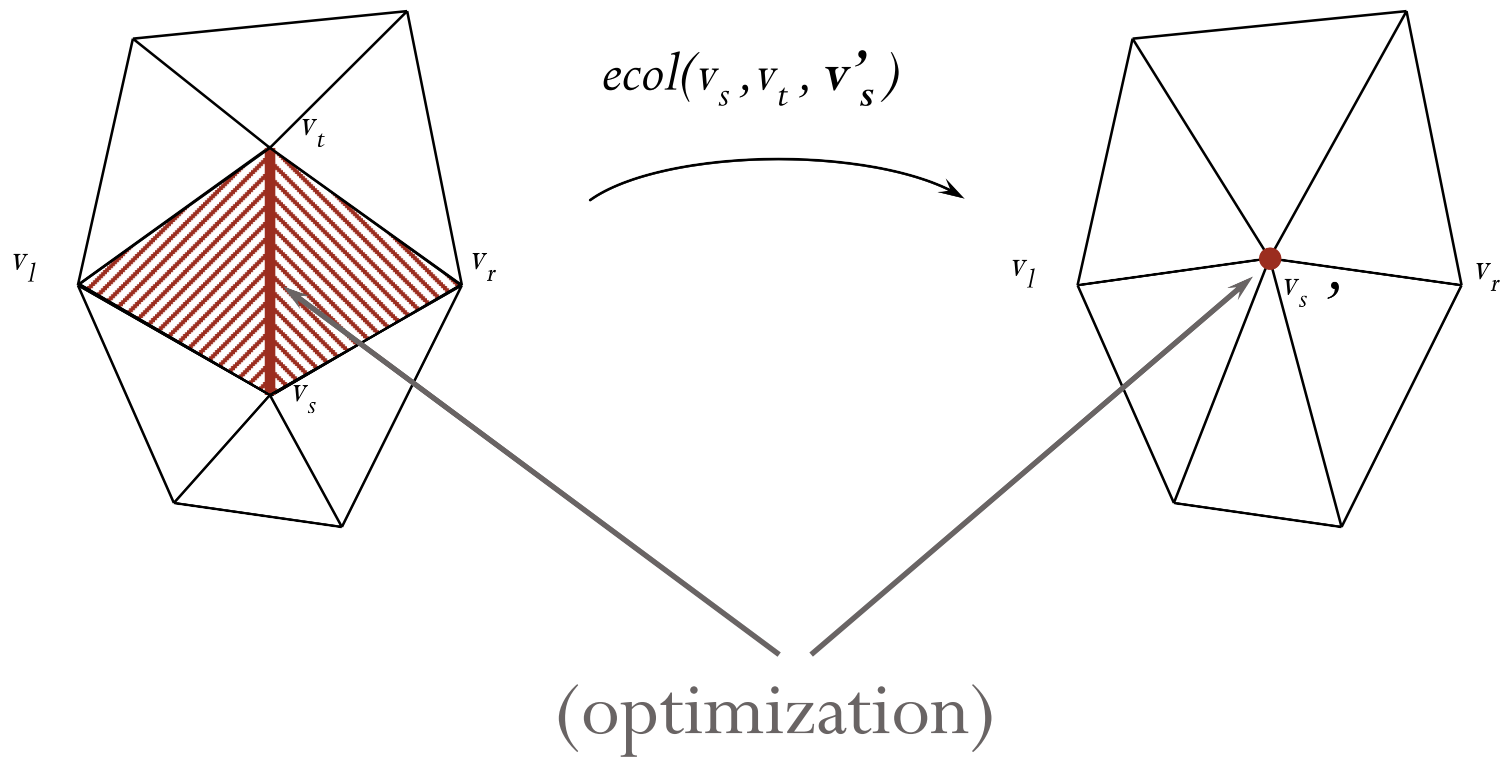
- A mesh simplification procedure for general input meshes
  - Preserve various properties (colors, normals, …)
  - Lossless
  - Continuous-resolution
  - Efficient (time and space)
  - Directly applicable for Progressive transmission

Level-of-detail (LOD)



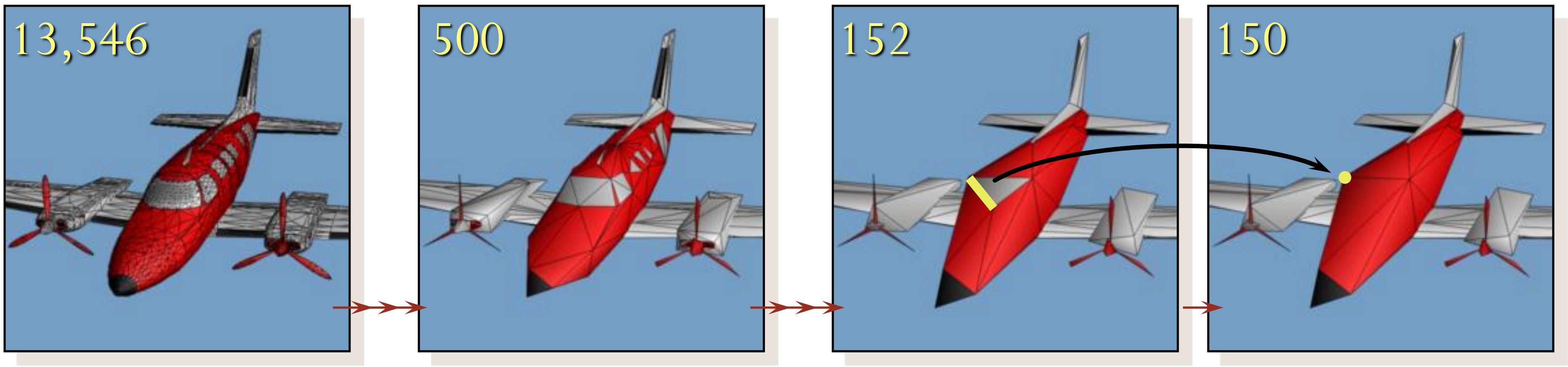
Mesh simplification procedure

- Idea: apply sequence of edge collapses:



Connectivity change can be easily implemented using Half-Edge Data Structure!

