# 01076566 Multimedia Systems

## Chapter 10: Media Compression: Graphics

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# Outline

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- The need for graphics compression
- 2D graphics objects
- 3D graphics objects
- Graphics compression in relation to other media compression
- Mesh compression using connectivity encoding
- Mesh compression using polyhedral simplification
- Multiresolution techniques – wavelet-based encoding
- Progressive encoding and level of detail
- 3D graphics compression standards

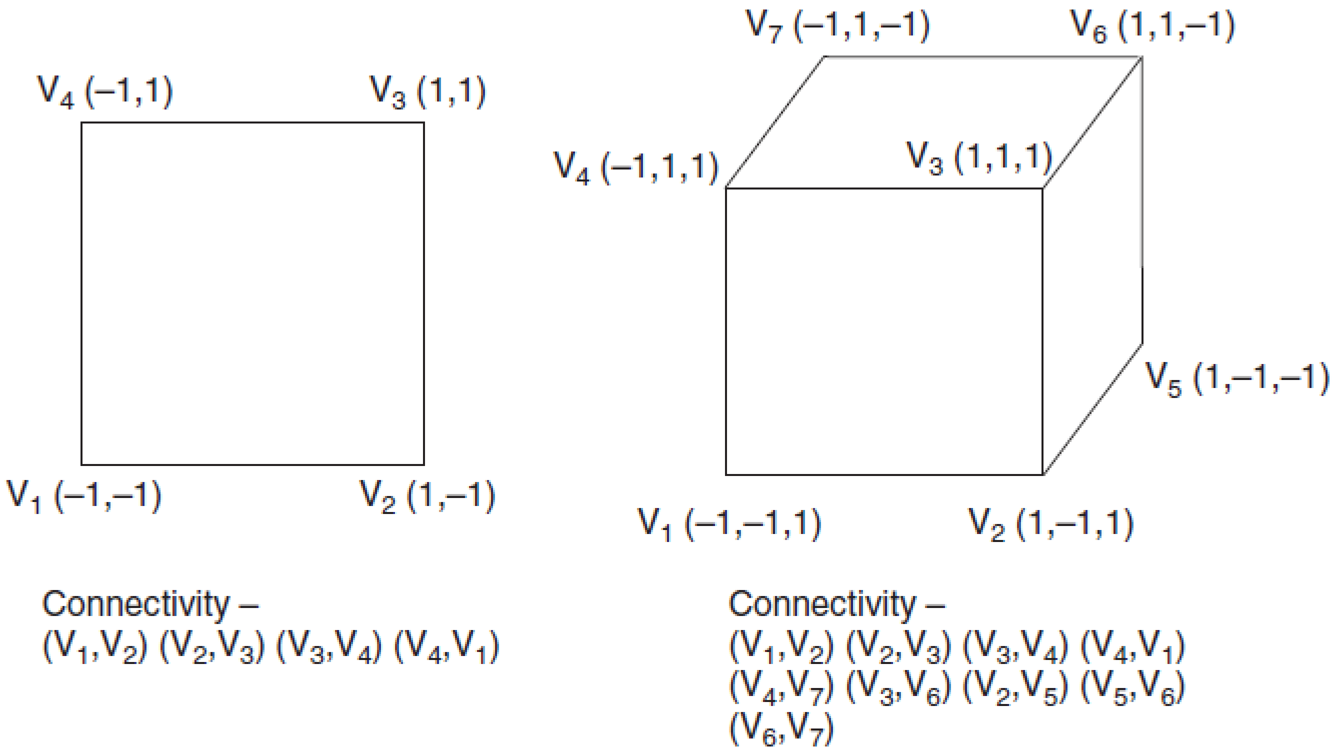


*Figure 10-1 Example of a 2D vector representation (left) and 3D representation (right). These vector representations provide more precision and potential to interact and hence are unlike the other visual media types, such as images and videos.*

# The need for graphics compression

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| Graphics data type | A simple 2D graphic | A character used in a 3D game | Models in 3D movies | CAD/CAM model |
|---|---|---|---|---|
| Number of polygons (normally triangles or quads) | Less than 500 | 4000–5000 | 20,000–50,000 | 2,000,000 |
| Approximate number of vertices | 250 | 2500 | 25,000 | 500,000 |
| Approximate file size in bytes (uncompressed) | 10 KB | 100 KB | 1 MB | 30 MB |
| Transmission times for one second of data (56 Kb modem) | 1.43 seconds | 14.28 seconds | 142 seconds | 4286 seconds |
| Transmission times for one second of data (780 Kb DSL) | 0.1 seconds | 1.06 seconds | 10.2 seconds | 307 seconds |

*Figure 10-2 Examples showing storage space, transmission bandwidth, and transmission time required for uncompressed 3D objects, assuming that the data consists only of geometry with no textures*

# 2D graphics objects

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- Points
- Regions
- Curves
  - An ordered list of coordinates
  - Or .. Approximation
    - Line (polynomials of degree 1) ; a.k.a., a polyline
    - Higher degree polynomials, such as 2

# 3D graphics objects: polygonal descriptions

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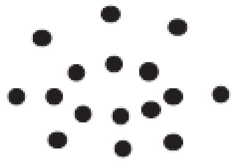
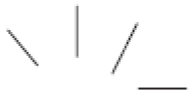
- **Polygonal mesh**
  - An array of $x, y, z$ positions for the vertices $v_1, v_2, v_3 \ldots v_n$



  - An array of index doubles for the edges $e_1, e_2, e_3 \ldots e_m$. Each edge $e_i$ is expressed as an index double $\langle k, l \rangle$ which implies an edge connection between vertices $v_k$ and $v_l$.



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- Polygonal mesh (Cont'd)
  - The mesh is further represented as faces
    - Combining edges together that form a face.
    - Each face $f_i$ is represented as an n-tuple $\langle i_1, i_2 \dots i_k \rangle$ implying that the face is formed by connecting vertices $v_{i_1}, v_{i_2} \dots v_{i_k}$
    - All faces are thus represented as an array of such n-tuples.
  - Additionally, each vertex may have properties needed for its representation, display, or rendering.

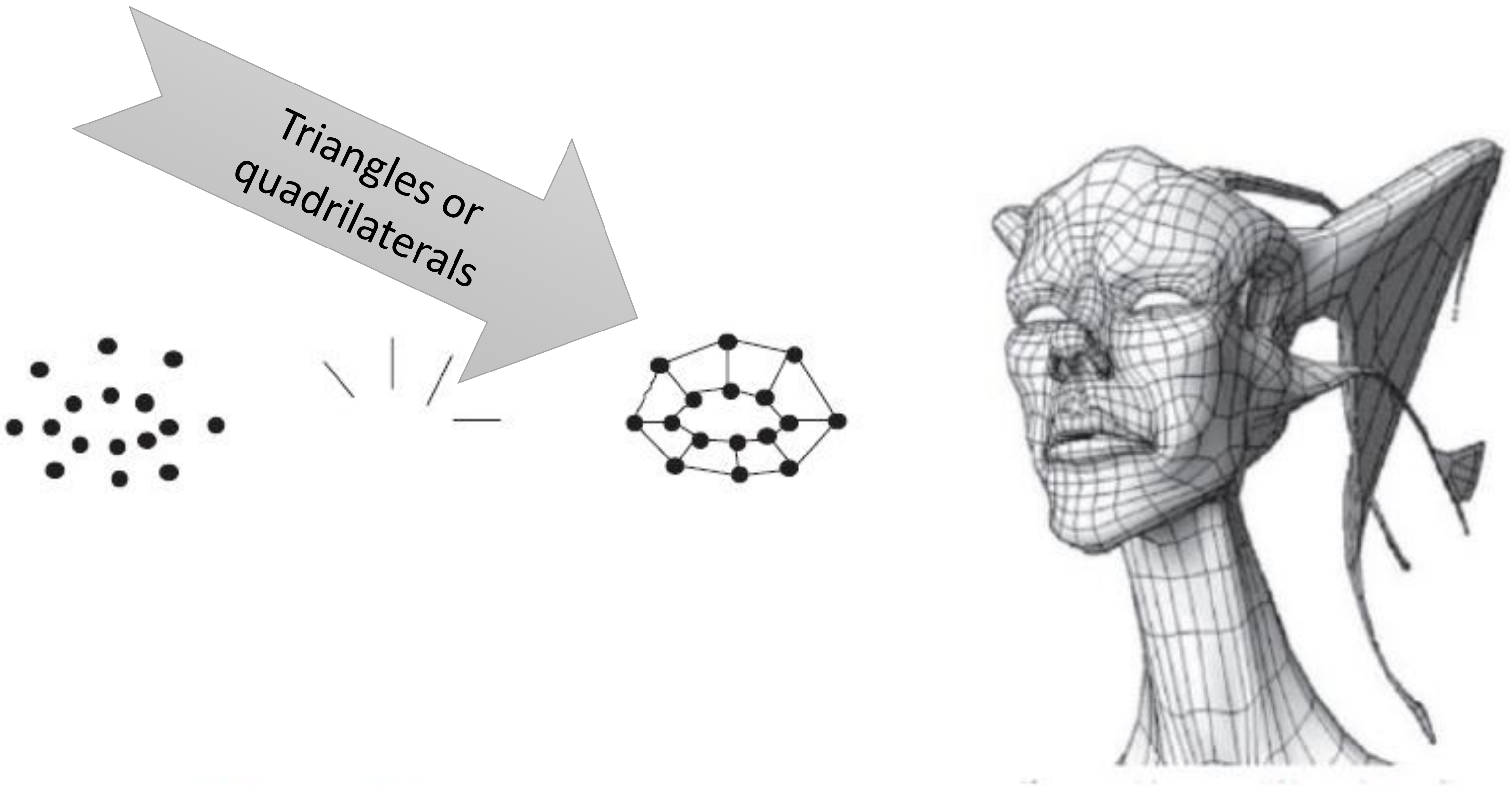


*Figure 10-3 Polygonal description—points, edges, polygons, and an object. Traditionally, objects are composed of polygons consisting of triangles and quadrilaterals.*

43,000 faces

lots of faces!

