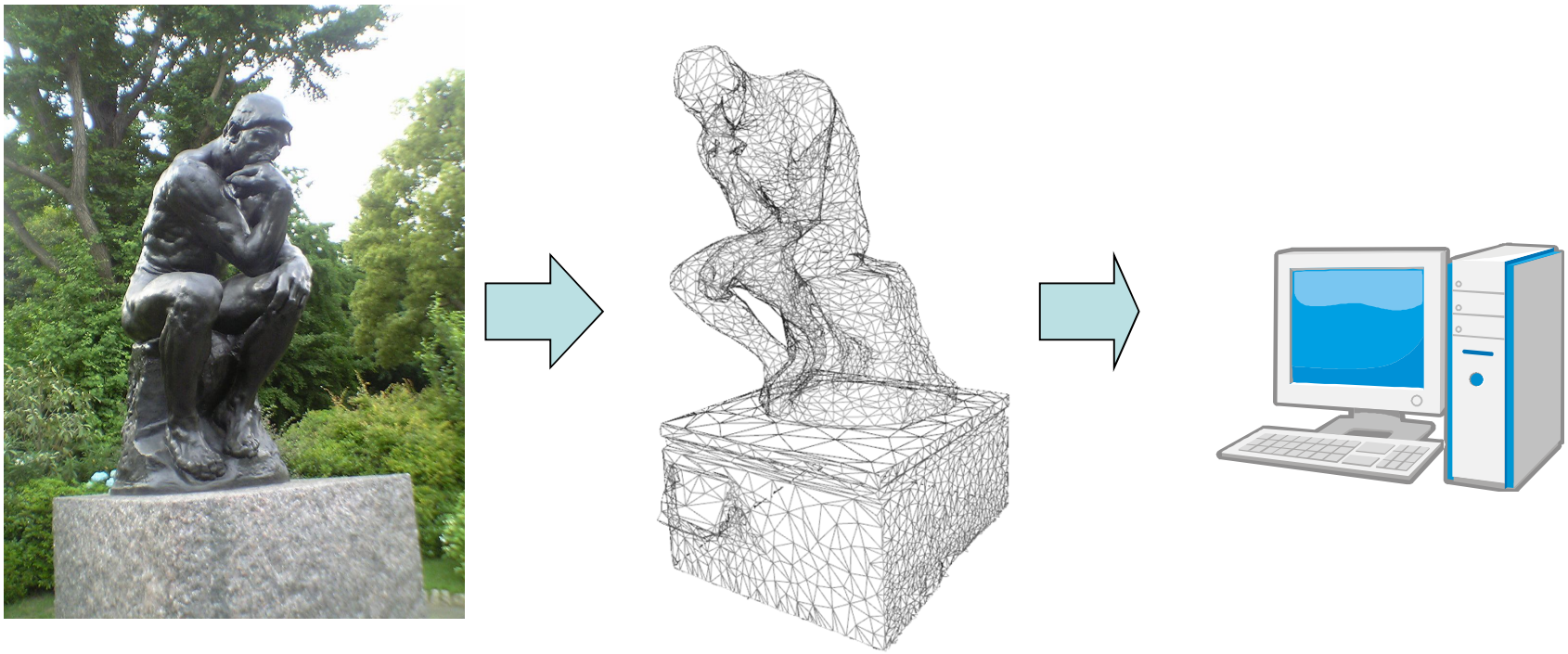
Data Visualization

Yasuhide Okamoto

Computer Vision

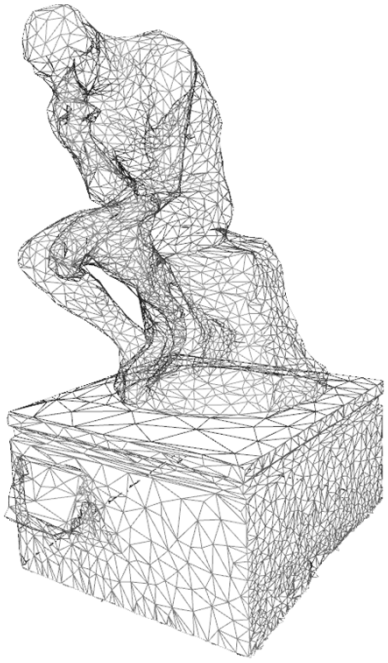
- Real scenes, objects -> Digital data



Utilization of 3D data

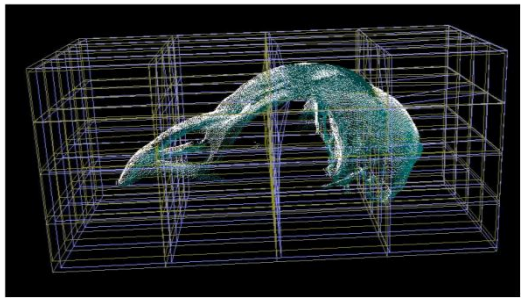
- What is obtained 3D data to be used for?

?

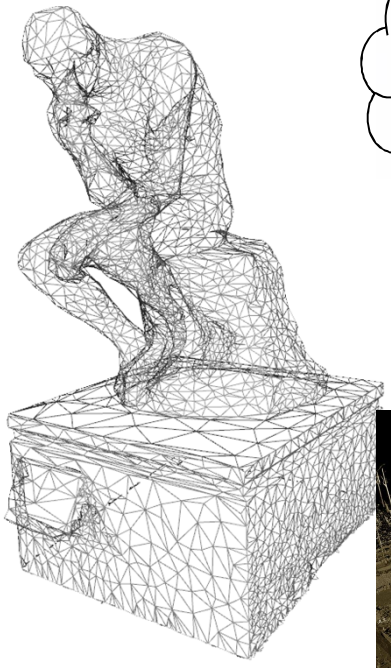


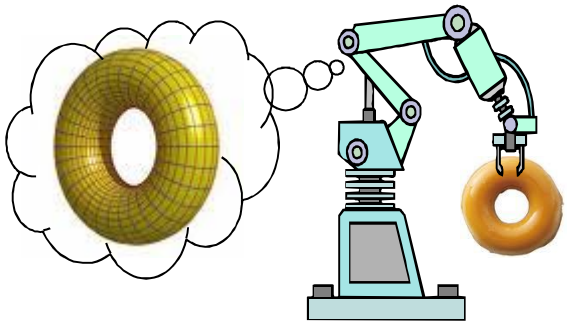
Utilization of 3D data

- What is obtained 3D data to be used for?

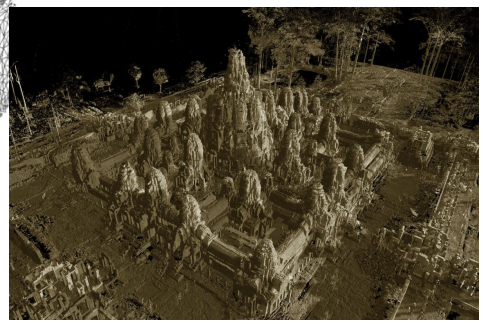


Analysis





Detection / Recognition

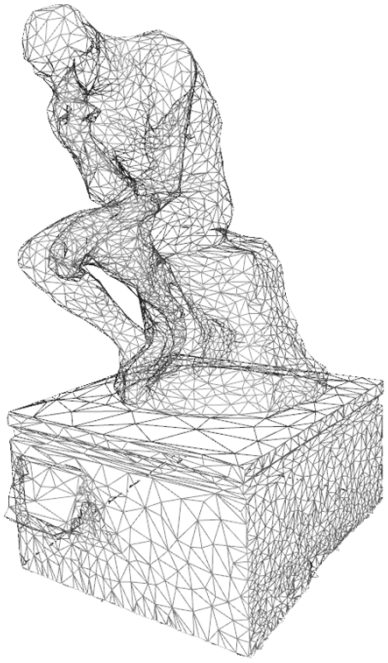


Entertainment

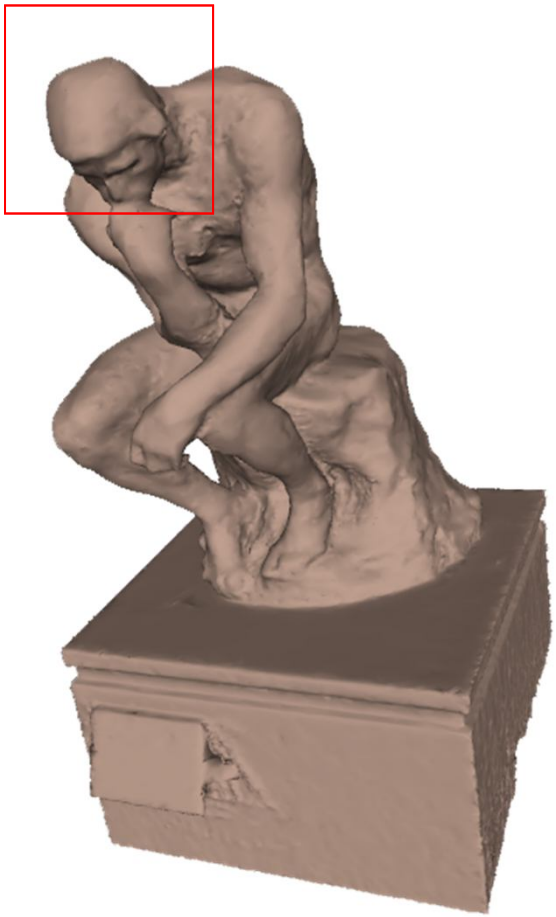
Utilization of 3D data

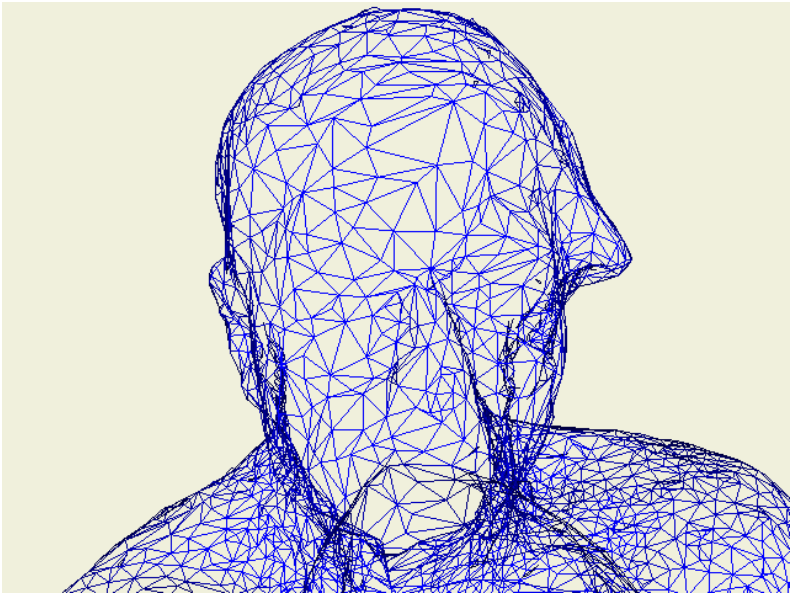
- How are they used?

?