Simplification process

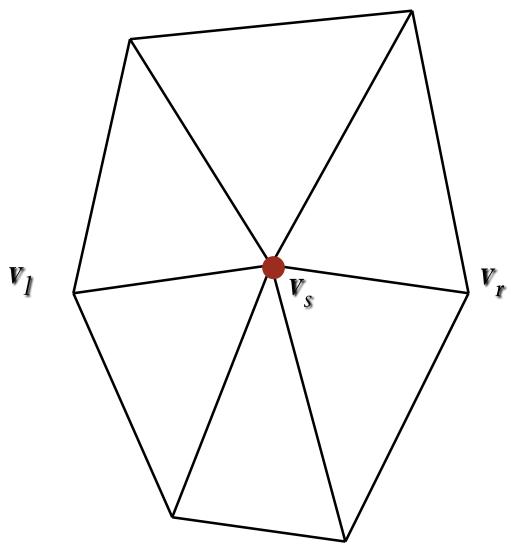


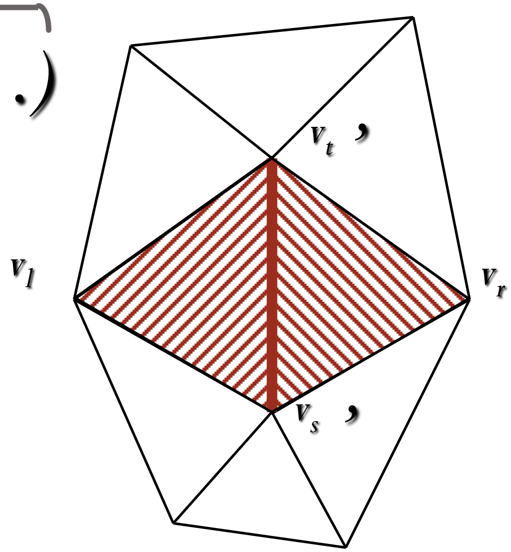
$$\hat{M} = M^n \xrightarrow{ecol_{n-1}} \rightarrow\rightarrow\rightarrow M^{175} \rightarrow\rightarrow\rightarrow \xrightarrow{ecol_i} M^1 \xrightarrow{ecol_0} M^0$$

Inverse Direction: Reconstruction

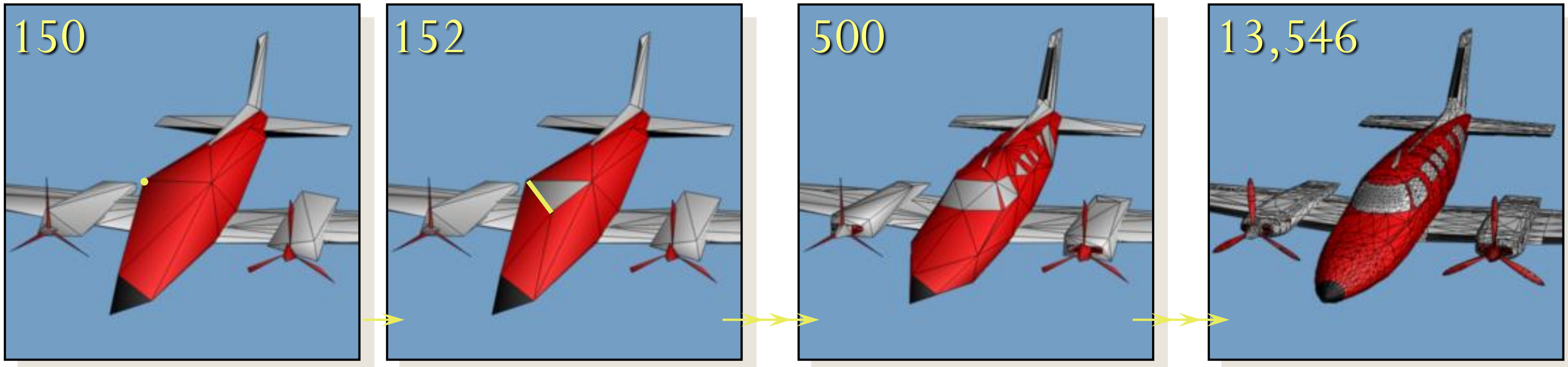
Vertex split transformation:

$$vspl(v_s, v_l, v_r, \underbrace{v'_s, v'_t, \ldots}_{attributes})$$





Reconstruction process



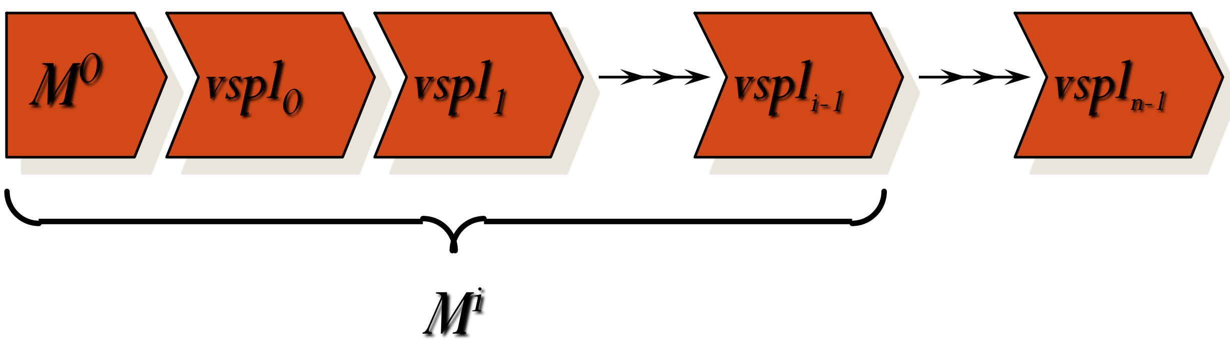
$M^0 \longrightarrow M^1 \longrightarrow \cdots \longrightarrow M^{175} \longrightarrow \cdots \longrightarrow M^n = \hat{M}$

$vspl_0$ … $vspl_i$ … $vspl_{n-1}$

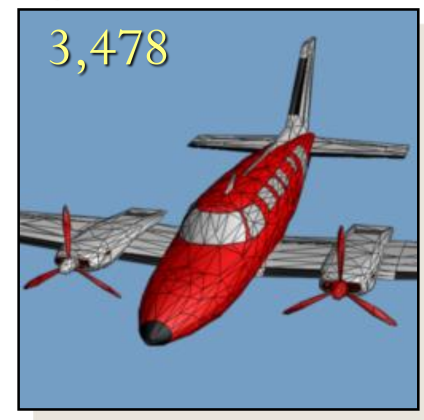
progressive mesh (PM) representation

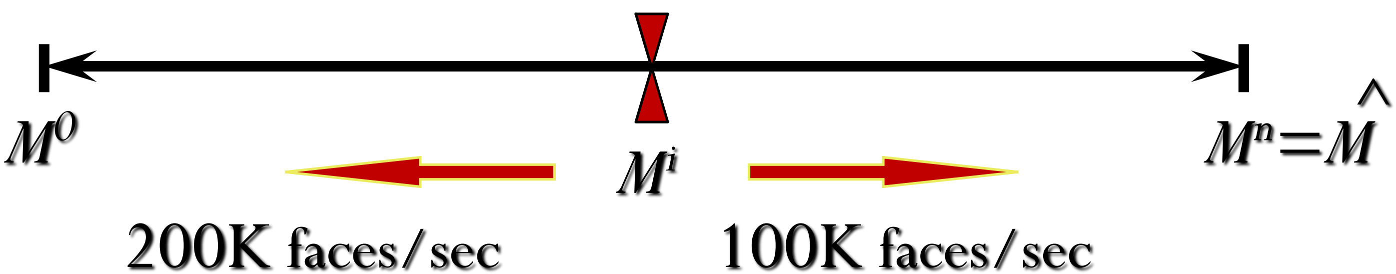
Continuous-resolution LOD

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



3,478 faces?