# Patch-based descriptions

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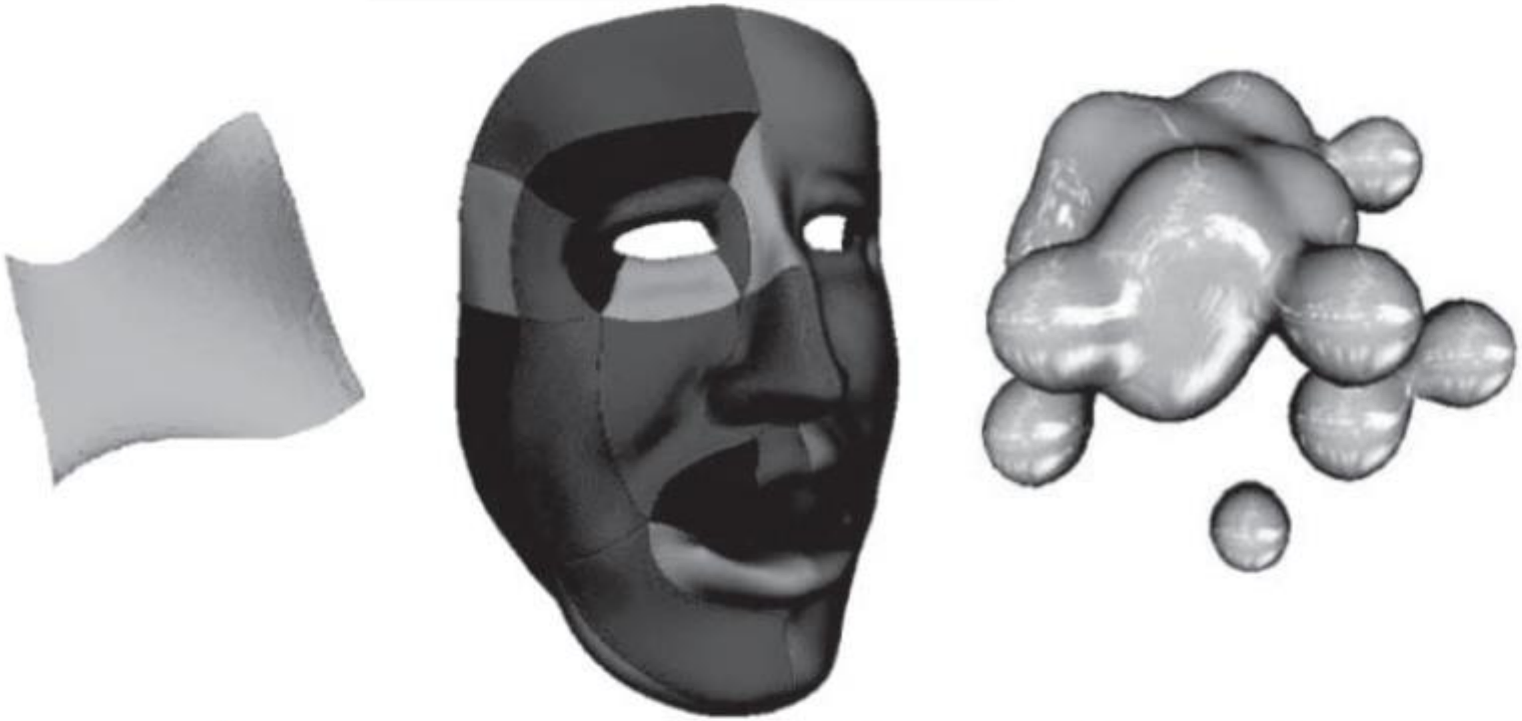

*Figure 10-4 Nonsmooth primitive used to describe 3D objects—a surface patch, a group of patches forming a face, and metaballs*

# Constructive solid geometry (CSG)

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- The modeling techniques using this representation are termed as **solid modeling** or **volume modeling**.

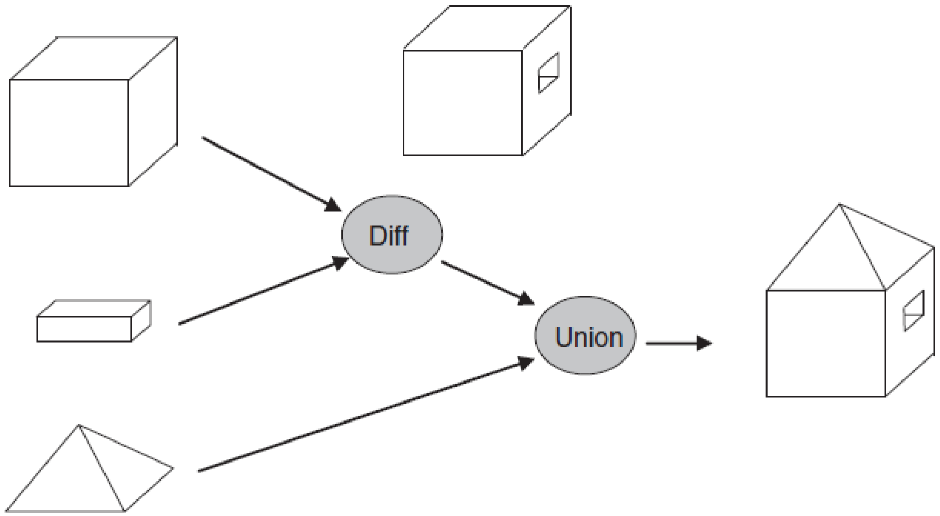


*Figure 10-5 Constructive solid geometry example. The cube, the rectangular prism, and the pyramid are combined using different Boolean operations to create a fairly complex object in two steps.*

# Graphics compression in relation to other media compression

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- **In 2D images**
  - The redundancy lies in the **similarity of local areas**
  - Thus, approximating higher-order frequency coefficients with fewer bits in comparison with lower-order coefficients
- **In videos**
  - The redundancy occurs **spatially in each frame** and **temporally from frame to frame**
  - Motion compensation helps to predict interframe motion that further helps approximate the redundancy

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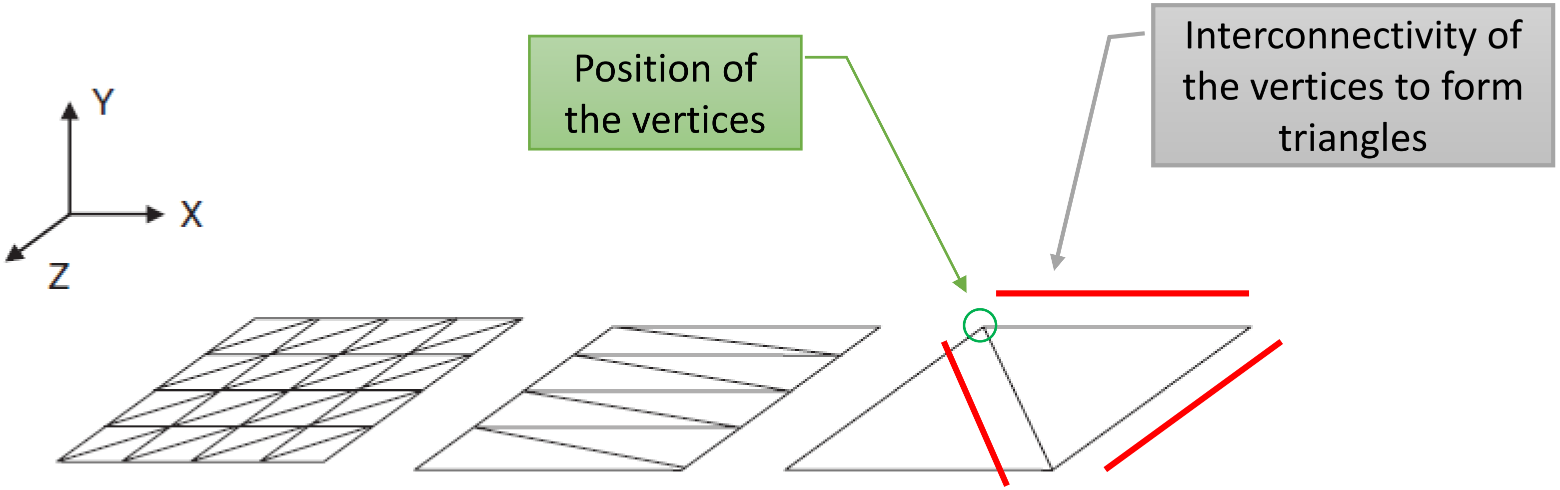


*Figure 10-6 Various ways of triangulating a planar surface. The plane has the same geometry in all figures irrespective of the number of points, edges, and triangles used to represent it. In 3D, you want to represent the object with as few vertex samples removing the redundancy.*

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- **In 3D meshes**
  - The information lies in
    - The position of the vertices
    - The interconnectivity of the vertices to form triangles
  - The redundancy can be categorized as
    - Representational redundancy
      - How the interconnectivity is specified
    - Surface redundancy
      - Occur in the large number of vertex samples approximating a surface

- Lossless
  - E.g., CAD/CAM – require high precision
- Lossy
  - E.g., visualization process can tolerant precision loss

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- Either lossy or lossless techniques can be divided into four categories depending of the information that is compressed
  - **Direct compression of properties**
  - **Connectivity encoding**: reduce the connectivity information by exploiting coherency in the connectivity information
  - **Polyhedral simplification**: reduce the number of vertices, edges, and triangles in the mesh
  - **Subband-based surface compression**: compress the 3D data by quantizing the frequency of components in different 3D bands

# Mesh compression using connectivity encoding

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- A triangular mesh is represented by a set of mesh points and their interconnectivity.
  - The mesh points are represented as 3D $(x, y, z)$ positions
  - The interconnectivity is specified by edges
- The connectivity information in a triangular mesh is represented by three indices per triangle