3D data format

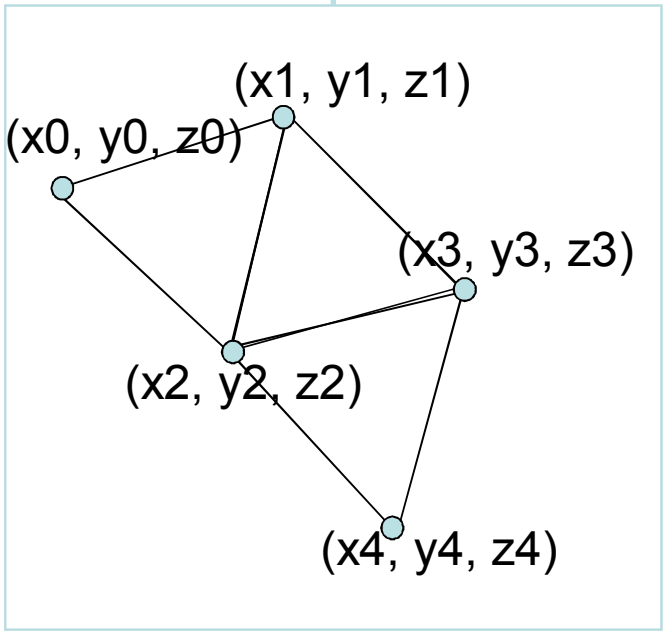




3D data in text format

```
#3D data format
#Vertex List
(x0, y0, z0)
(x1, y1, z1)
(x2, y2, z2)
…

#Face List
(0, 1, 2)
(1, 2, 3)
(1, 3, 4)
…
```

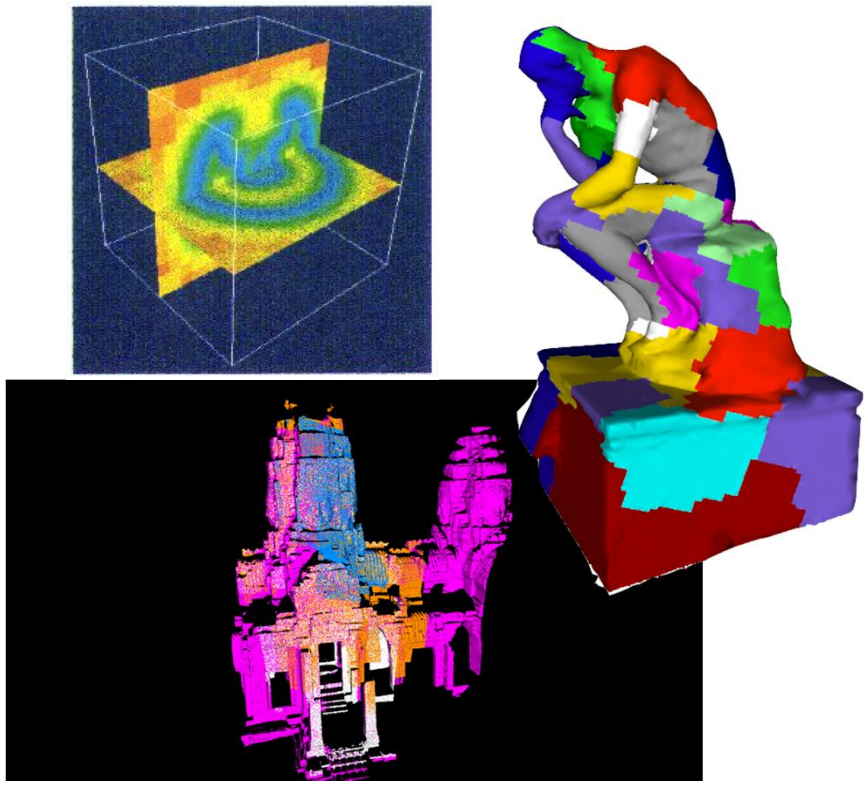


Difficult to understand by human…

Visualized 3D data

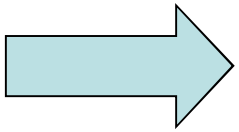
#3D data format
#Vertex List
(x_0, y_0, z_0)
(x_1, y_1, z_1)
(x_2, y_2, z_2)
…

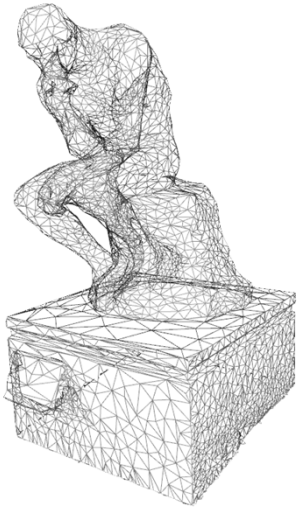
#Face List
(0, 1, 2)
(1, 2, 3)
(1, 3, 4)
…

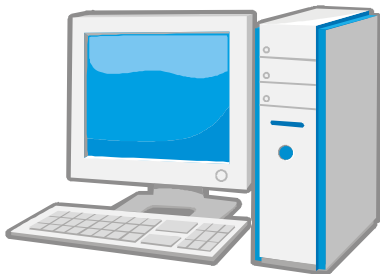


Easy to understand by human!

Next Step







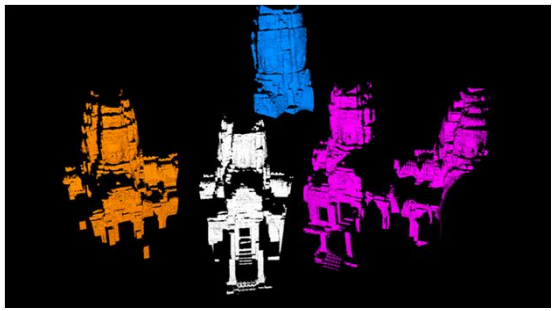
Visualization

≒ Computer graphics

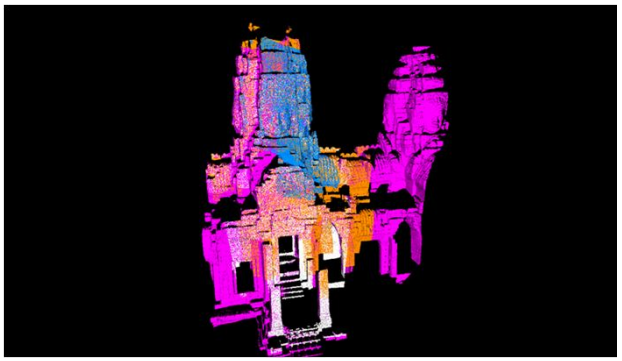
Visualization for Huge 3D Data

Modeling from real objects

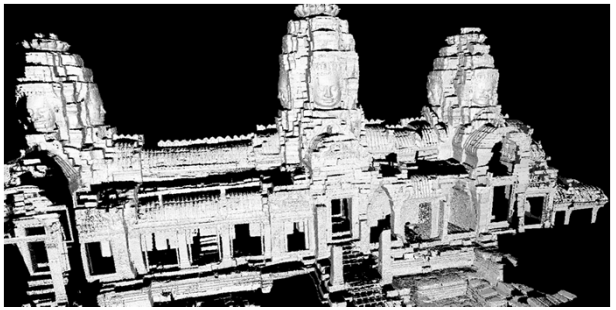
Data acquisition



Alignment



Merging



3D sensing technology

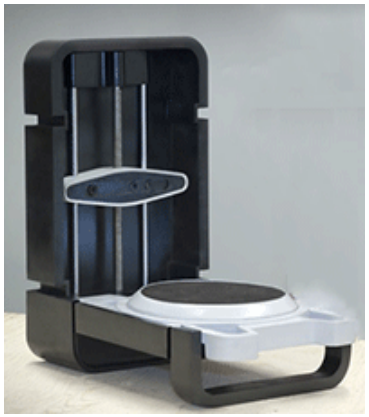
Leica ScanStation

Konica Minolta
VIVID Series

Zoller+Frohlich
Imager

3D sensing technology

Microsoft Kinect



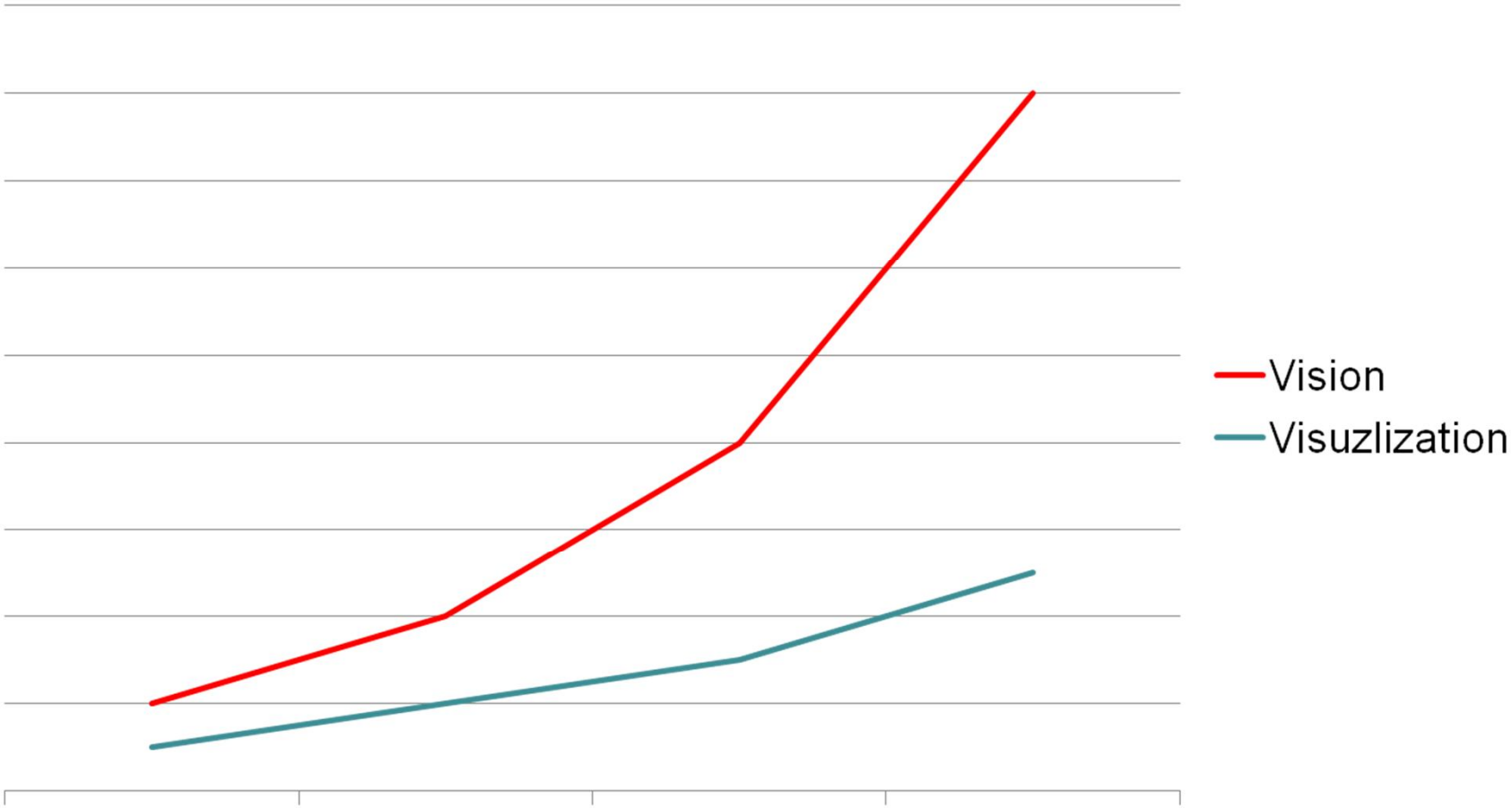
Matter&Form Photon

3D systems Sense

Easy to obtain fine and huge 3D data

Visualization technology

Improvement of vision / visualization ability

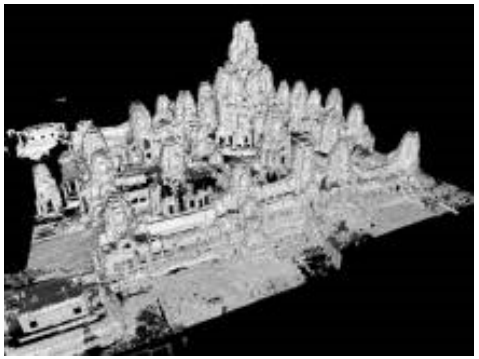


(note: Just a image!)