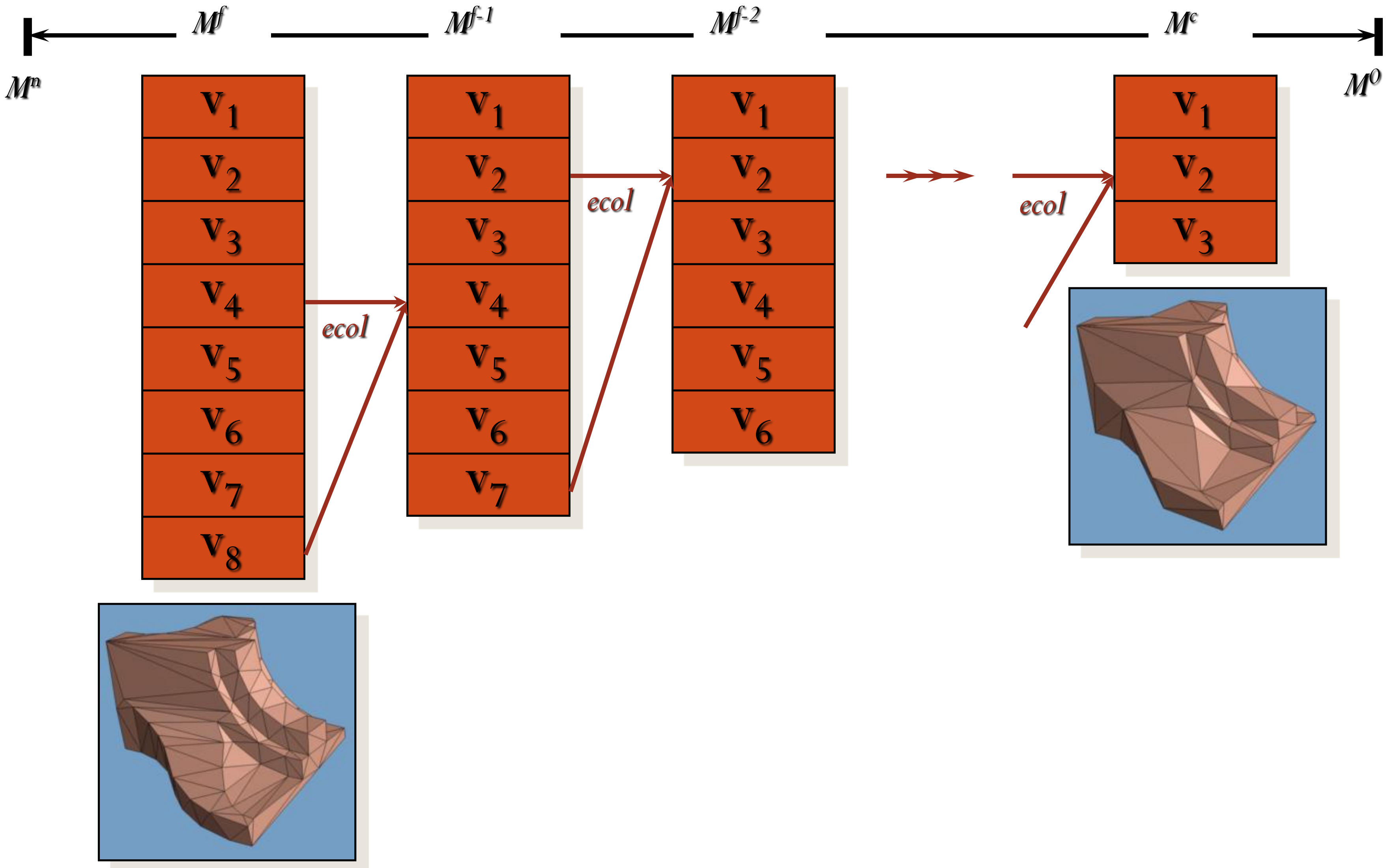




Video

(166 MHz Pentium)

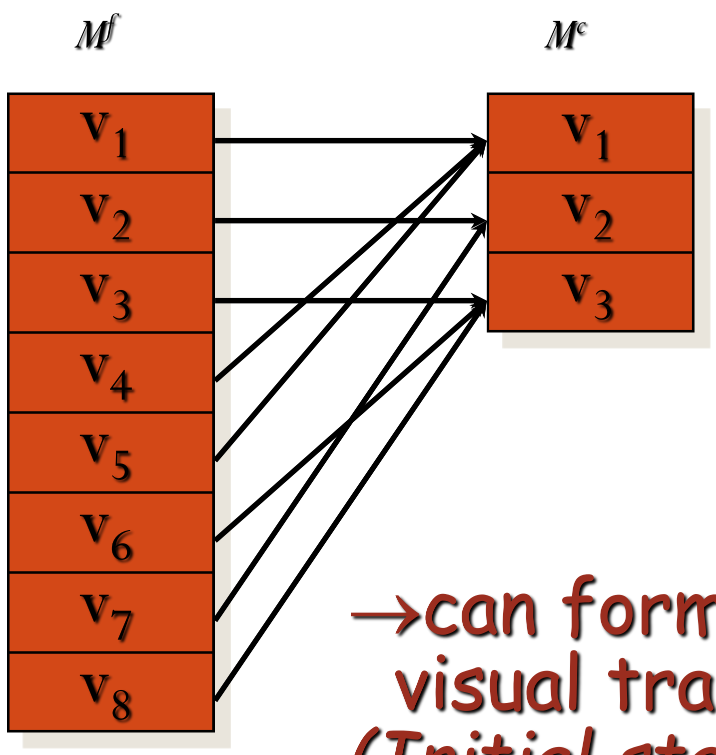
Property: Vertex correspondence

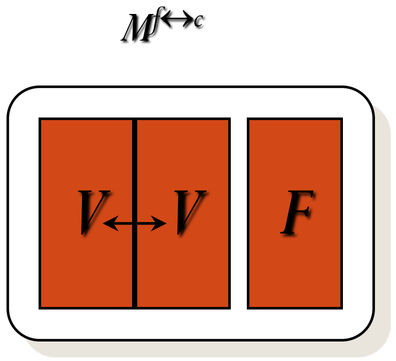


Application: Smooth transitions

Correspondence is a surjection:

Video





→can form a smooth visual transition: *geomorph*

(Initial status: topologically M^f, geometrically $M^{f\text{->}c}$)