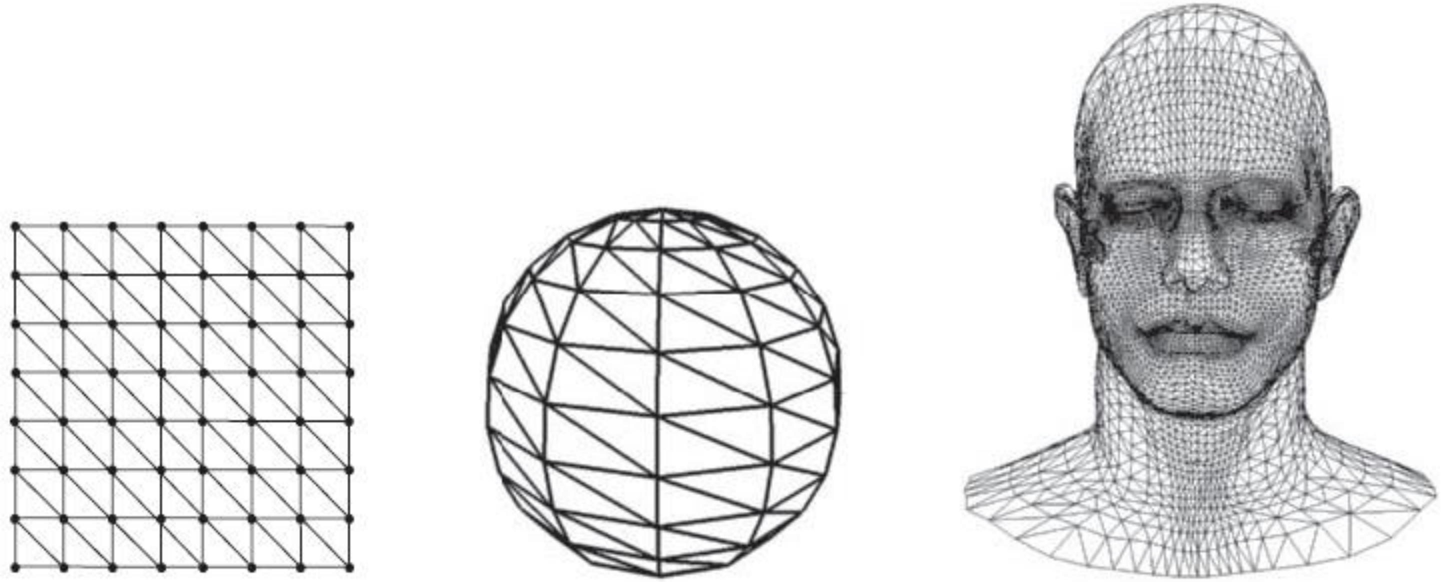

*Figure 10-7 Example of triangular meshes. Left: A well-organized grid, where the edge interconnectivity can be derived from an ordered sequence of vertices and the number of rows and columns. Middle: A parametric surface where the mesh interconnectivity can also be derived. Right: An organic natural surface where triangles have to be explicitly specified.*

# Triangle runs

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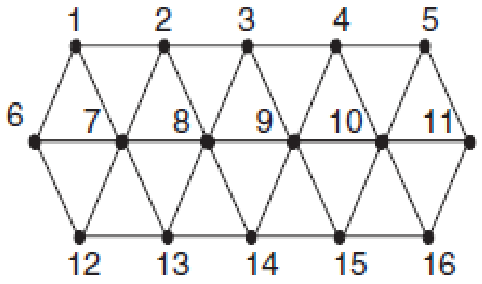
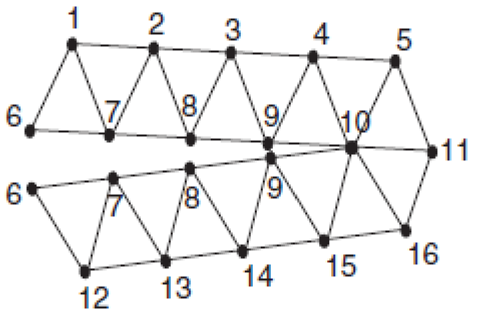
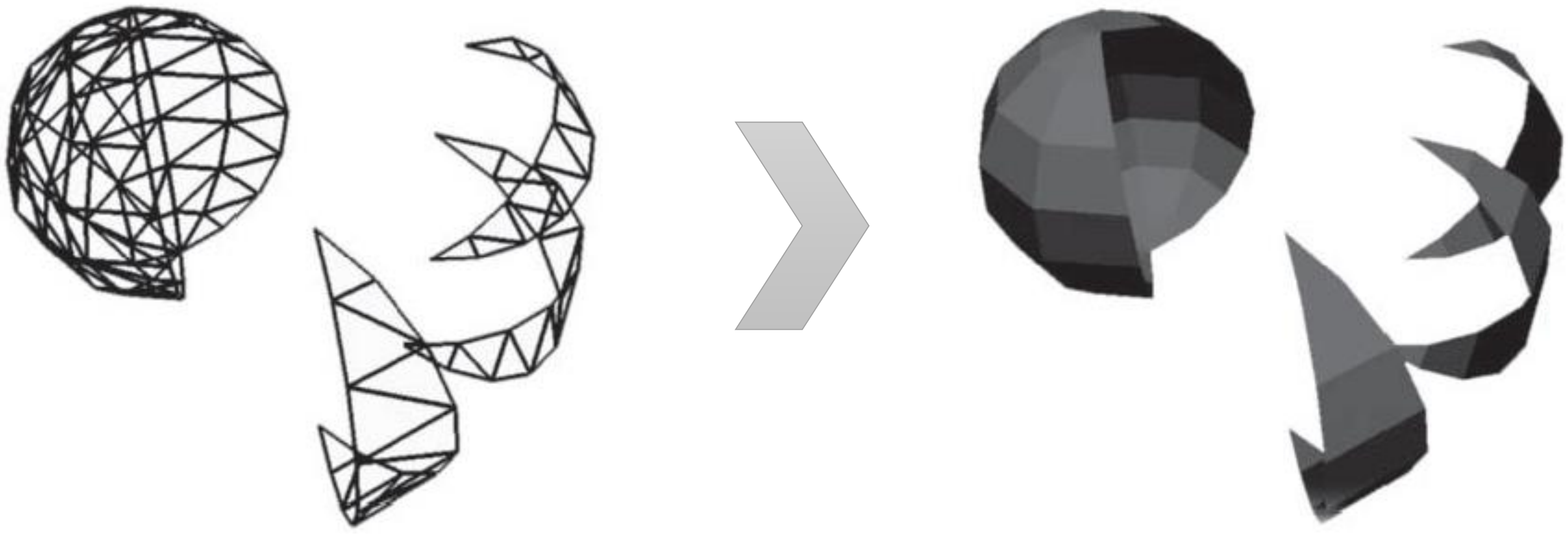



Triangle mesh specified by 16 points and 18 triangles. Each triangle is a triplet of indices (1,6,7) (7,1,2) (2,7,8) (8,2,3) …(13,8,7) (7,12,13) (12,7,6)—a total of 54 indices.




Same mesh is cut open and approximated by a triangular strip with indices 6,1,7,2,8,3,9,4,10,5, 11,16,10,15,9,14,8,13,7,12,6—a total of 21 indices. The triangles are implicitly defined as a moving window of three indices—6,1,7 – 1,7,2 – 7,2,8.



# Topological Surgery (TS) compression algorithm

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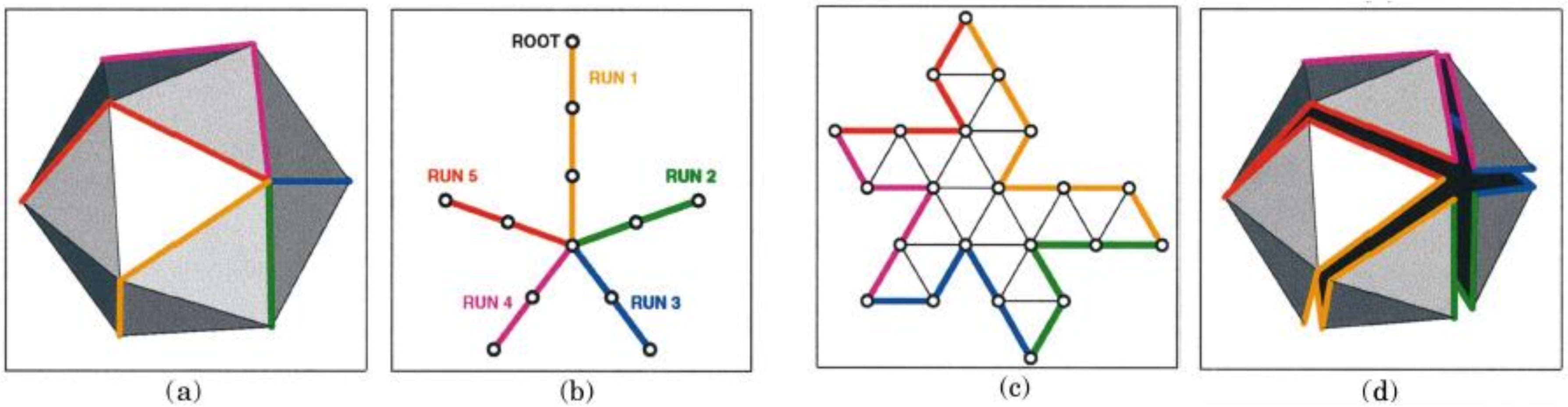
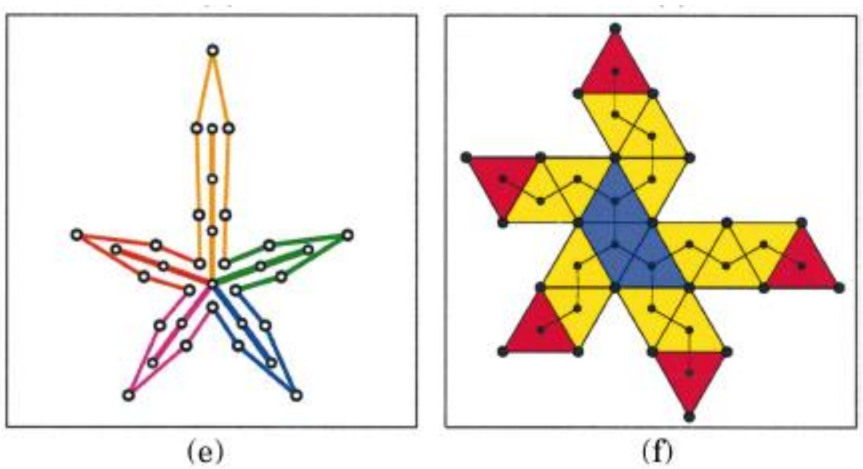
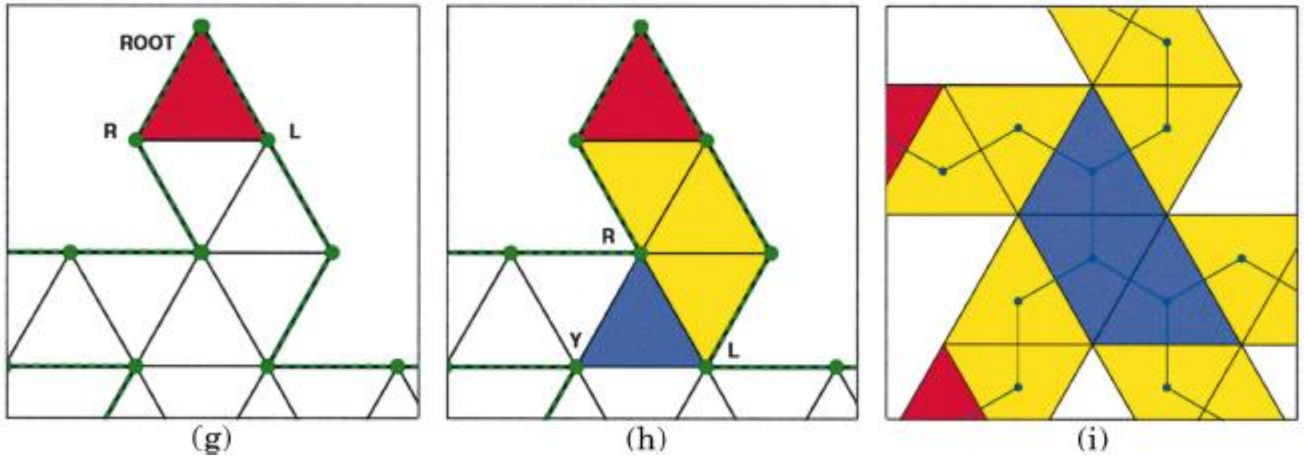