Problem

- Huge and fine 3D data cannot be used on commodity computers because of the size

Nara buddha
Triangles: 2milions
Data size: 120MB

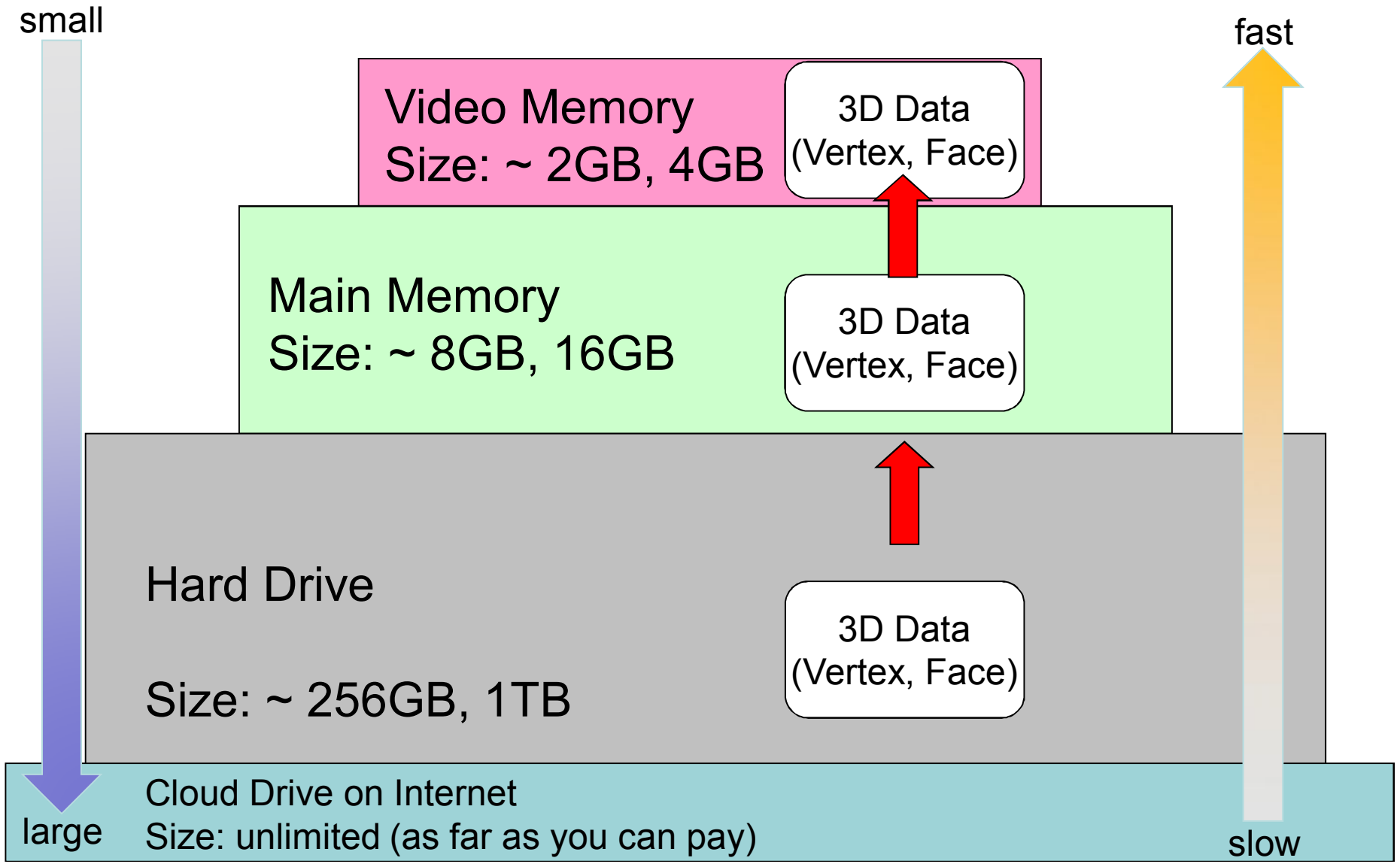


Bayon temple
Triangles: 1bilions
Data size: 100GB

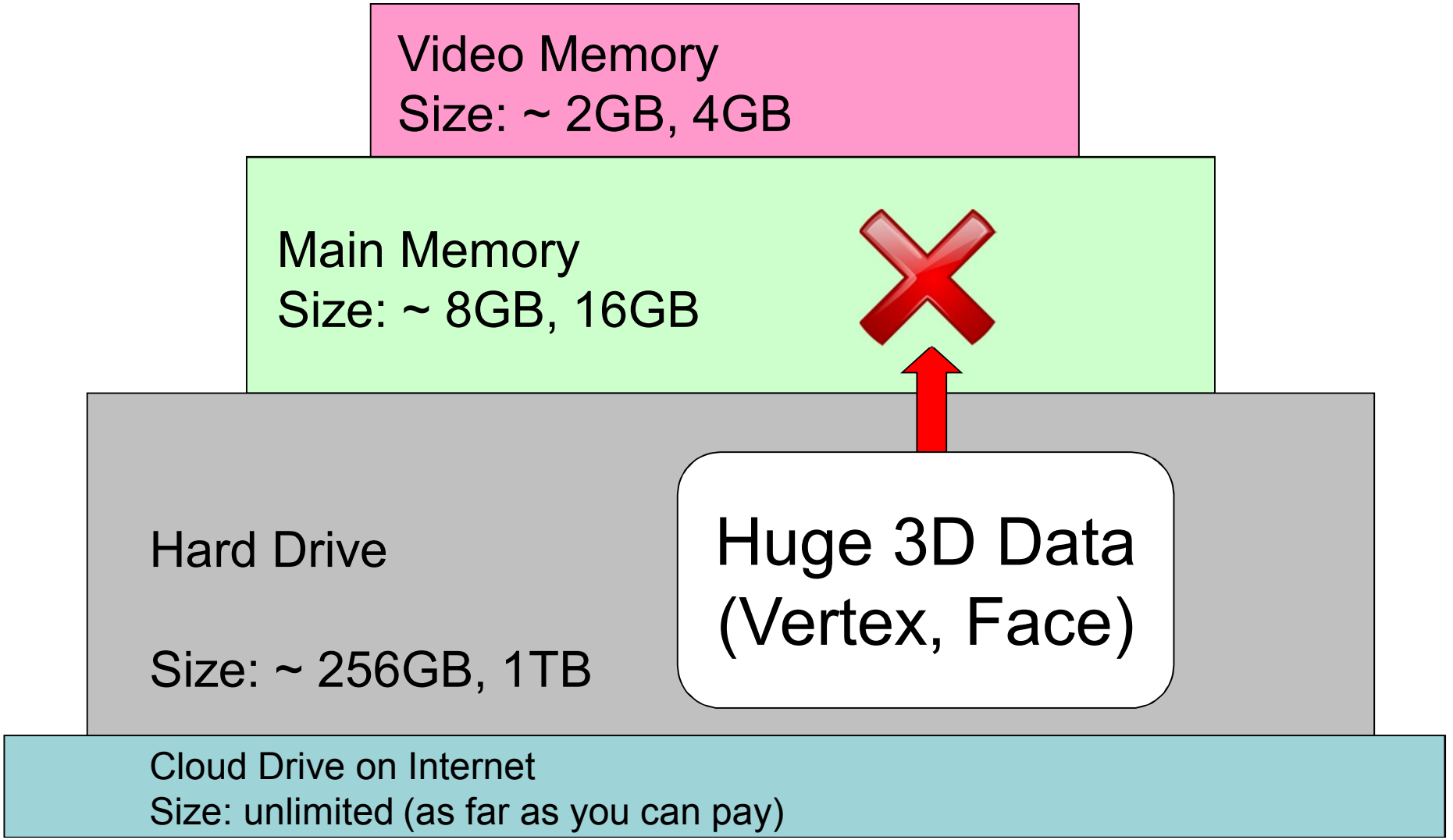
Today's Content

- How to treat huge 3D models
  - Simplification using Quadric error metrics [Garland97]
  - Progressive Meshes [Hoppe 96]
  - Adaptive Tetrapuzzles [Cignoni 2004]

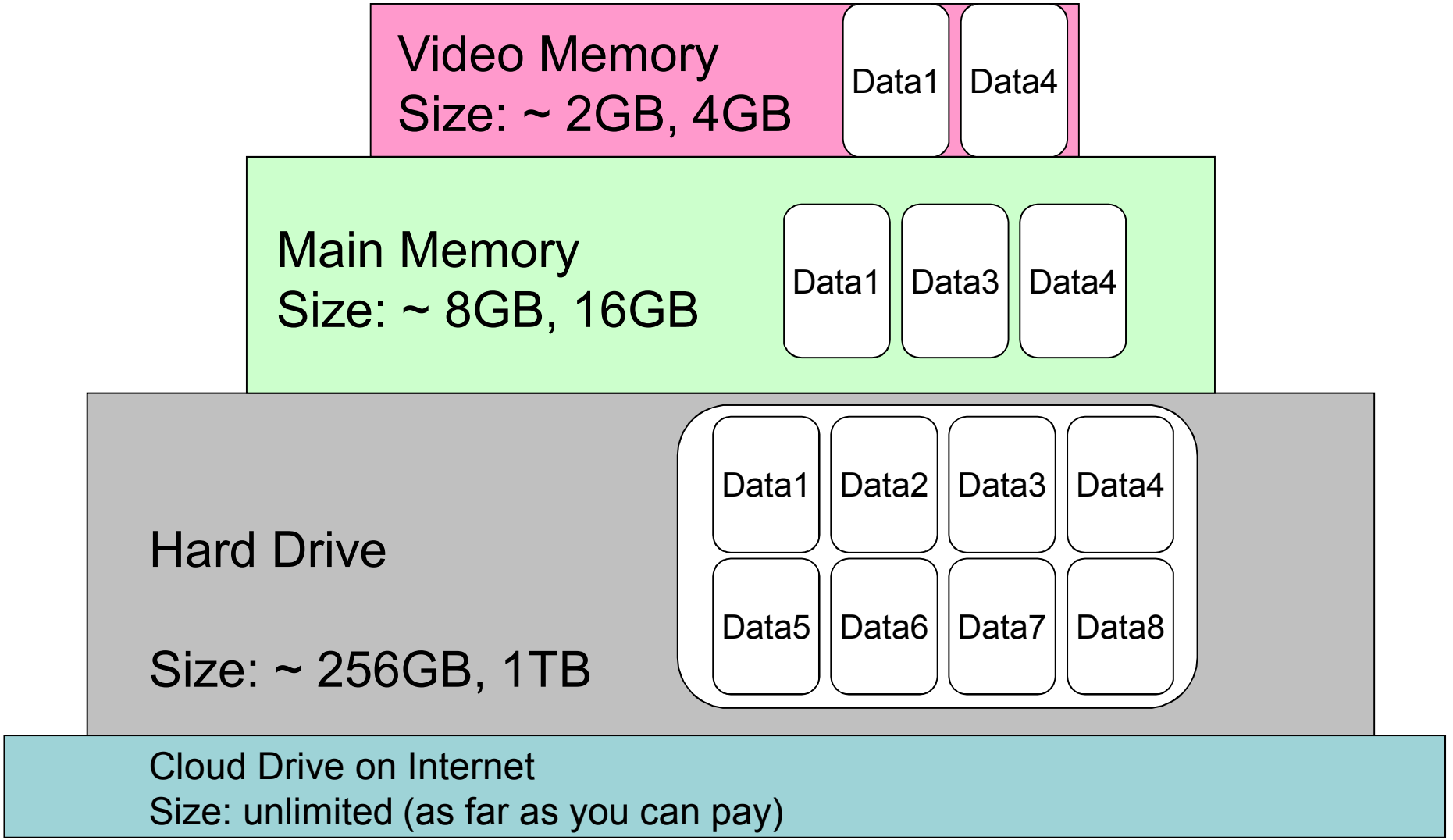
Memory hierarchy



Storage limitation

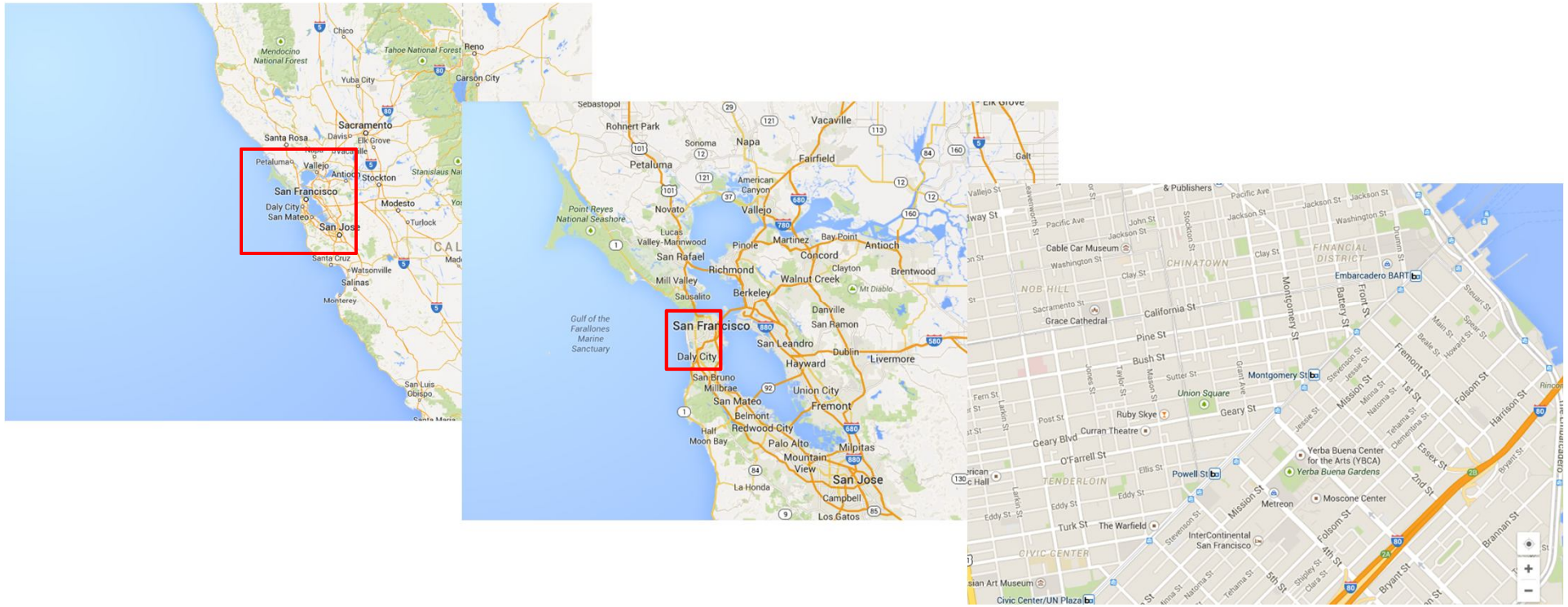


Out of Core


Video Memory
Size: ~ 2GB, 4GB
Data1
Data4
Main Memory
Size: ~ 8GB, 16GB
Data1
Data3
Data4
Hard Drive
Size: ~ 256GB, 1TB
Data1
Data2
Data3
Data4
Data5
Data6
Data7
Data8
Cloud Drive on Internet
Size: unlimited (as far as you can pay)