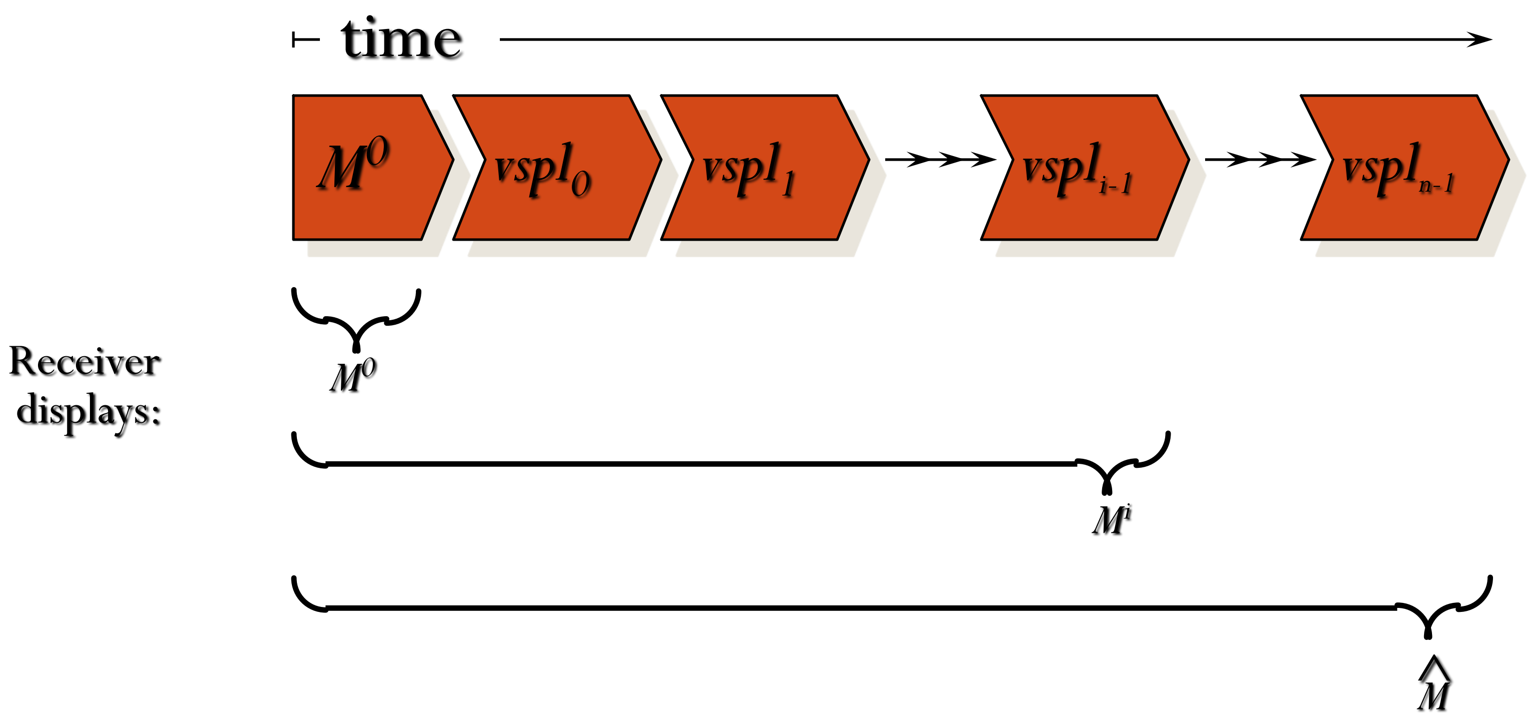
Morphing by Linear Interpolation

- Source mesh M1={V1, ..., Vn}
- Target mesh M2={U1, ..., Un}
- The linear interpolation:

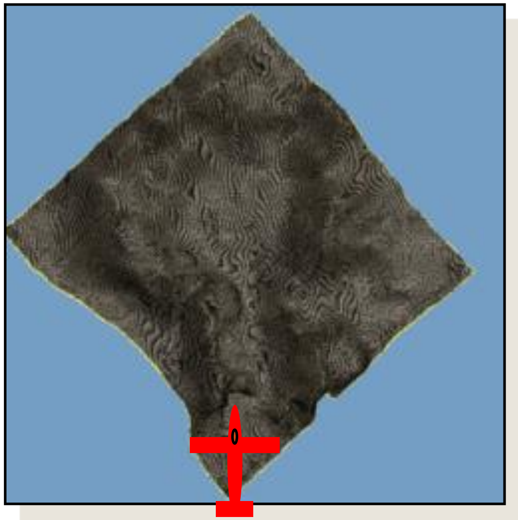
$$M(t) = \{V1*(1-t)+U1*t, \ldots, Vn*(1-t)+Un*t\}$$

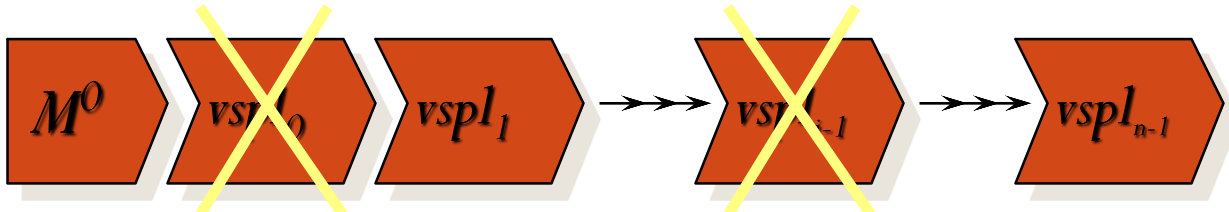
Application: Progressive transmission

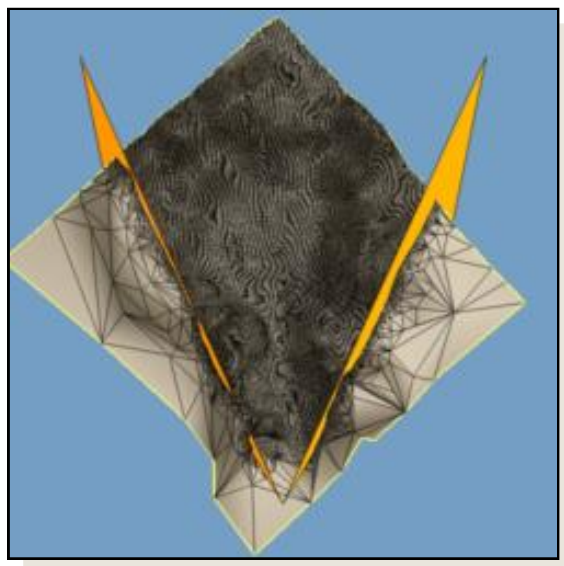
Transmit records progressively:

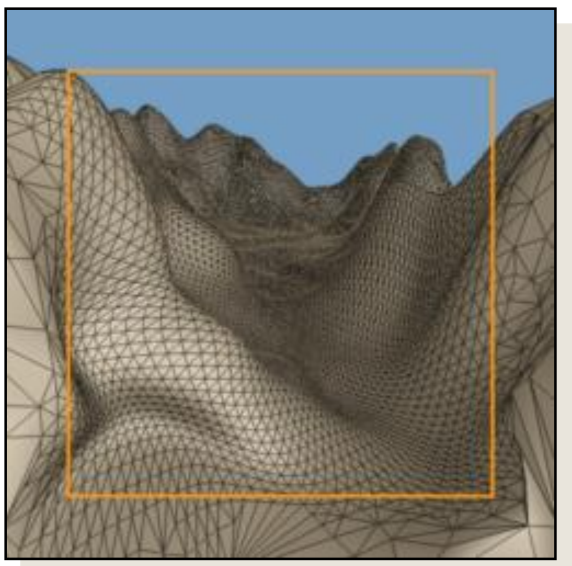


Application: Selective refinement







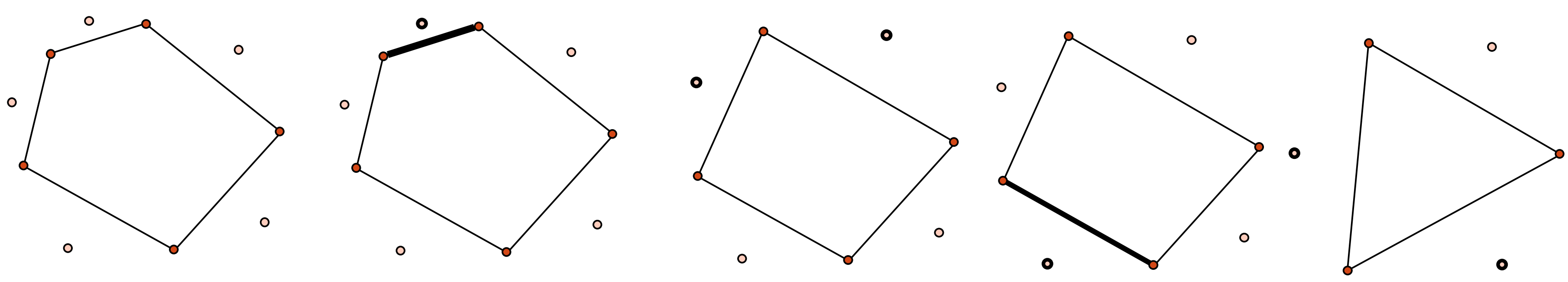


(e.g. view frustum)

Where to place the new vertex?

- A simple strategy: pick shortest edge + use the midpoint
- *An locally optimal solution:
  - To measure the shape error due to the edge collapse: QEM ["Surface Simplification Using Quadric Error Metrics," Garland and Heckbert 97]
    - After an edge collapse, the error of a new vertex is the sum of squared distances to originally associated planes
    - Iteratively collapse the edge (u,v) with the lowest E(u,v) into the minimizer P(u,v), update the minimizers and QEMs of the new edges (suitable data structure: heap)

An analogous example in 2D:



A Quadratic Energy to Measure the Error

- Squared distance of point p to plane q:

$$p = (x, y, z, 1)^T, \quad q = (a, b, c, d)^T$$

$$dist(q, p)^2 = (q^T p)^2 = p^T (q q^T) p =: p^T Q_q p$$

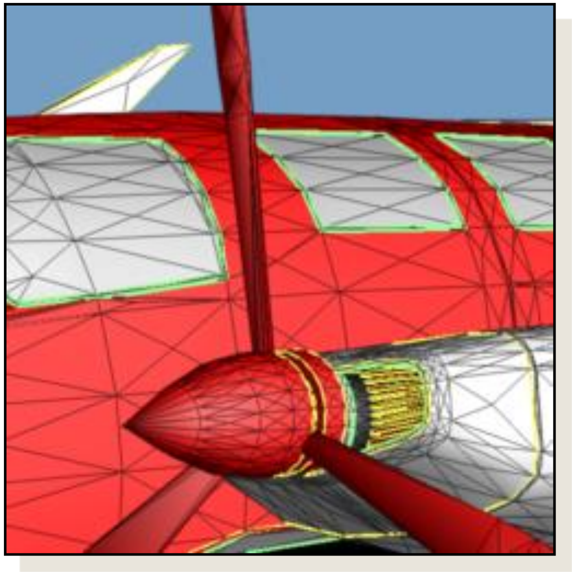
$$Q_q = \begin{bmatrix} a^2 & ab & ac & ad \\ ab & b^2 & bc & bd \\ ac & bc & c^2 & cd \\ ad & bd & cd & d^2 \end{bmatrix}$$