(a) (b) Vertex runs

(c) (d) Cutting through the vertex tree edges




(e) The boundary loop is the boundary of the polygon
(f) The dual graph of the polygon is the triangle spanning tree




(g) A root triangle (in red)
(h) Marching edges connect consecutive triangles within a triangle run
(i) Two consecutive branching triangles define a run of length one

# Analysis of topological surgery

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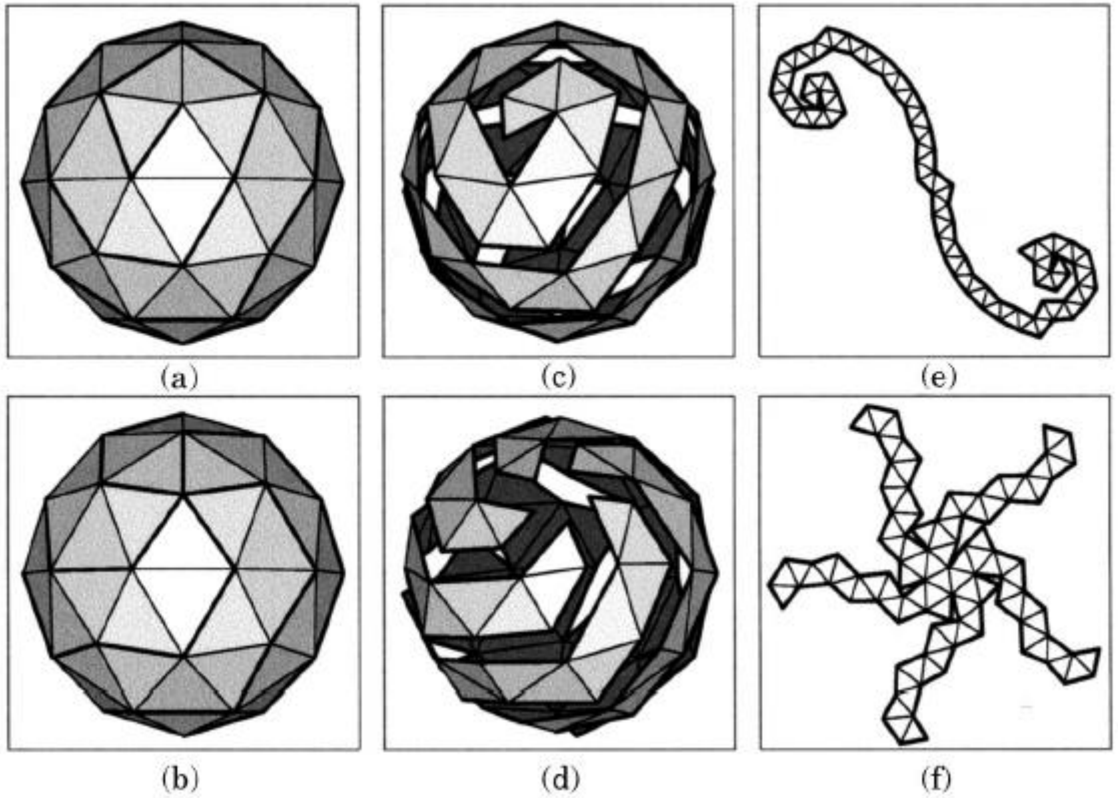

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- The **amount of compression** achieved can **vary** depending on how the initial mesh is cut; in other words, how the vertex-spanning tree is constructed.

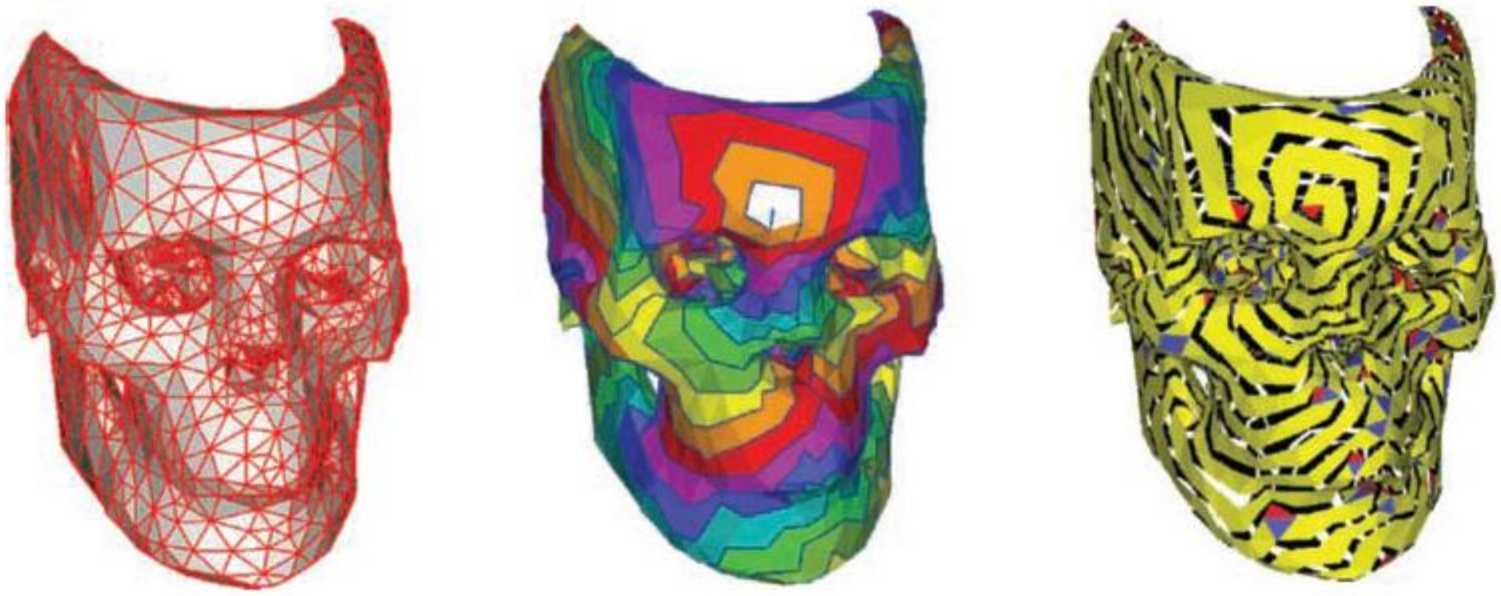

Figure 10-11

*Figure 10-11 Topological surgery (images courtesy of Gabriel Taubin). Example on a skull mesh. The original mesh is shown on the left; the vertex spanning is shown in the center—the colors indicate the distance from the root node. The cut-open mesh is shown on the right. The right image shows color-coded run triangles (yellow), branching triangles (blue), and leaf triangles (red). See the color insert in this textbook for a full-color version of this image.*

# Mesh compression using polyhedral simplification

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Iteratively removing vertices, edges, and faces from a mesh representation such that the overall geometric perception of the object is still maintained