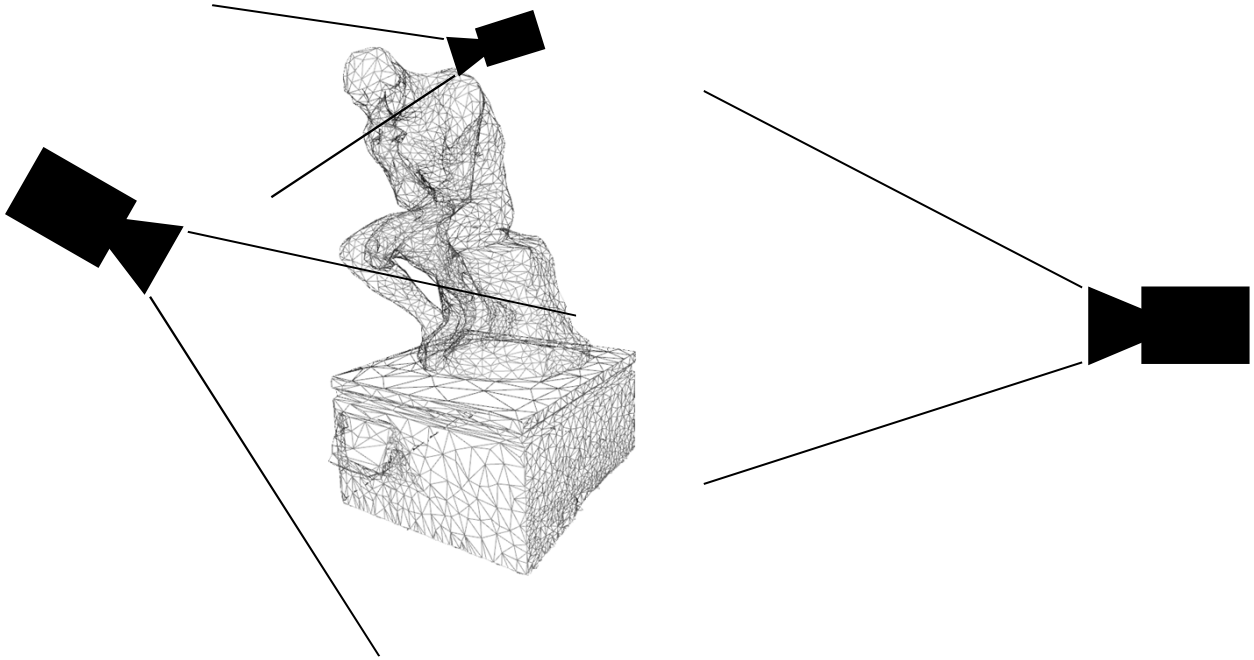
Out of Core for 2D data

- Required data selection is easy
  - (ex. Online map like Google maps)
  - Level of Detail, Multiresolution



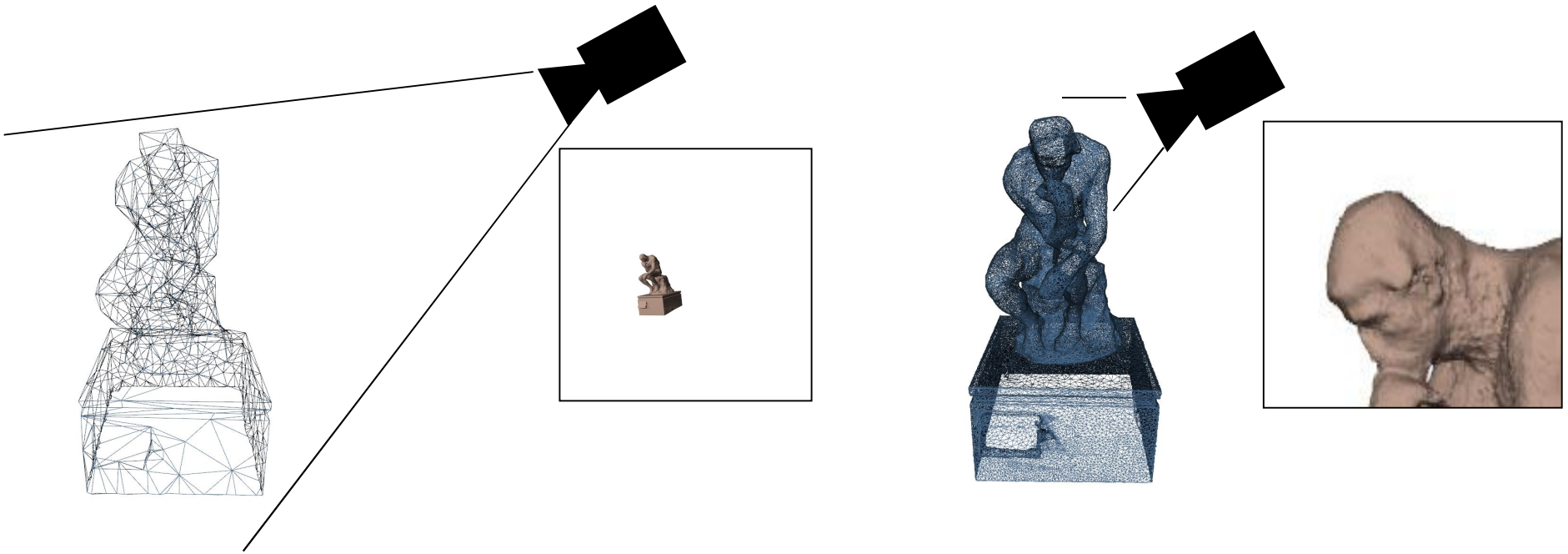
Out of Core for 3D data

- Required data selection is difficult
  - Many data access patterns



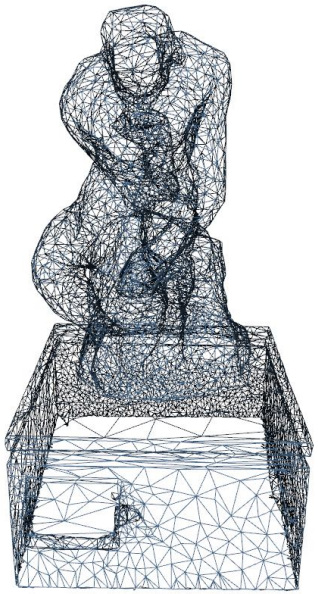
Level of Detail in 3D

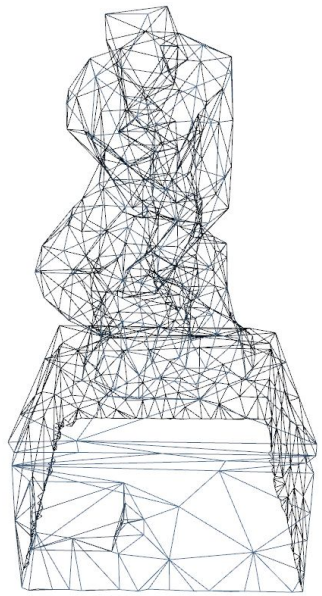
- Far side -> using rough model
- Near side -> using fine model