- • Sum distances to planes of neighboring triangles:

$$\sum_i dist(q_i, p)^2 = \sum_i p^T Q_{q_i} p = p^T \left(\sum_i Q_{q_i} \right) p =: p^T Q_p p$$

More Criteria to pick edges

- An energy to describe the deviation of *appearance* :
  - geometric shape
  - scalar fields (e.g. color)
  - Feature (discontinuity) curves
  - …



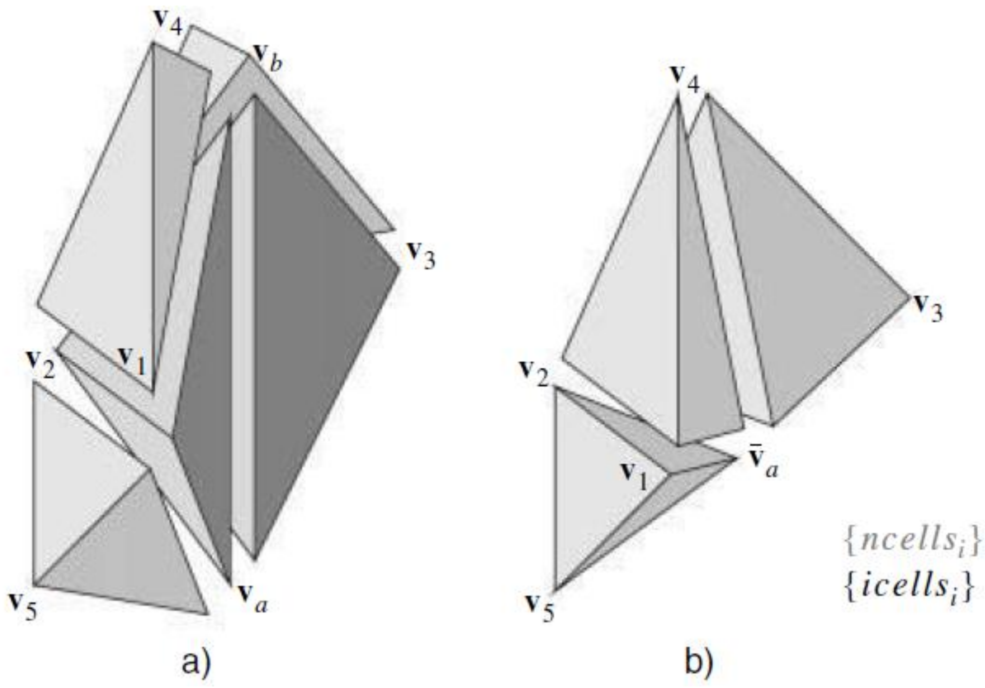
- In general, greedy strategy to always collapse edge resulting in smallest ΔE

Summary

- With the half-edge data structure, can you implement this idea using the simplest strategy (pick shortest edge, use mid-point)
- Now consider the generalization of PM to 3D…

Progressive Tetrahedral Meshes

Edge Collapse



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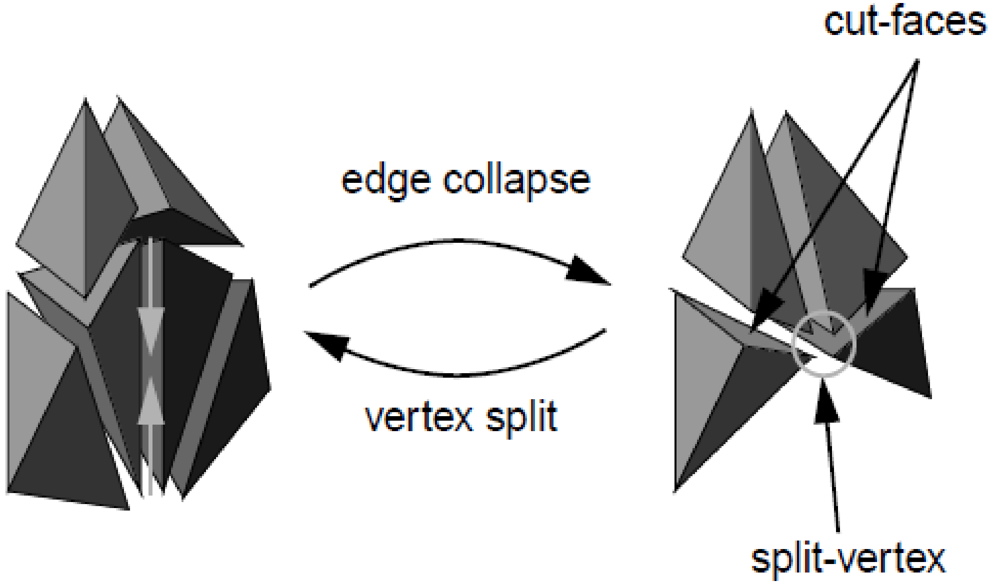
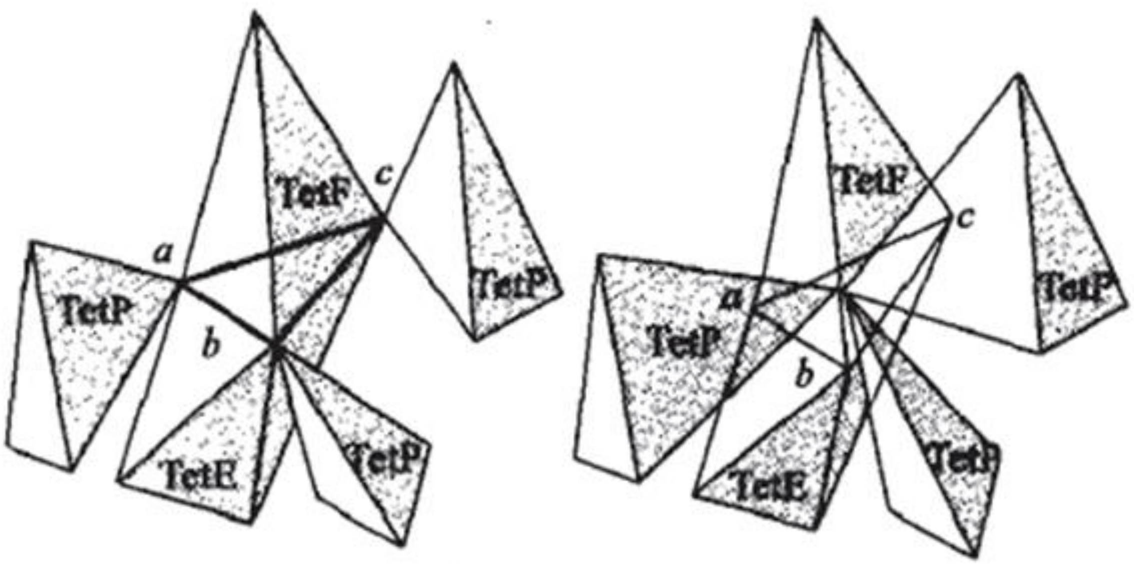