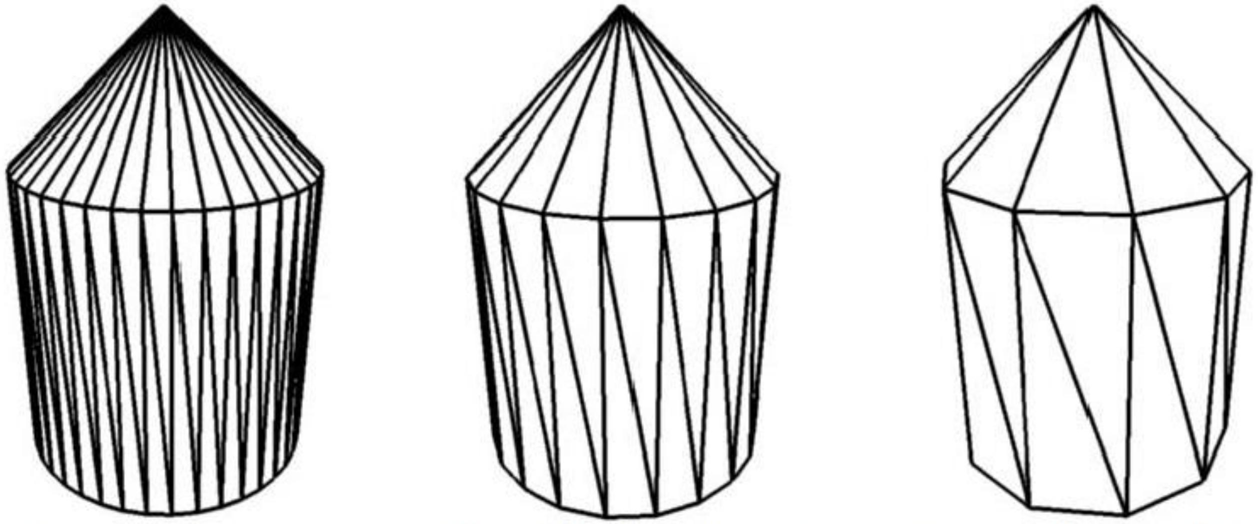
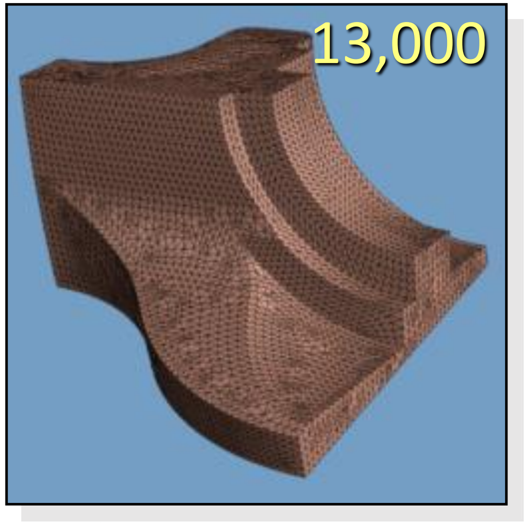
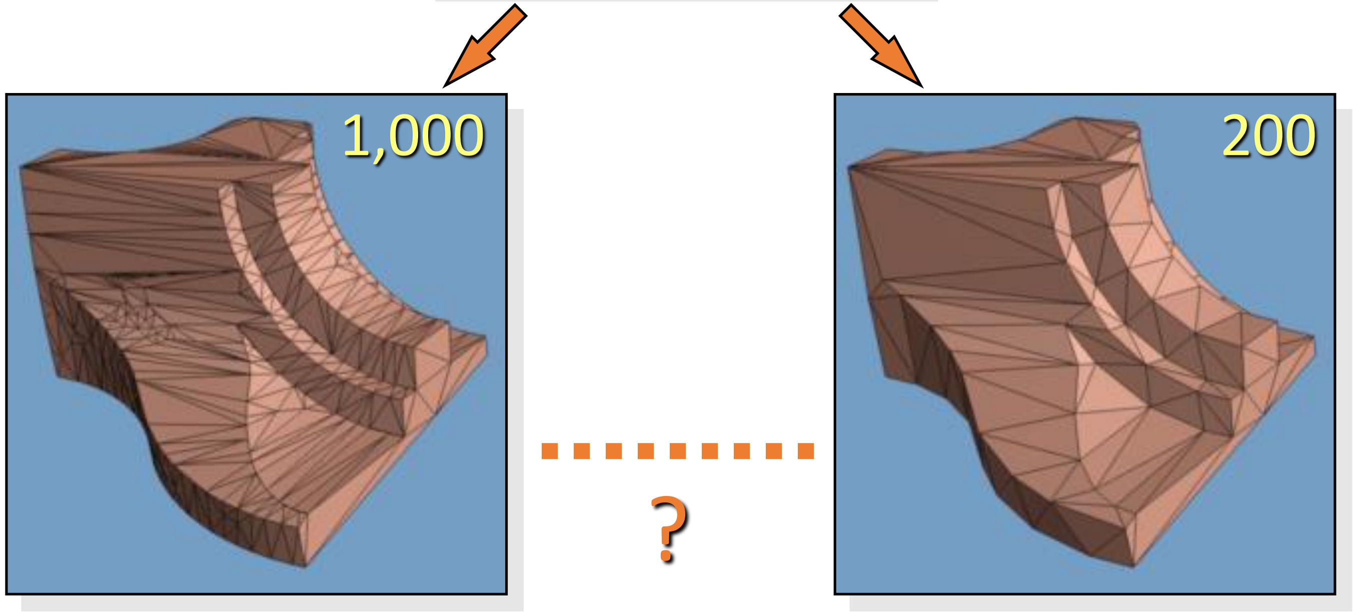


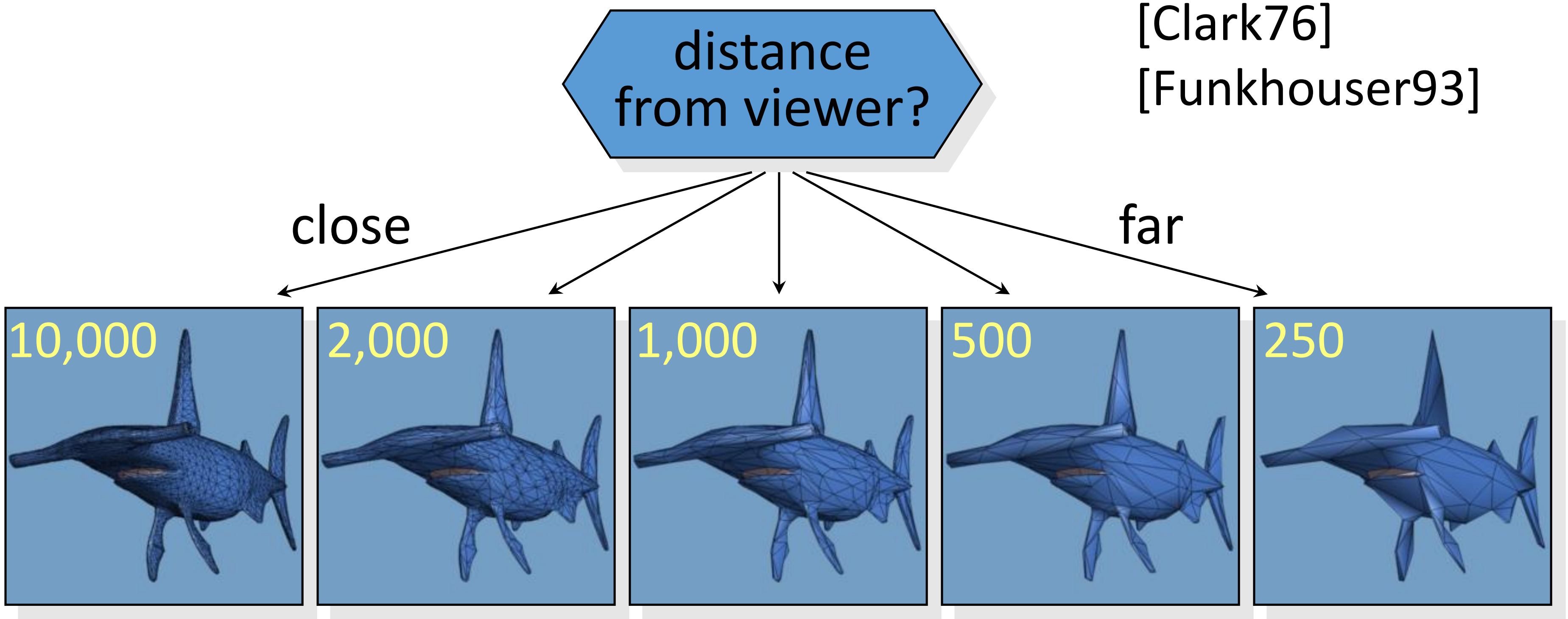
*Figure 10-12 Example of a simplified polyhedron. The left figure shows a polyhedron that has been simplified into coarser representations. The objective of such simplification techniques is to minimize the distortion in perception of the 3D shape.*




[Schroeder-etal92]
[Turk92]
[Hoppe-etal93]
[Rossignac-Borrel93]
[Cohen-etal96]
...



[Clark76]
[Funkhouser93]




Concern: transitions may “pop”

→ would like smooth LOD

# Progressive meshes

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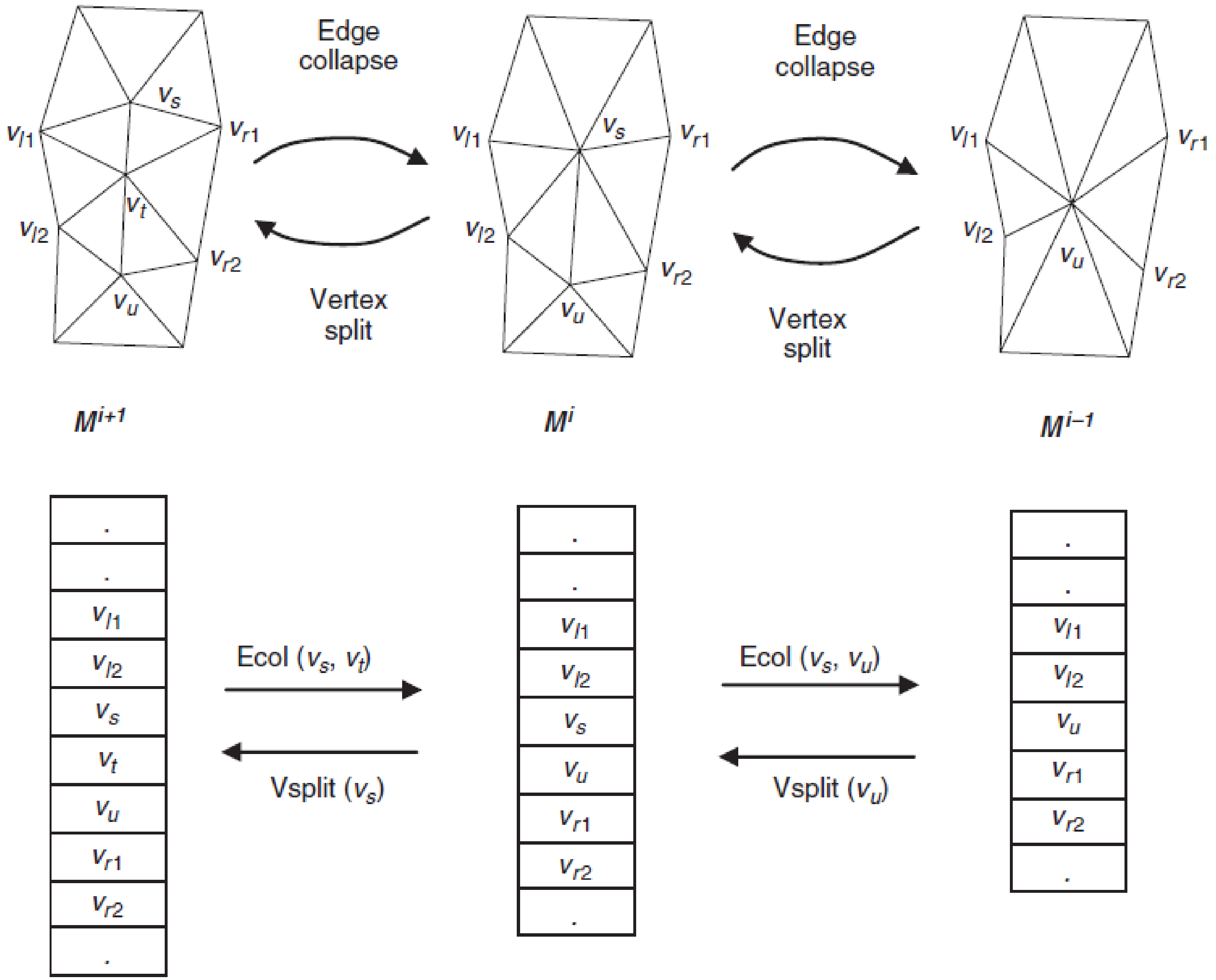