Level of Detail in 3D

- Multilevel resolution model



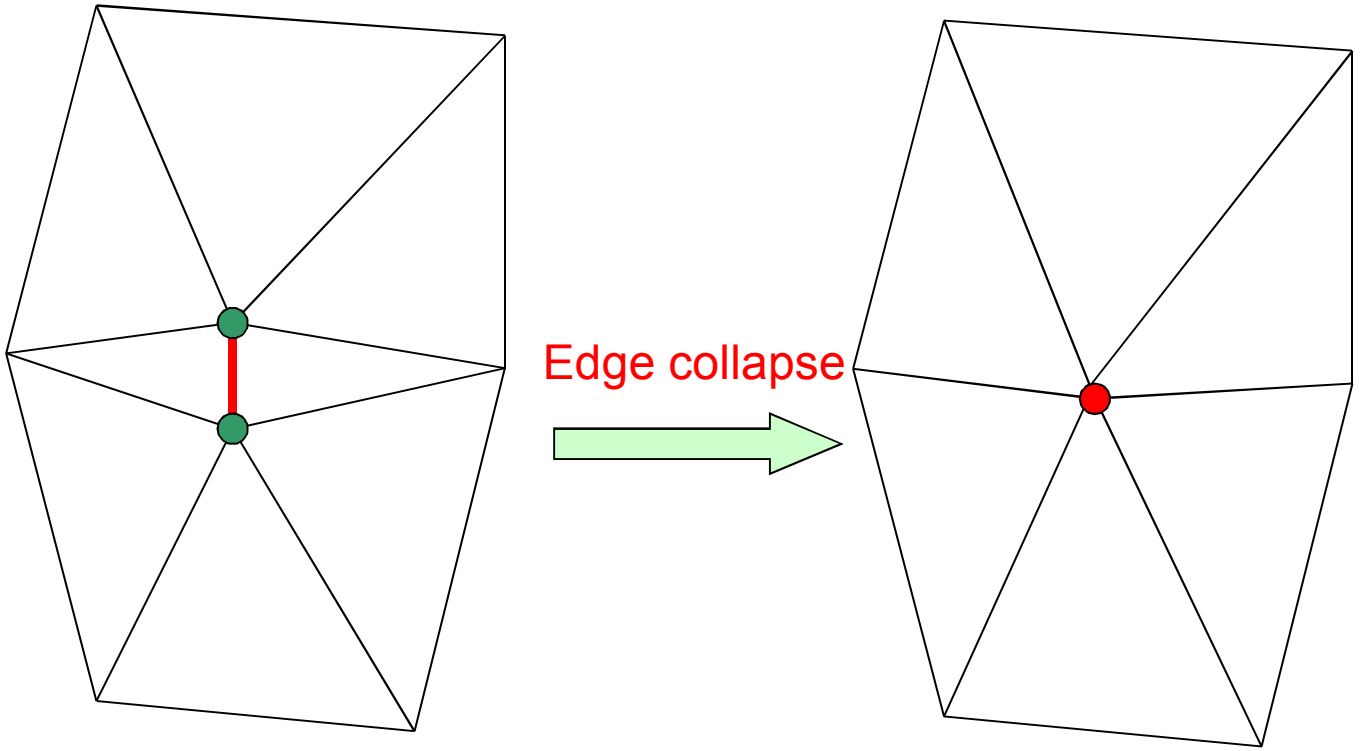


Data size: large

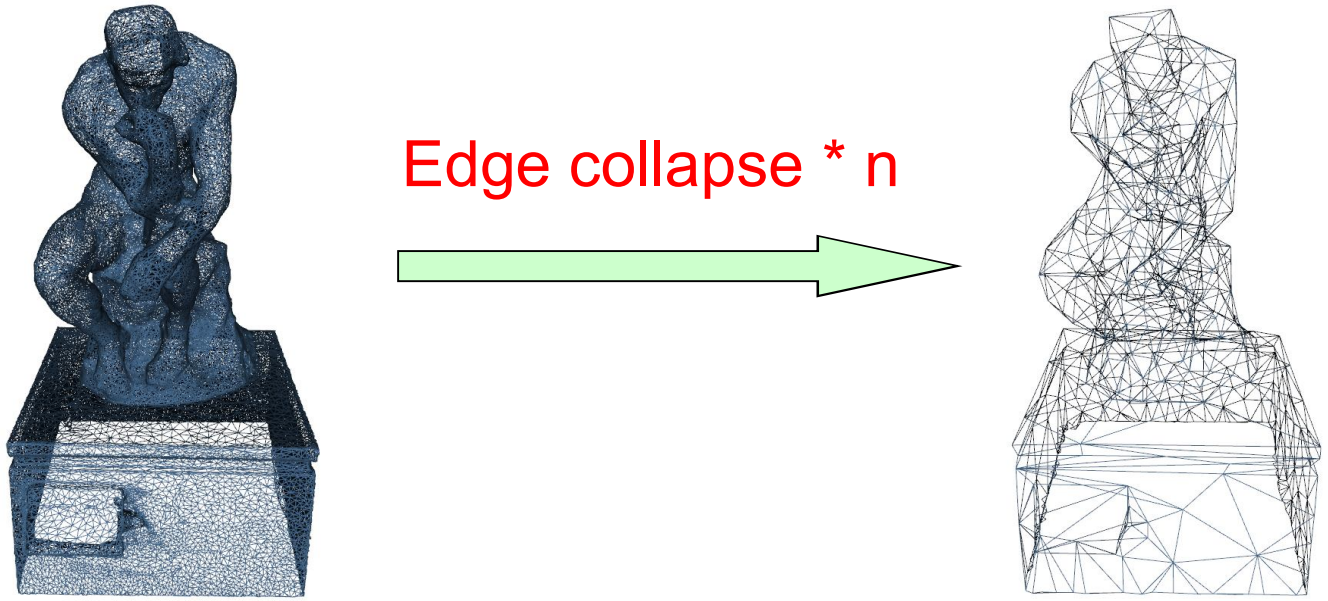
Data size: small

Mesh simplification

- Edge collapse



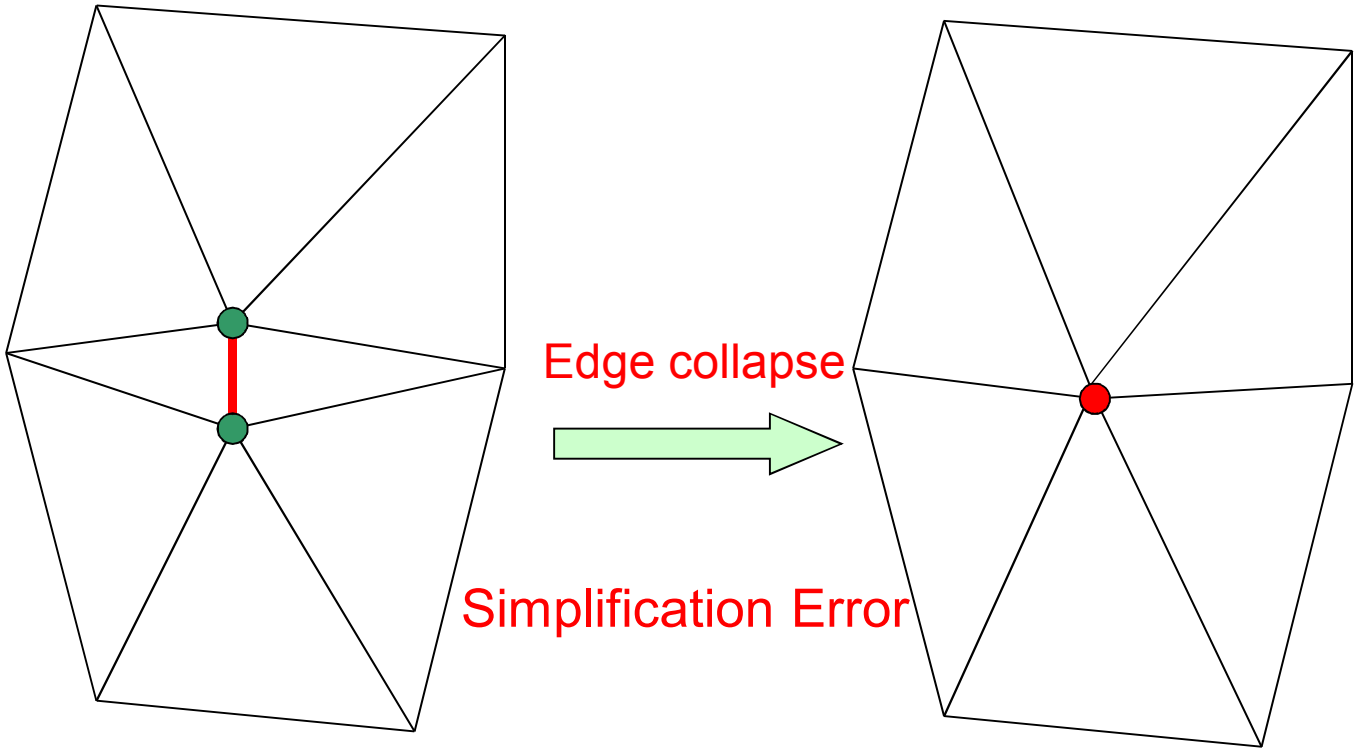
Mesh simplification



Surface simplification using Quadric Error Metrics [Garland97]

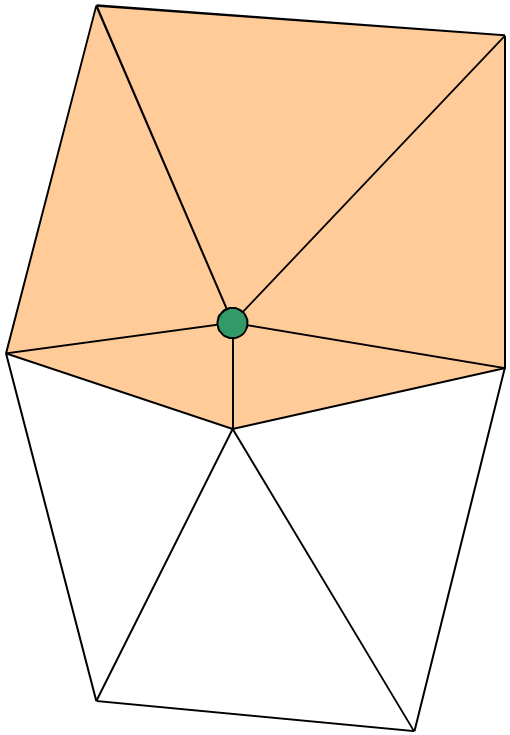
- Simplification method
  - with high quality approximations
  - can work efficiently
  - supporting highly complex objects

Define error of edge collapse



Error Metric

- Each vertex is the intersection of a set of planes



Error Metric

- Define the error at each vertex to be the sum of the squared distances to planes

$$\Delta(\mathbf{v}) = \Delta([v_x\ v_y\ v_z\ 1]^\mathsf{T}) = \sum_{\mathbf{p}\in\text{planes}(\mathbf{v})} (\mathbf{p}^\mathsf{T}\mathbf{v})^2$$

Where $p = [a\,b\,c\,d]^T$ represents the plane $ax + by + cz + d = 0$ with $a^2 + b^2 + c^2 = 1$

Error Metric

$$\Delta(v) = \sum_{p \in planes(v)} (p^T v)^2$$

$$= \sum_{p \in planes(v)} (p^T v)^T (p^T v)$$

$$= \sum_{p \in planes(v)} (v^T p)(p^T v)$$

$$= \sum_{p \in planes(v)} v^T (pp^T) v$$

$$= v^T \left(\sum_{p \in planes(v)} (pp^T) \right) v$$

Error Metric

$$\Delta(v) = v^T \left(\sum_{p \in planes(v)} (pp^T) \right) v$$

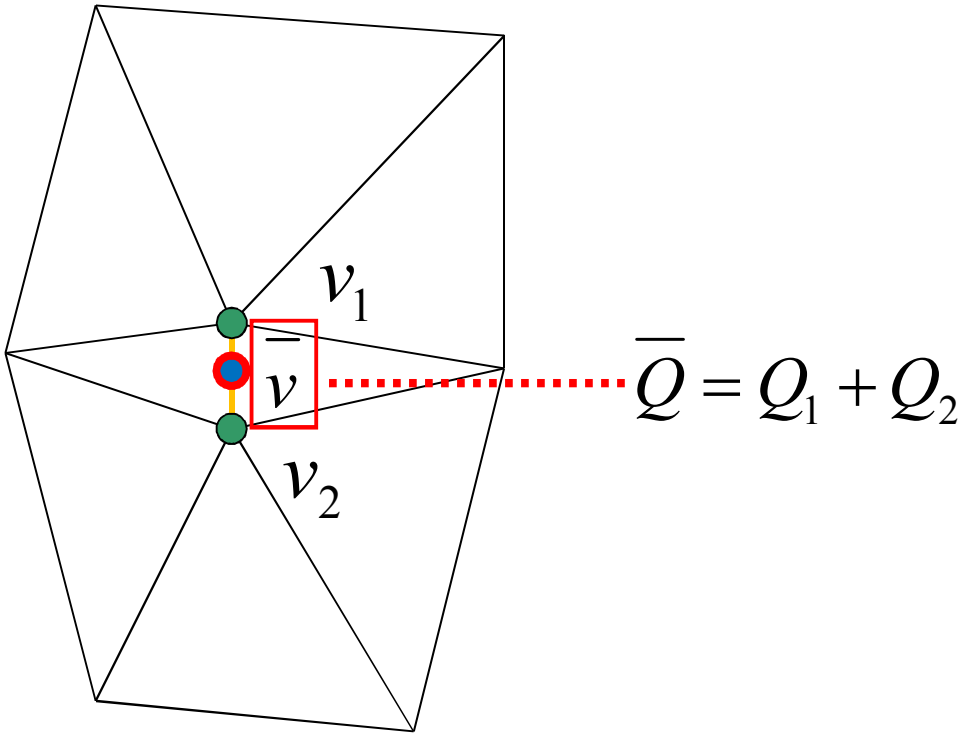
$$= v^T \left(\sum_{p \in planes(v)} K_p \right) v$$

$$\text{Where } K_p = pp^T = \begin{bmatrix} a^2 & ab & ac & ad \\ ba & b^2 & bc & bd \\ ac & bc & c^2 & cd \\ ad & bd & cd & d^2 \end{bmatrix}$$

The Kp can be used to find the squared distance of any point in space to the p.
We can sum these Kp and represent an entire set of planes by a single matrix **Q.**

Error Metric

- For each vertex v_i store a 4x4 matrix Q_i
- For a edge $(v_1, v_2) \rightarrow \bar{v}, \text{let } \bar{Q} = Q_1 + Q_2$



Where is $\bar{v}$?