Progressive Tetrahedral Meshes

Is "Edge Collapse" the only way?



Progressive Tetrahedral Meshes

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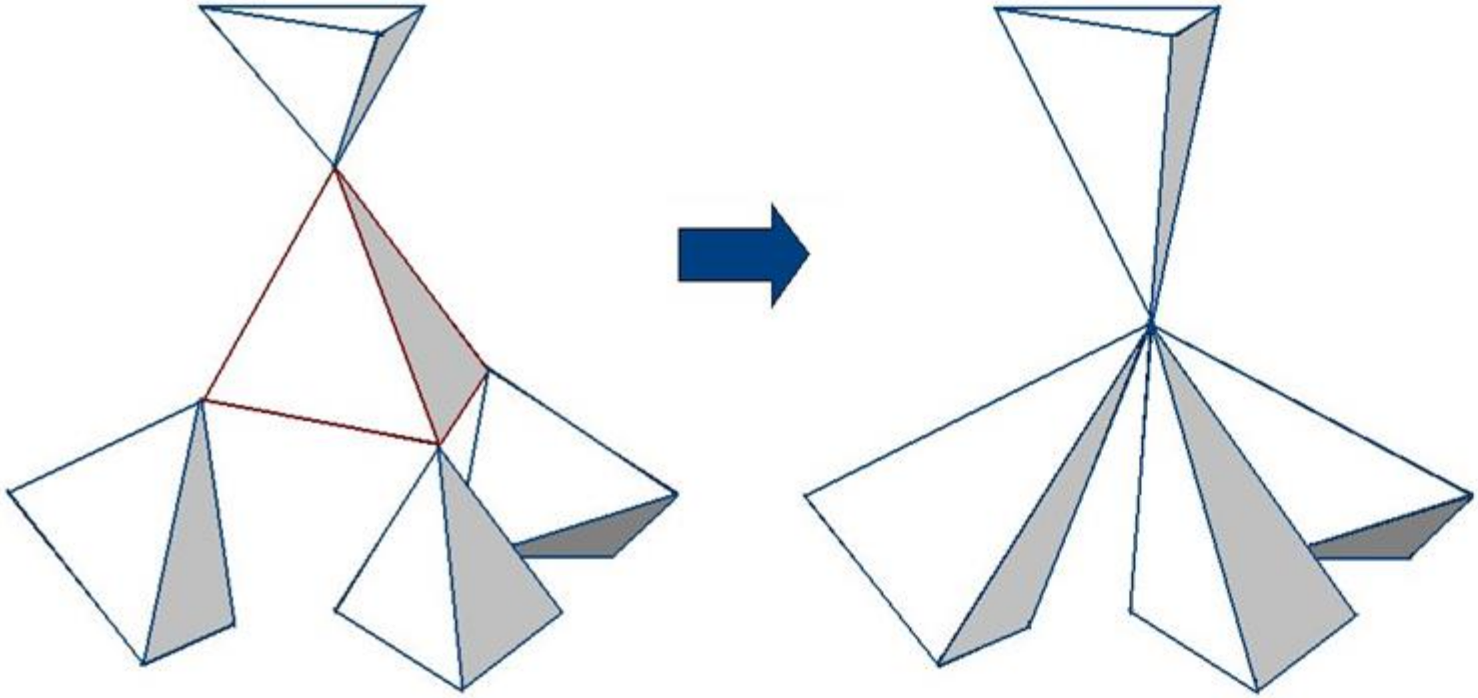

An application in Morphing

Course Project Candidate:

Inter-surface mapping and morphing