*Figure 10-13 Transformations in mesh simplification in progressive meshes—edge collapse and the complementary operation vertex split*

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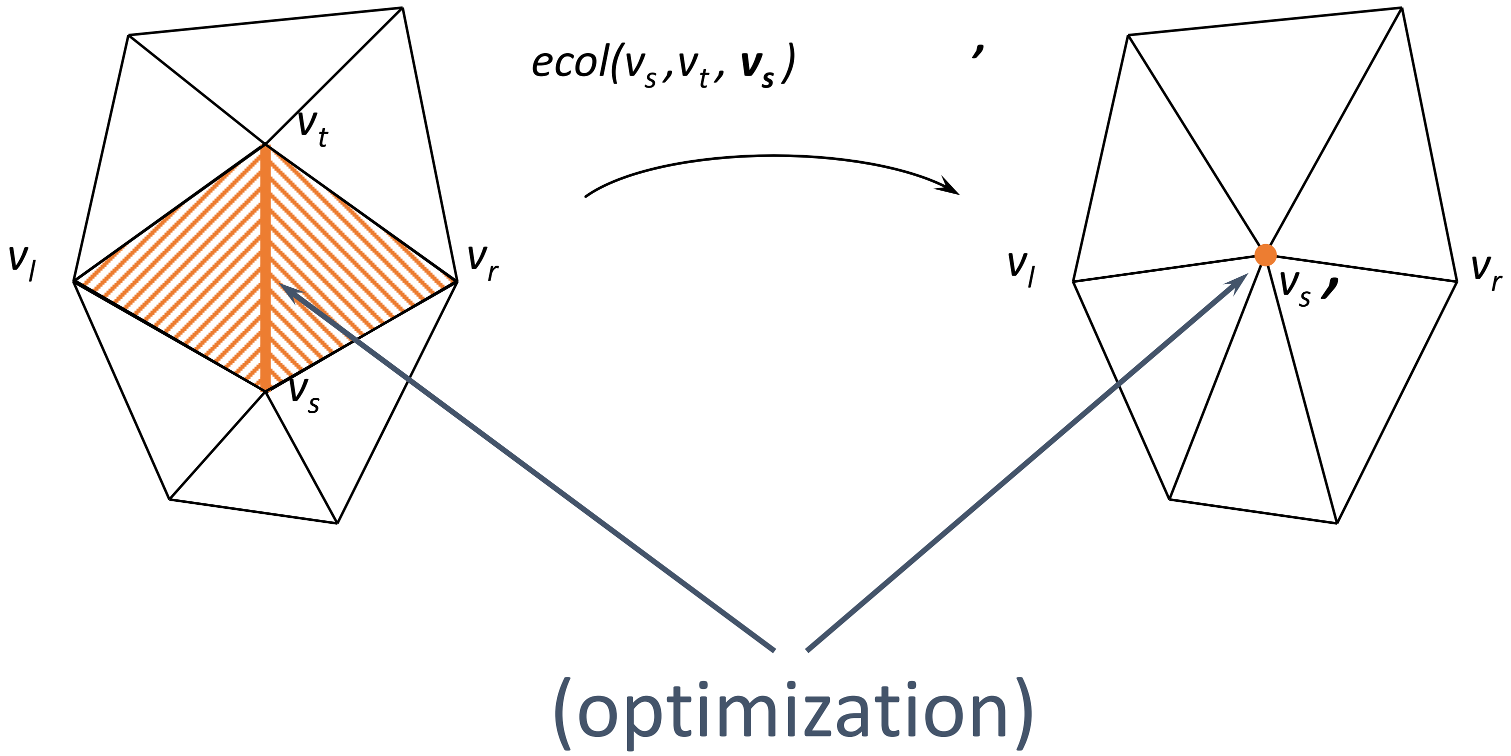
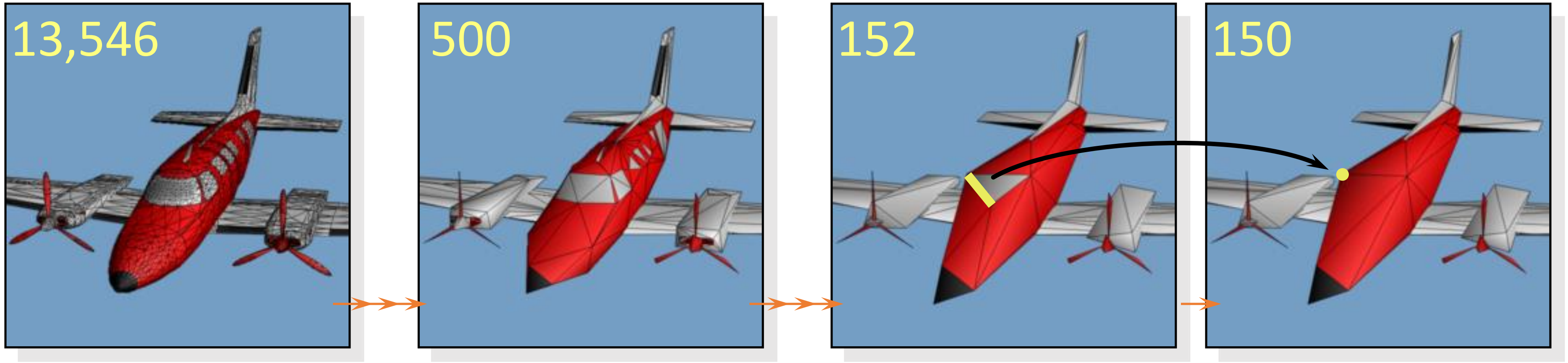
- Idea: apply sequence of edge collapses:






$$\hat{M}=M^n \xrightarrow[ecol_{n-1}]{} \;\twoheadrightarrow\; M^{175} \;\twoheadrightarrow \xrightarrow[ecol_i]{} M^1 \xrightarrow[ecol_0]{} M^0$$

# Invertible!

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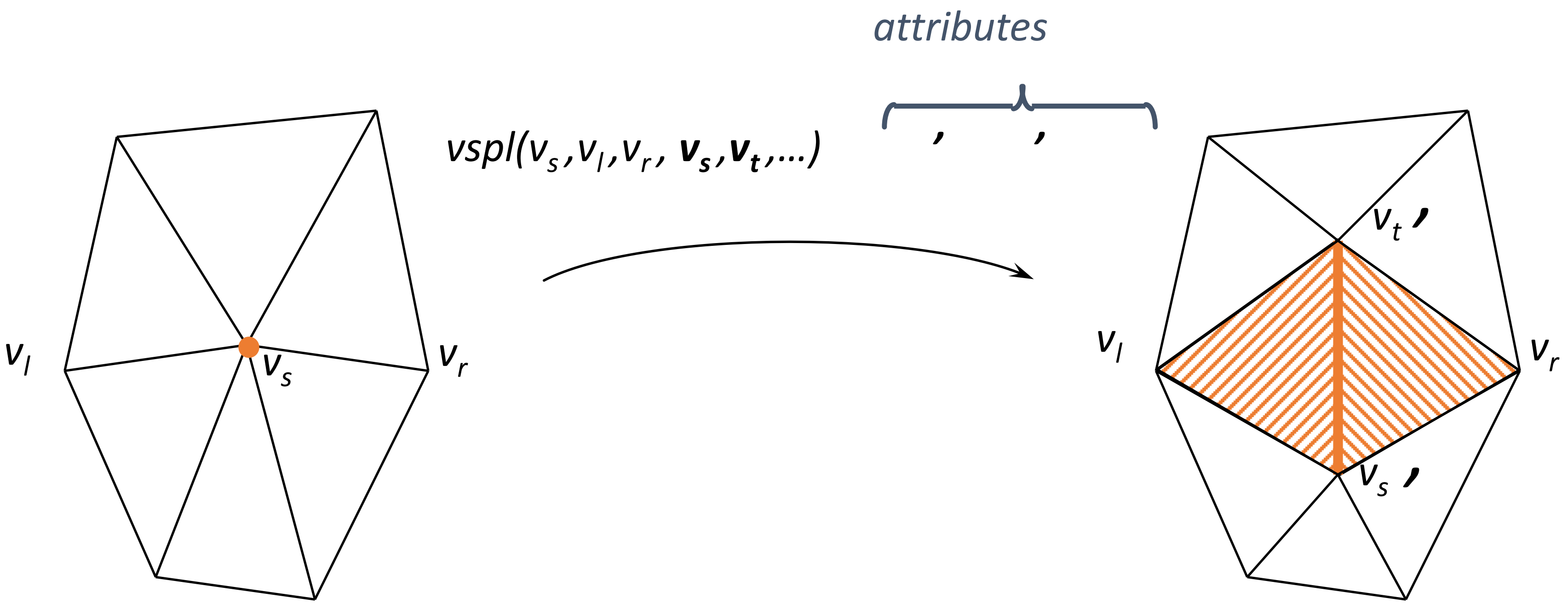
## Vertex split transformation:



# Reconstruction process

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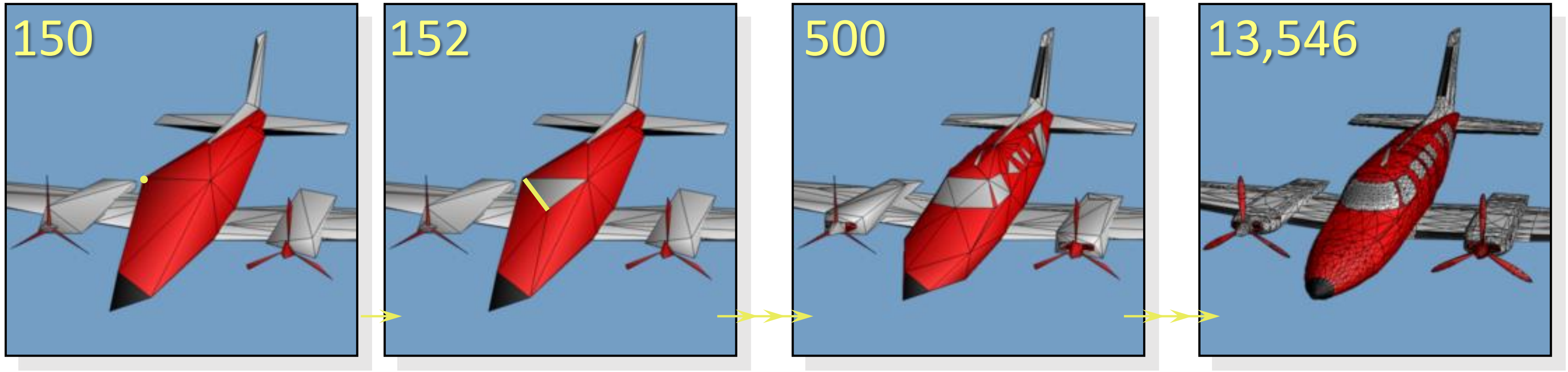


$M^0 \longrightarrow M^1 \longrightarrow \rightarrow\rightarrow\rightarrow M^{175} \rightarrow\rightarrow\rightarrow \longrightarrow M^n = \hat{M}$

$vspl_0$ … $vspl_i$ … $vspl_{n-1}$

*progressive mesh (PM)* representation

# Multiresolution techniques – wavelet-based encoding

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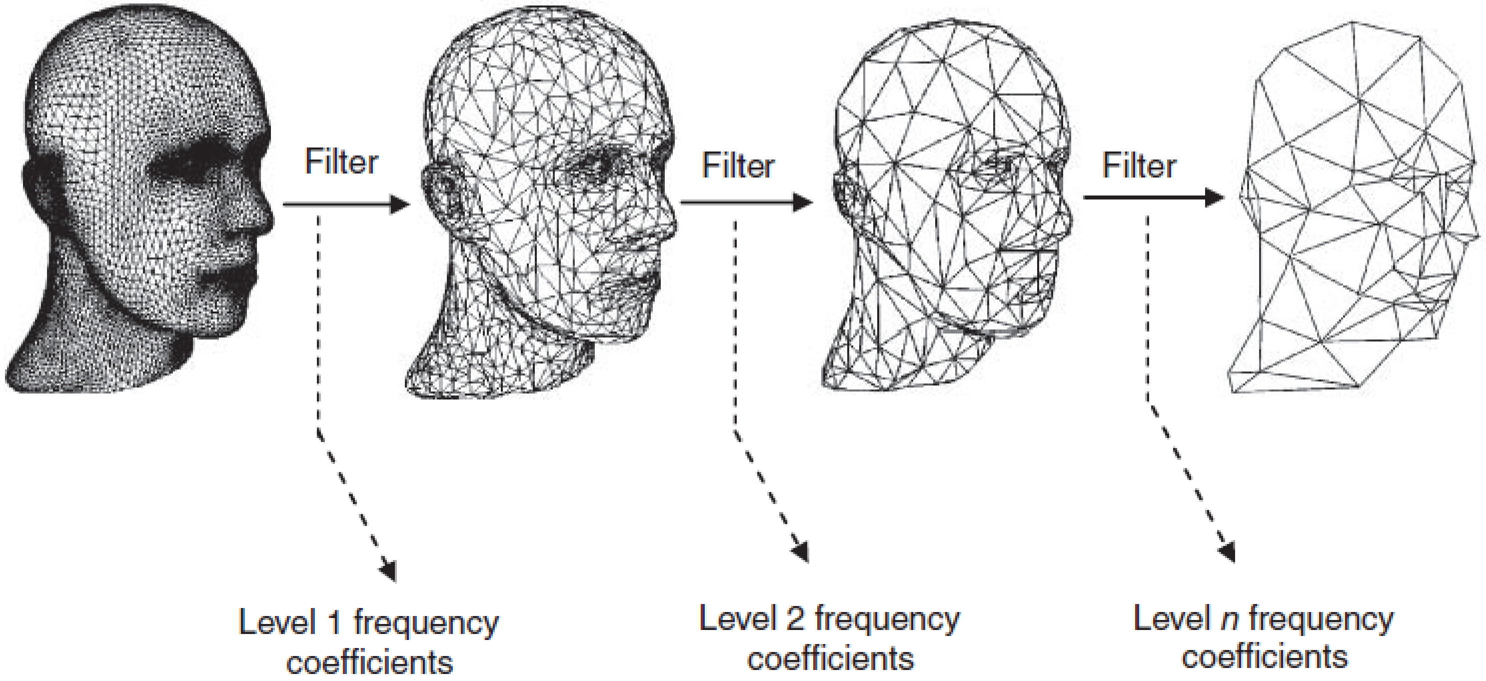


*Figure 10-15 Multiresolution surface approximation example. The high-resolution surface shown on the left can be filtered successively using 3D frequency transforms to approximate lower-resolution meshes along with frequency coefficients. Quantization of the frequency coefficients would lead to compression.*

# Progressive encoding and level of detail

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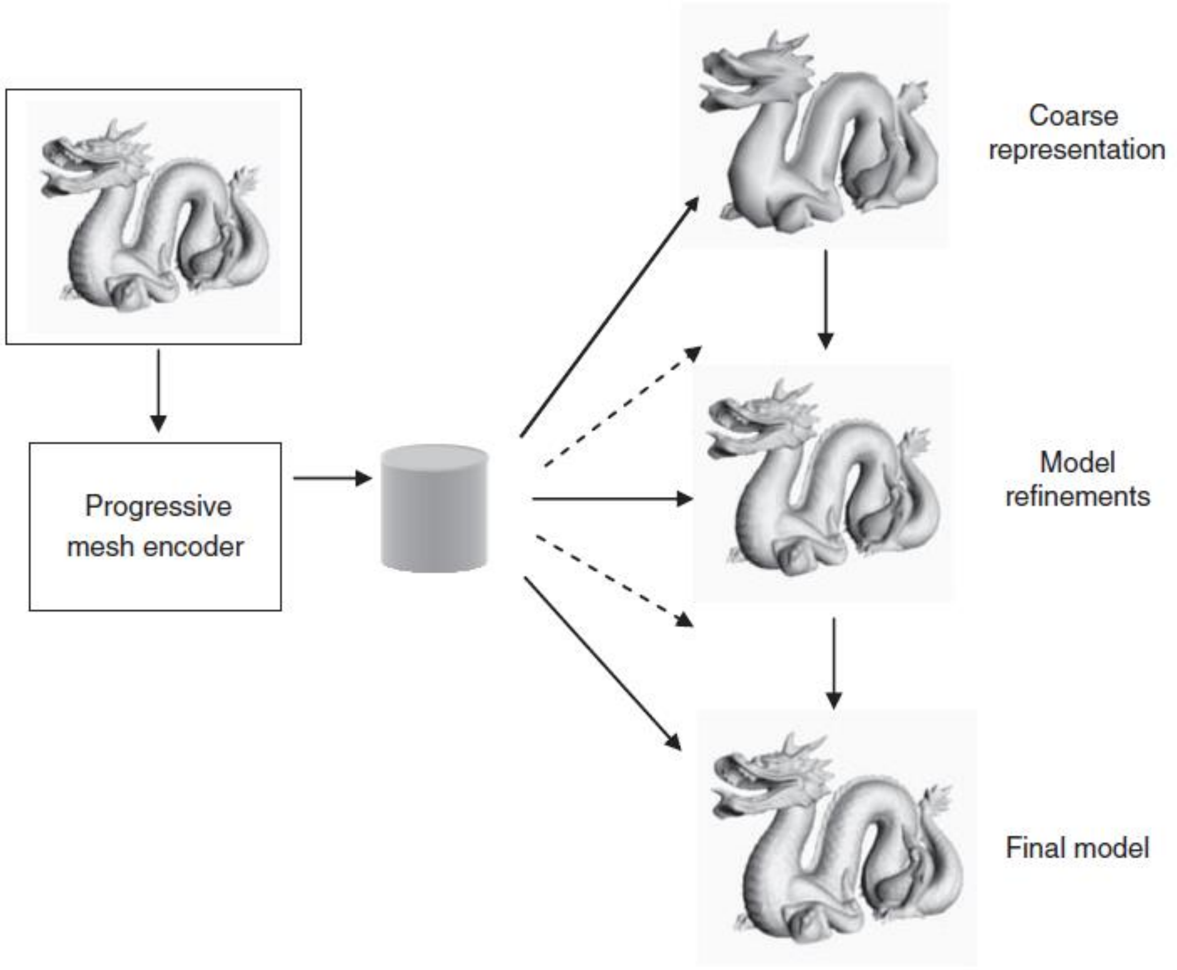


*Figure 10-16 Progressive mesh encoding. The compressed bit stream is organized so that a coarse representation is encoded first, followed by refinement information, which increases the details on the decoded models.*