- Simple scheme

  v_1 or v_2

  $(v_1 + v_2)/2$

- $\bar{v}$ which minimizes $\Delta(\bar{v})$

More on Quadrics

$$v_h = \begin{bmatrix} v_x & v_y & v_z & 1 \end{bmatrix}^T, p = \begin{bmatrix} a & b & c & d \end{bmatrix}^T$$

$$\begin{aligned} D^2(v_h) = (p^T v_h)^2 &= (n^T v + d)^2 \quad where\ n = \begin{bmatrix} a & b & c \end{bmatrix}^T \\ &= (v^T n + d)(n^T v + d) \\ &= (v^T n n^T v + 2dn^T v + d^2) \\ &= (v^T (nn^T) v + 2(dn)^T v + d^2) \end{aligned}$$

$$X = nn^T = \begin{bmatrix} a^2 & ab & ac \\ ba & b^2 & bc \\ ac & bc & c^2 \end{bmatrix} \quad y = dn = \begin{bmatrix} da & db & dc \end{bmatrix}^T \quad z = d^2$$

More on Quadrics

$$Q = \begin{bmatrix} a^2 & ab & ac & ad \\ ba & b^2 & bc & bd \\ ac & bc & c^2 & cd \\ ad & bd & cd & d^2 \end{bmatrix} = Q(X, y, z)$$

$$X = nn^T = \begin{bmatrix} a^2 & ab & ac \\ ba & b^2 & bc \\ ac & bc & c^2 \end{bmatrix} \quad y = dn = \begin{bmatrix} da & db & dc \end{bmatrix}^T \quad z = d^2$$

$$\Delta(v) = v^T Q v = v^T X v + 2 y^T v + z$$

Optimum $\bar{v}$

$$\text{specify minimum } \Delta(\bar{v}) \rightarrow \nabla(\Delta(\bar{v})) = 0$$

$$\nabla(\Delta(\bar{v})) = 2X\bar{v} + 2y$$

$$2X\bar{v} + 2y = 0 \Rightarrow \bar{v} = -X^{-1}y$$

The associated minimum error is :

$$\Delta(\bar{v}) = y^T\bar{v} + z = -y^T X^{-1}y + z$$

Algorithm

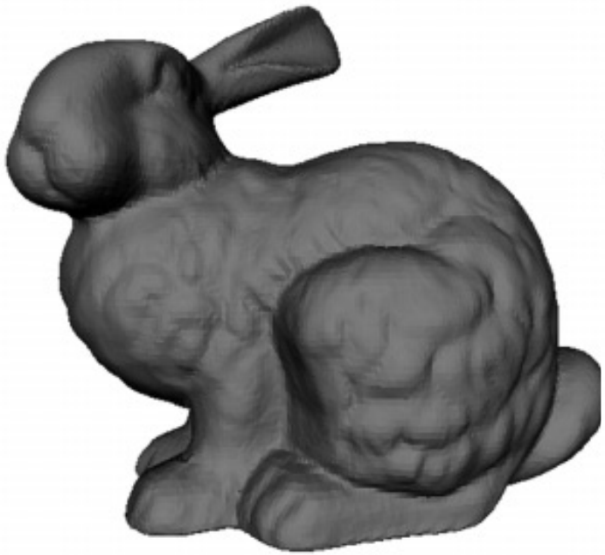
1. Compute initial Q_i for all vertices

2. Compute v_i and $\overline{Q}$ for all edges

3. Search the edge with least error,
   Remove the edge,
   and Update errors around the edge

4. Iteratively do 3

Results

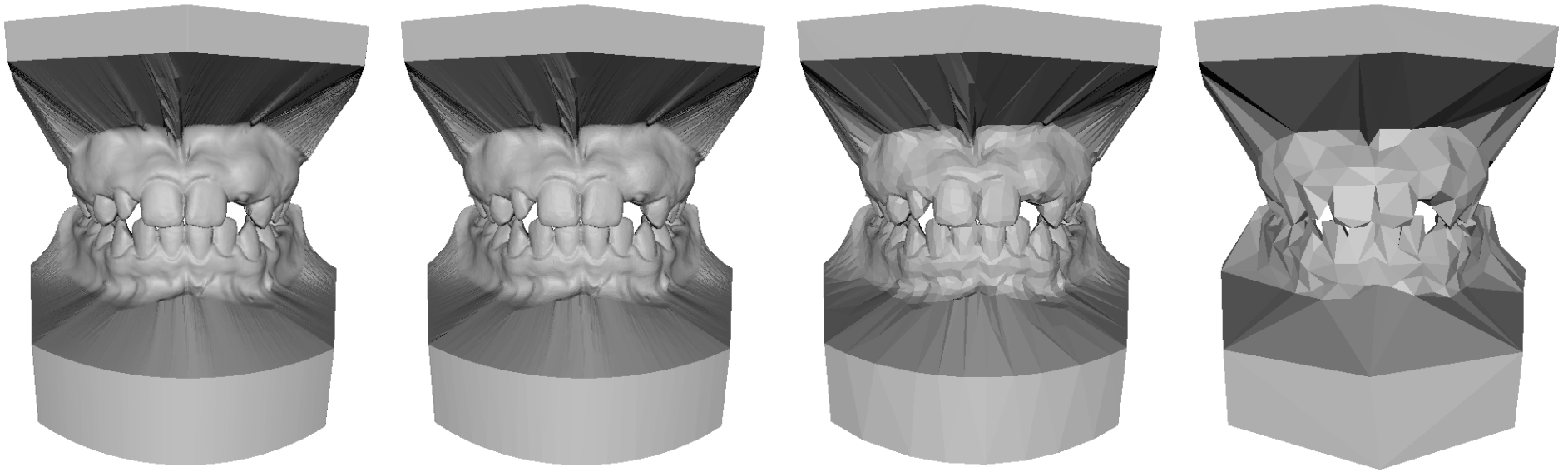


69,451

1000

100

Results



424,376 60,000 8,000 1,000

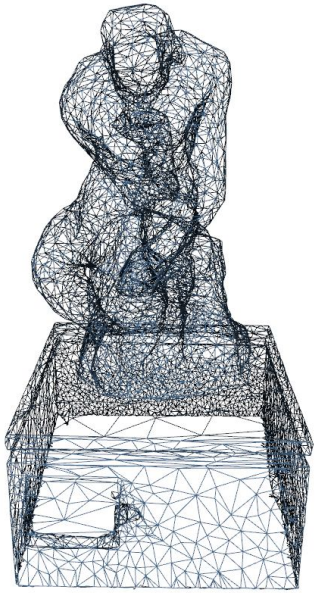
Summary of QEM

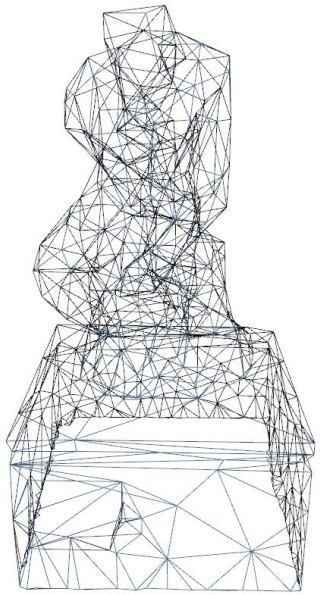
- Simplification using quadric error metric
  - High approximation
  - High efficiency

- QSlim
  - ┬http://mgarland.org/software/qslim.html

Difficulty in fixed level LOD

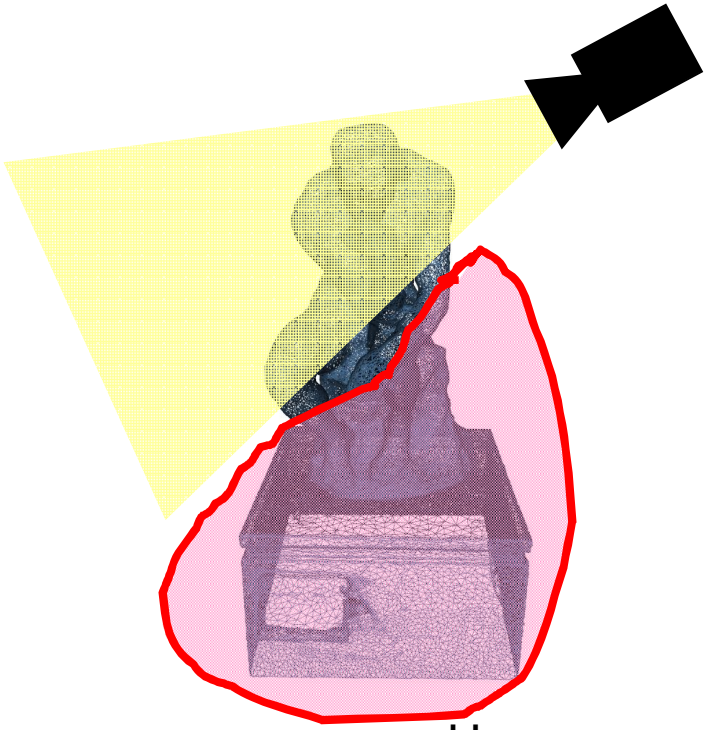
- Transition of resolution is not smooth





Difficulty in fixed level LOD

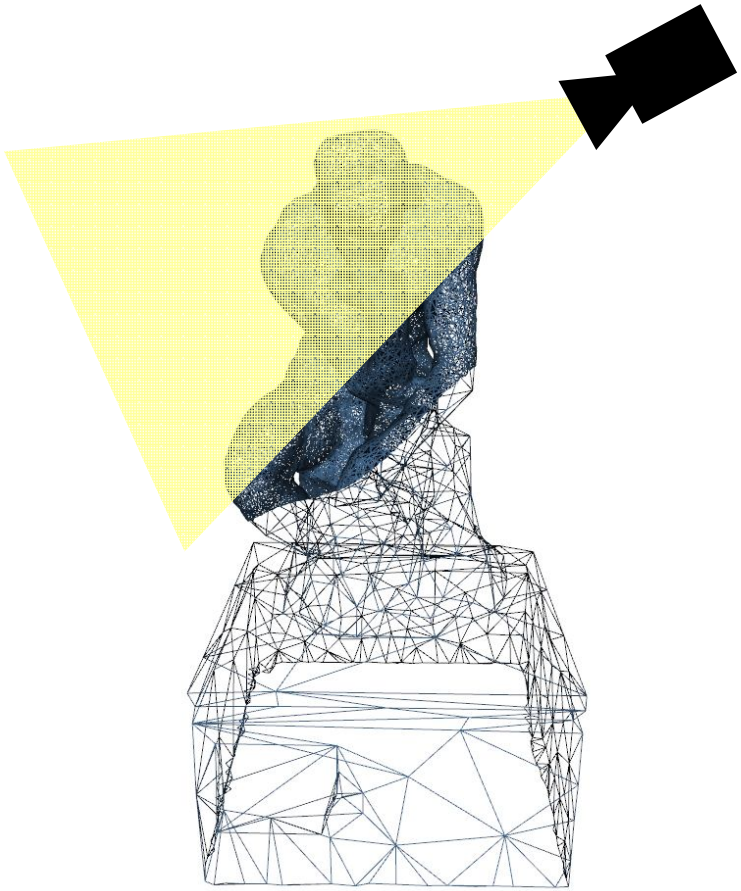
- Too fine triangles outside screen must be rendered when the camera is near-side.



Unnecessary parts

Solution

- Smooth, and partial LOD control

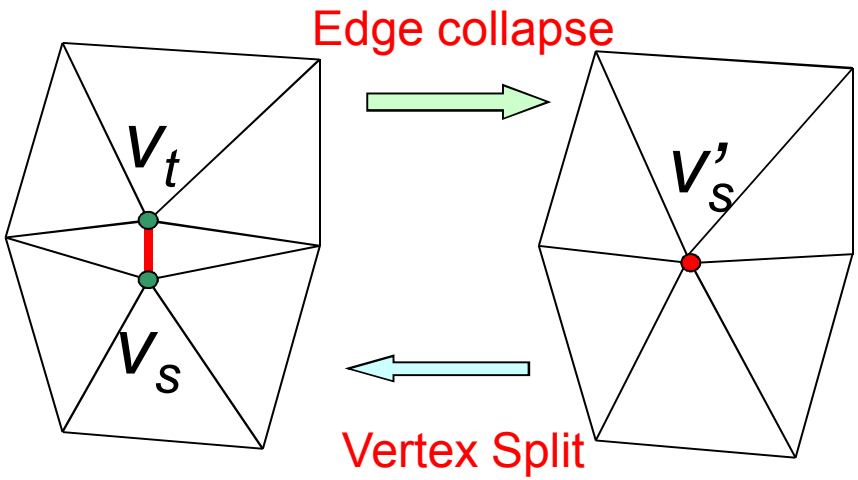


Progressive Meshes [Hoppe96]

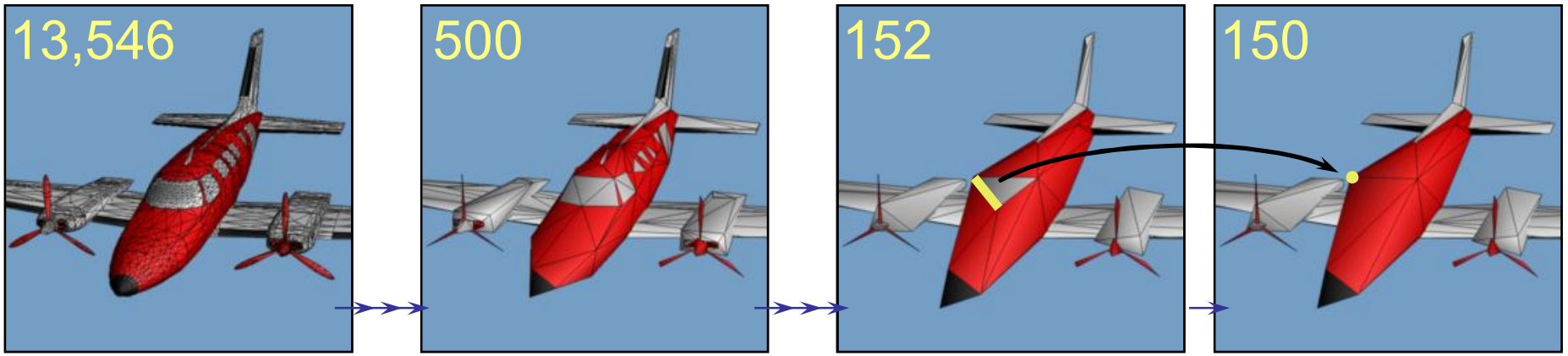
- Simplification method
  - Lossless
  - Continuous resolution
  - Progressive
  - Using edge collapse and vertex split

Recording the sequence of edge collapses

$ecol(v_s, v_t, \mathbf{v'_s})$



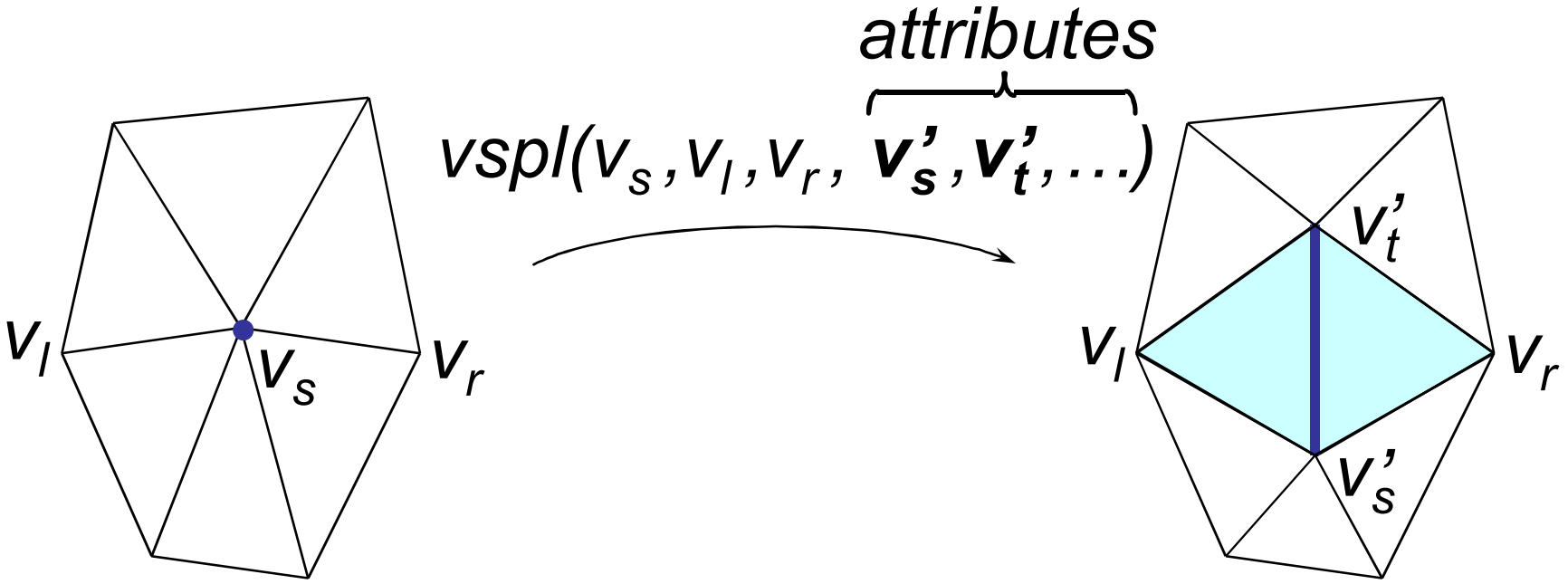
Recording the sequence of edge collapses



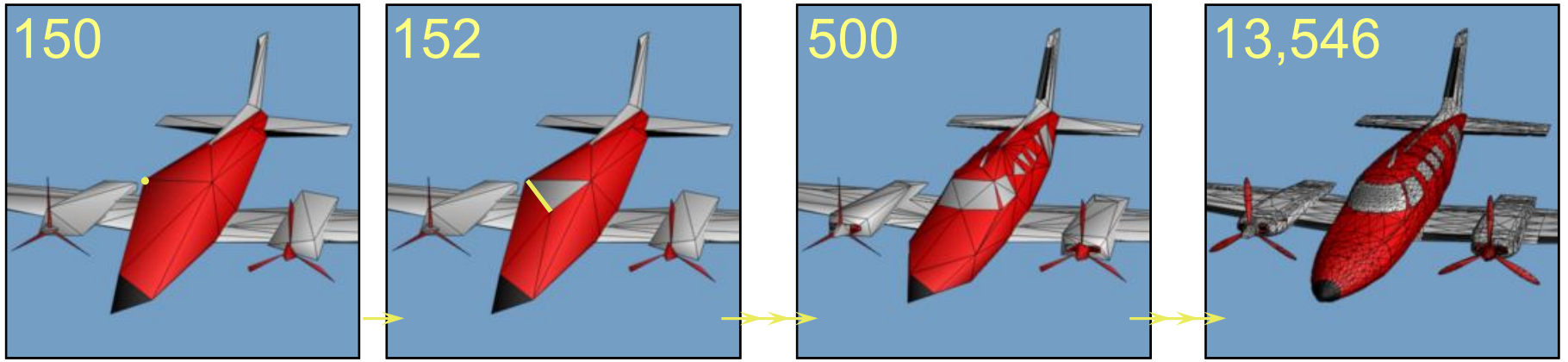
$\hat{M}=M^n \xrightarrow{ecol_{n-1}} \cdots \xrightarrow{} M^{175} \cdots \xrightarrow{ecol_i} M^1 \xrightarrow{ecol_0} M^0$

Edge collapse is invertible

Vertex split transformation:



Reconstruction process

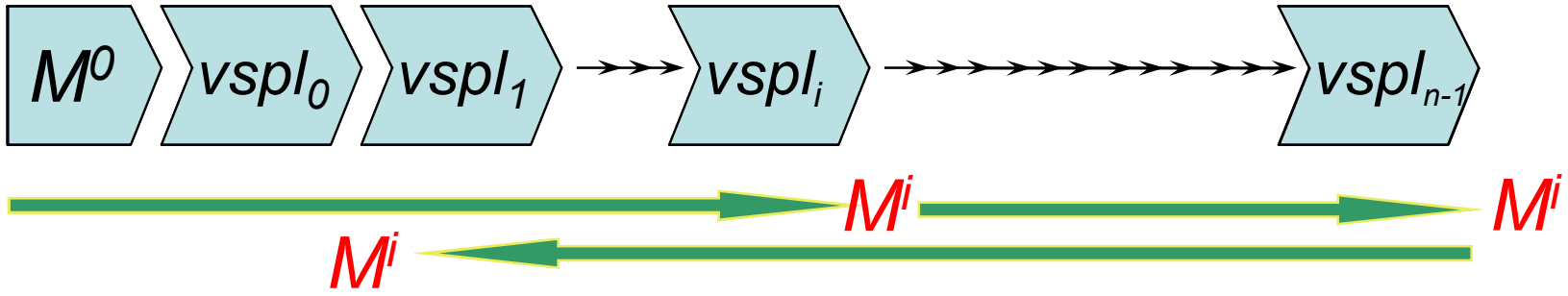


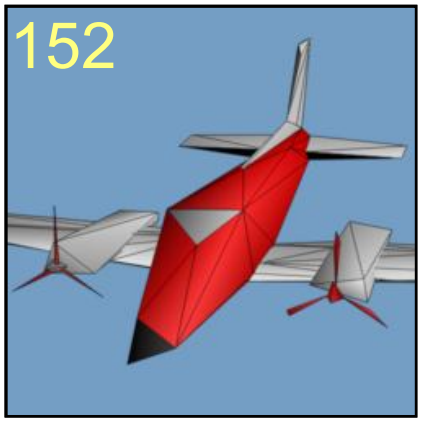
$M^0 \longrightarrow M^1 \longrightarrow \cdots \longrightarrow M^{175} \cdots \longrightarrow M^n = \hat{M}$

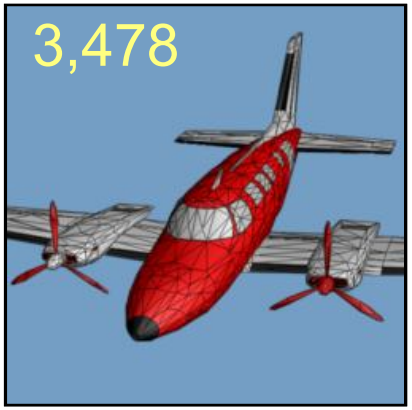
$vspl_0 \quad \ldots \quad vspl_i \quad \ldots \quad vspl_{n-1}$