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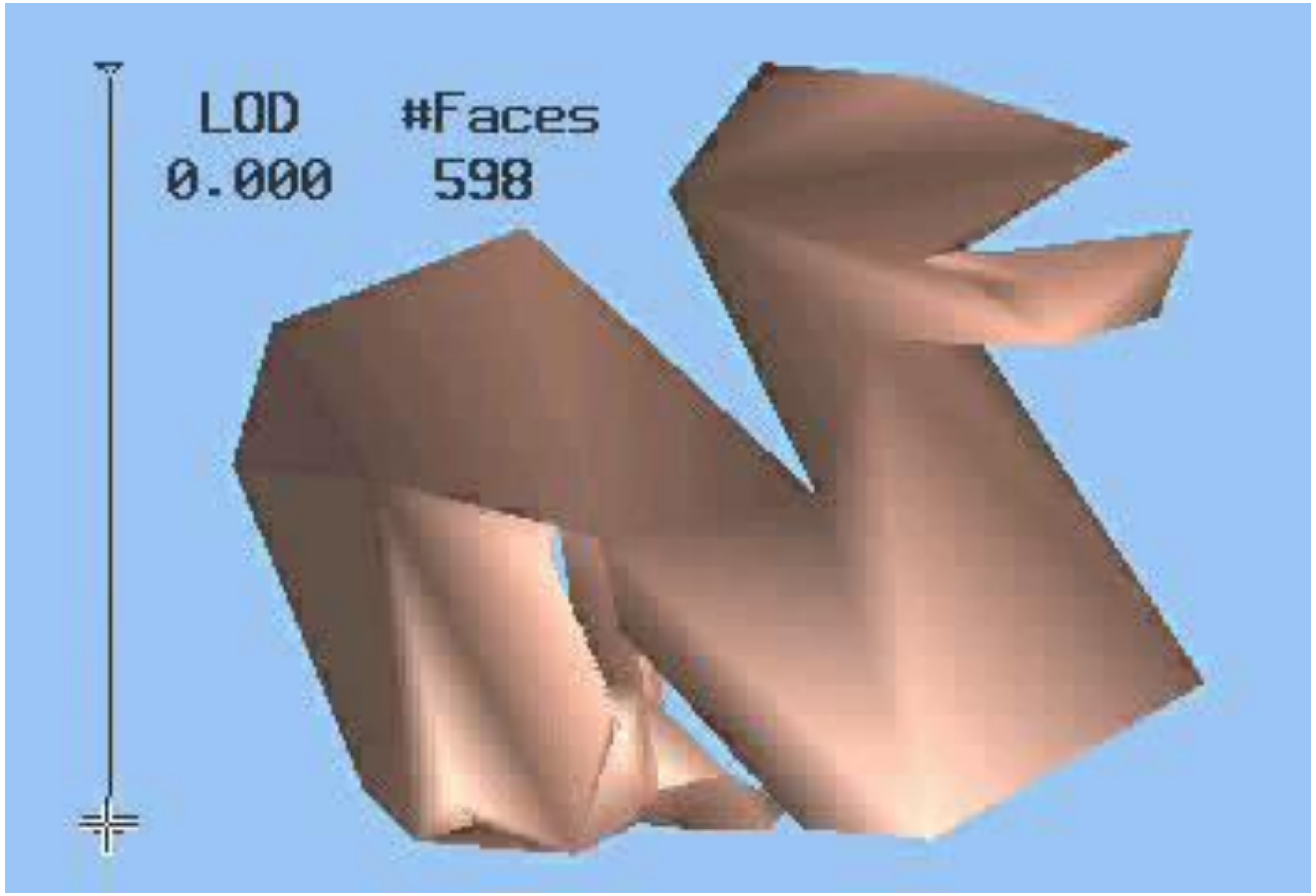

# 3D graphics compression standards



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- VRML : Virtual Reality Modeling Language
- X3D : eXtensible 3D
  - A software standard aimed at formalizing the web-based and broadcast-based interactive 3D content
  - Aim at
    - Description
    - Animation and interaction
    - Scripting and programming
    - Encoding and compression

```
<X3D version=‘3.1’ profile=‘Immersive’ xmlns:xsd=
‘http://www.w3.org/2001/XMLSchema-instance’ xsd:noNamespaceSchemaLocation=
‘http://www.web3d.org/specifications/x3d-3.1.xsd’>
<head>
    <meta name=‘filename’ content=‘example.x3d’/>
    <meta name=‘author’ content=‘authorName’/>
    <meta name=‘created’ content=‘March 20 2003’/>
    <meta name=‘keywords’ content=‘X3D VRML binary compression’/>
    <meta name=‘url’ content=‘file://C:/multimedia/3d/example.x3d’/>
</head>
<Scene>
    <Viewpoint position=‘0.0 0.0 1.0’ description=‘camera view’/>
    <Background groundColor=‘0.5 0,5 0.5’/>
    <Transform scale=‘0.25 0.25 0.25’>
      <Shape>
        <Appearance>
          <Material diffuseColor=‘1.0 0 0’/>
        </Appearance>
        <IndexedFaceSet coordIndex=‘0 3 4 -1 2 42 1 -1 3 4 7 -1 2 4 11 -1 2 14
16 -1 5 11 71 -1 12 35 67 -1 45 23 7 -1 3 44 56 -1. . . .’>
          <Coordinate point=‘0.2138 0.2339 0.09065, 0.1078 0.2532 0.1026,’
0.2138 0.2339 0.09065, 0.1078 0.2532 0.1026, ‘0.2138 0.2339 0.09065, 0.1078 0.2532
0.1026,’ 0.2138 0.2339 0.09065, 0.1078 0.2532 0.1026, ‘0.2138 0.2339 0.09065, 0.1078
0.2532 0.1026,’ 0.2138 0.2339 0.09065, 0.1078 0.2532 0.1026, ‘0.2138 0.2339 0.09065,
0.1078 0.2532 0.1026, . . . .’/>
        </IndexedFaceSet>
      </Shape>
    </Transform>
  </Scene>
</X3D>
```

**Figure 10-17 X3D description of a static 3D geometry set in XML format. The section included within the scene tag corresponds to the actual geometric content listing color assignments, appearance information, and the actual coordinates. The Coordinate point tag gives the x, y, z floating-point representations of vertices, whereas the IndexedFaceSet tag gives the interconnectivity between the vertices. The list shows three indices separated by a −1, suggesting triangle vertex indices pointing to coordinate point vertices.**

```
<X3D version=‘3.1’ profile=‘Immersive’ xmlns:xsd=
‘http://www.w3.org/2001/XMLSchema-instance’ xsd:noNamespaceSchemaLocation=
‘http://www.web3d.org/specifications/x3d-3.1.xsd’>
  <head>
    <meta name=‘filename’ content=‘example.x3d’/>
    <meta name=‘author’ content=‘authorName’/>
    <meta name=‘created’ content=‘March 20 2003’/>
    <meta name=‘keywords’ content=‘X3D VRML binary compression’/>
    <meta name=‘url’ content=‘file://C:/multimedia/3d/example.x3d’/>
  </head>
  <! ---- compressed binary data ---->
</X3D>
```

**Figure 10-18 A compressed representation of the X3D description in Figure 10-17. The compressed binary data corresponds to a stream of binary bits that are obtained by compressing the scene information tag.**

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- MPEG-4
  - Provide a compression ratio of 30:1 to 40:1
  - Provide functionality as in the following list
    - Progressive or increment rendering
    - Support for nonmanifold object
    - Error resiliency support

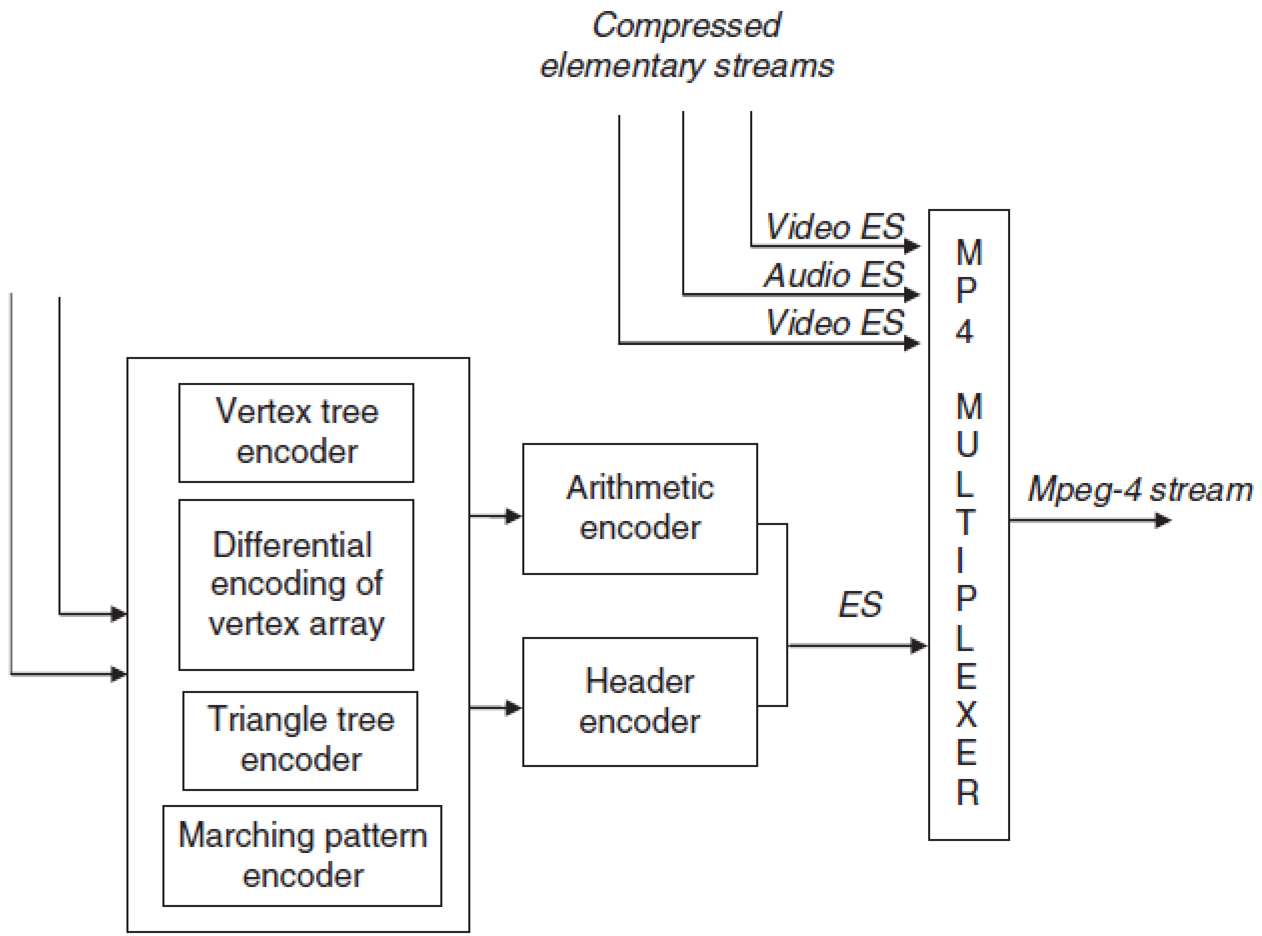


*Figure 10-19 MPEG-4 3D mesh encoding. The mesh encoding process is based on the topological surgery algorithm discussed in Section 5.2. The resulting compressed bit stream, an elementary stream, is then multiplexed with other media elementary streams.*

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# Q & A