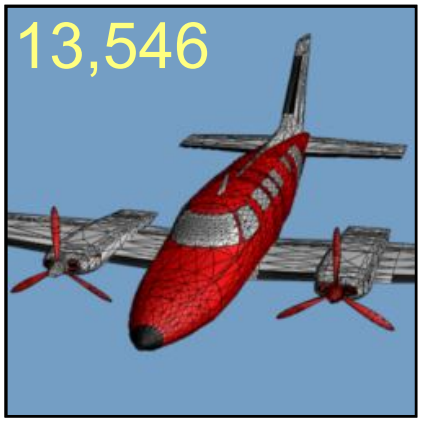
progressive mesh (PM) representation

Continuous LOD

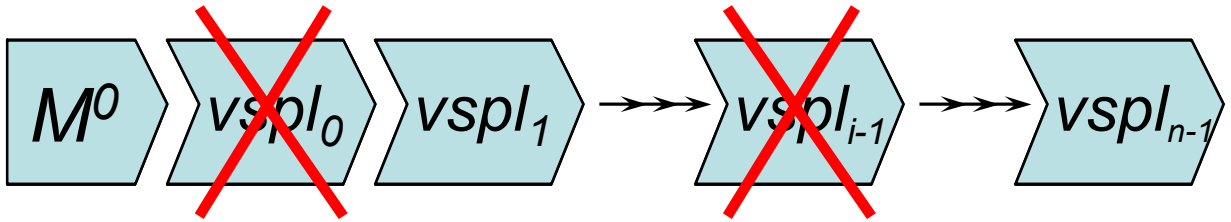


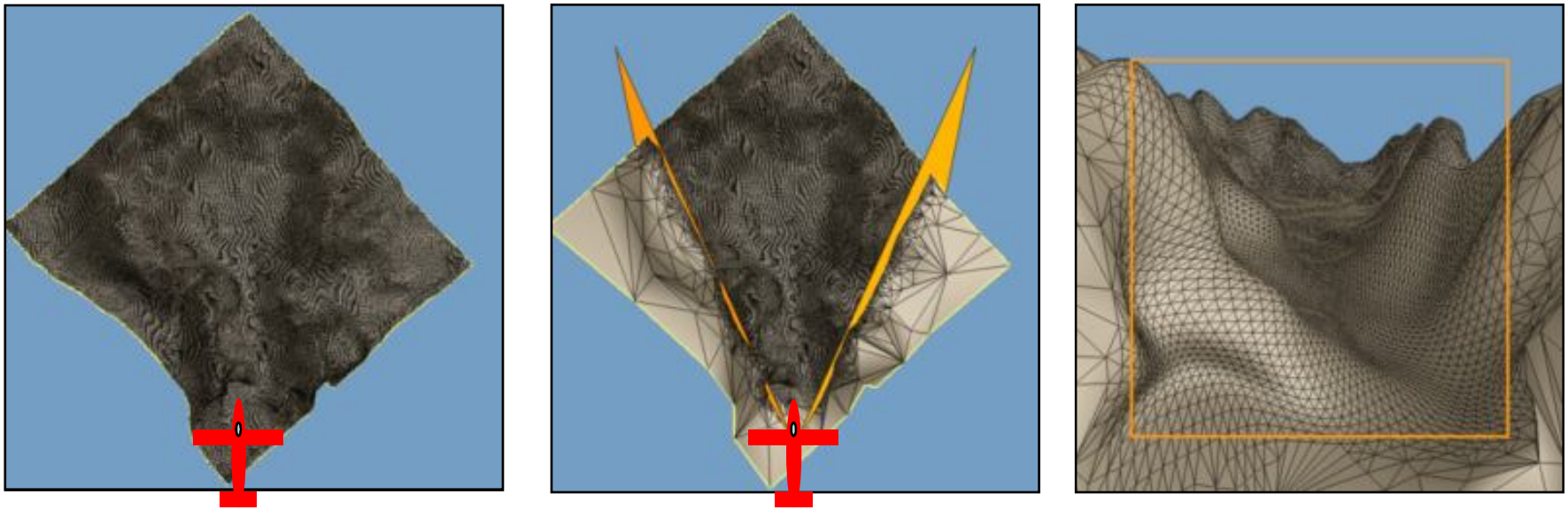




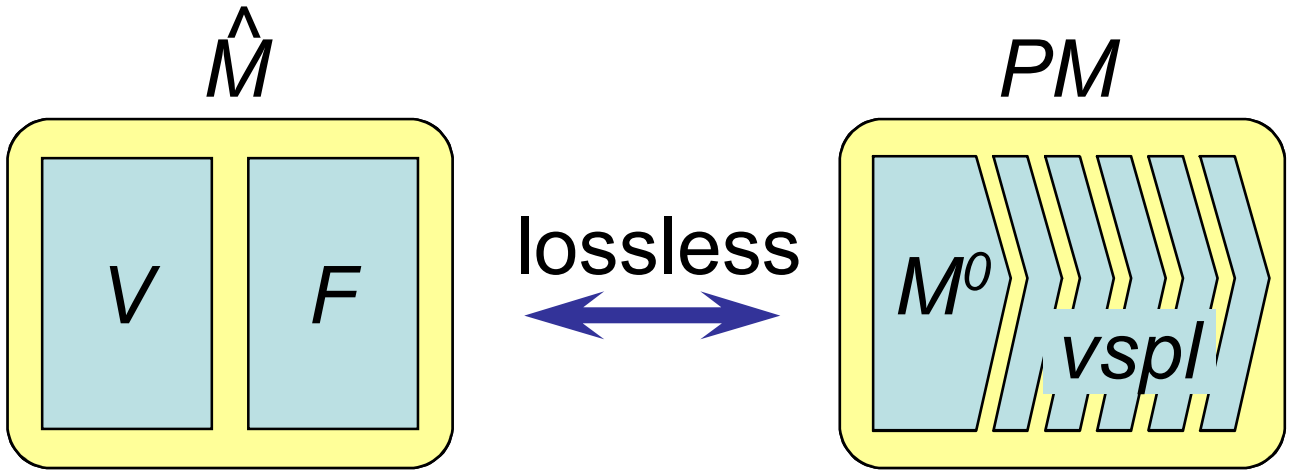


Selective refinement





Summary of PM

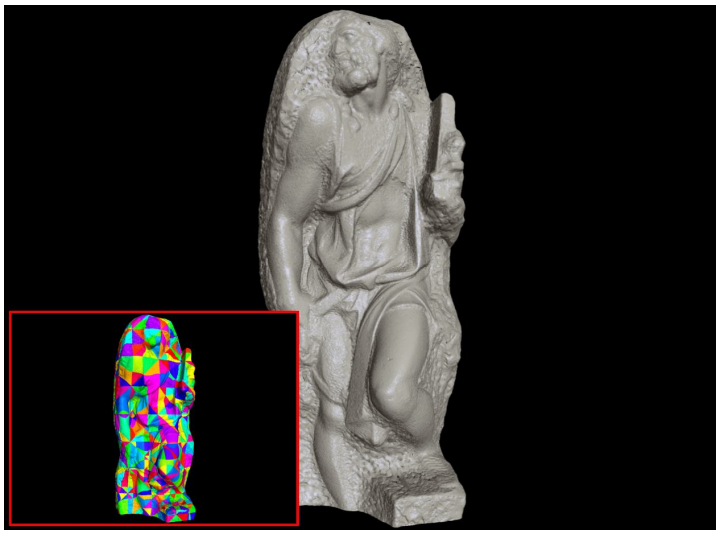


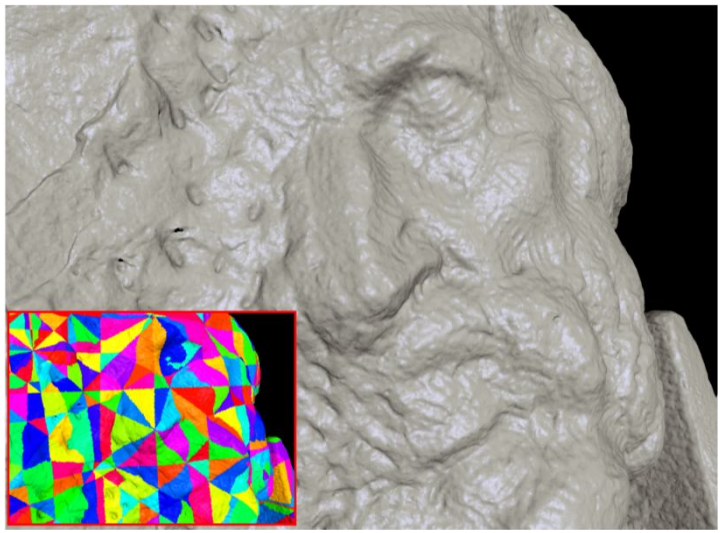
- single resolution

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

Adaptive Tetrapuzzles [Cignoni 04]

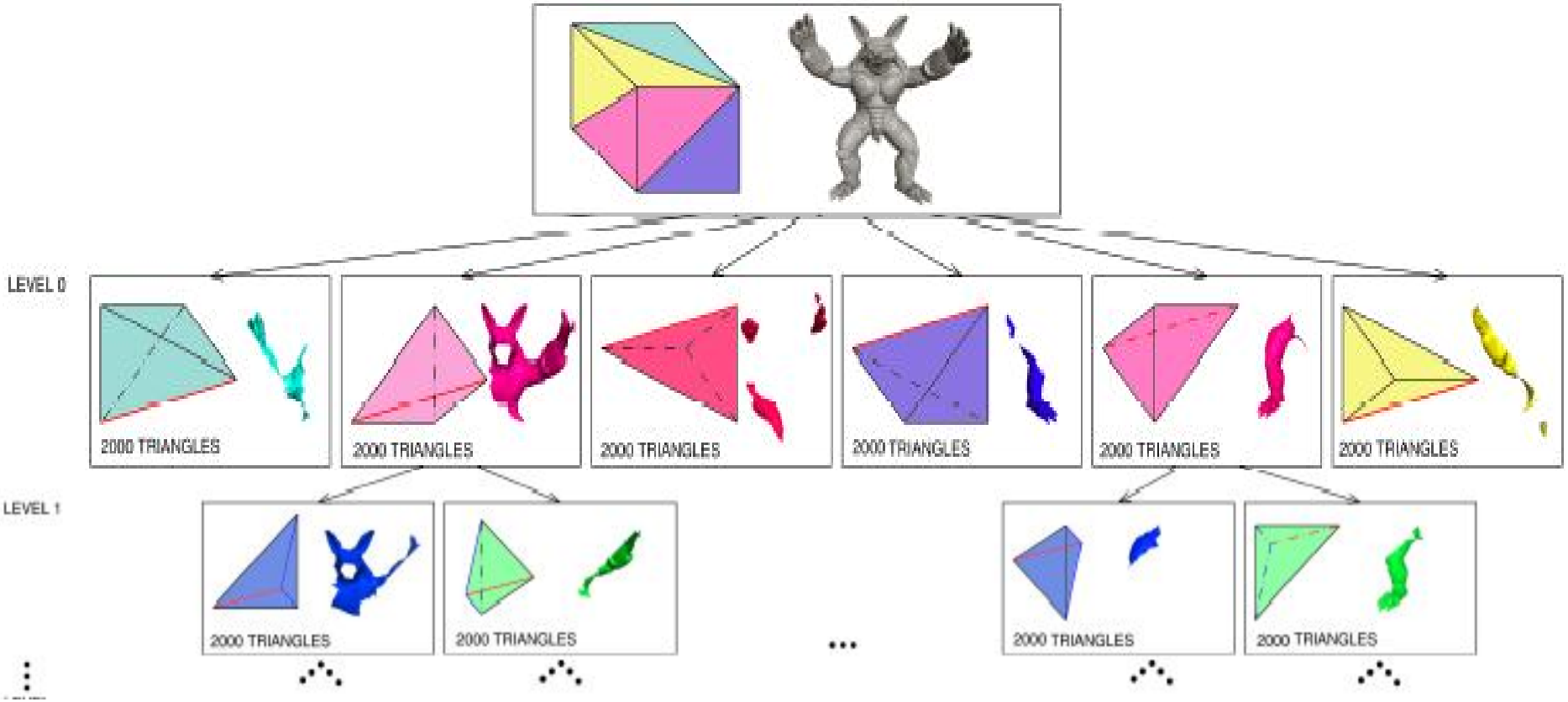
- Patch based LOD method
  - Not triangle based
    - Can reduce the cost of refine and simplification



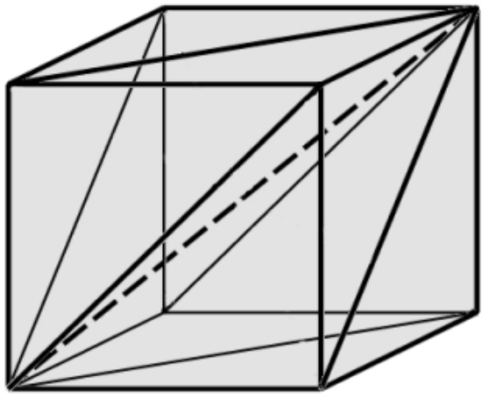


Multiresolution structure

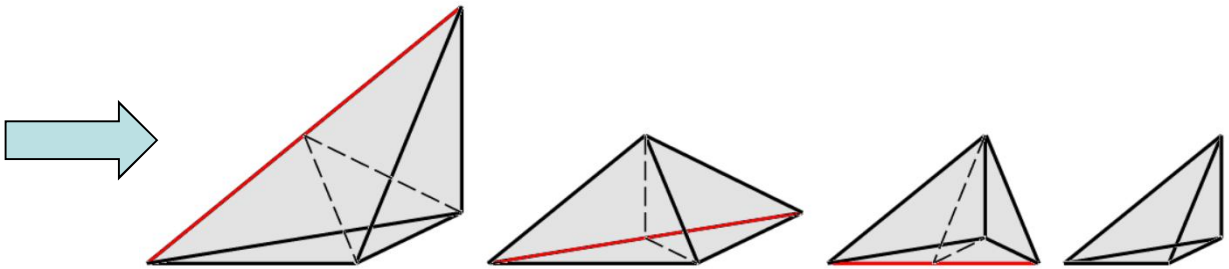
- Recursive volumetric subdivision by tetrahedra



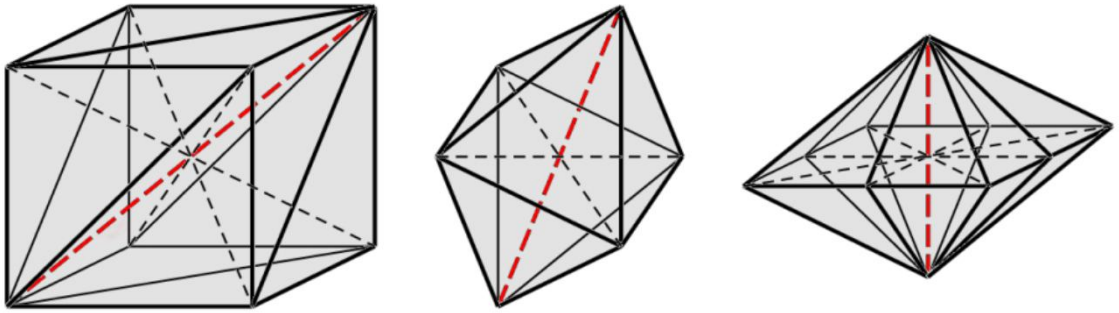
Tetrahedral partitioning



Initial partition



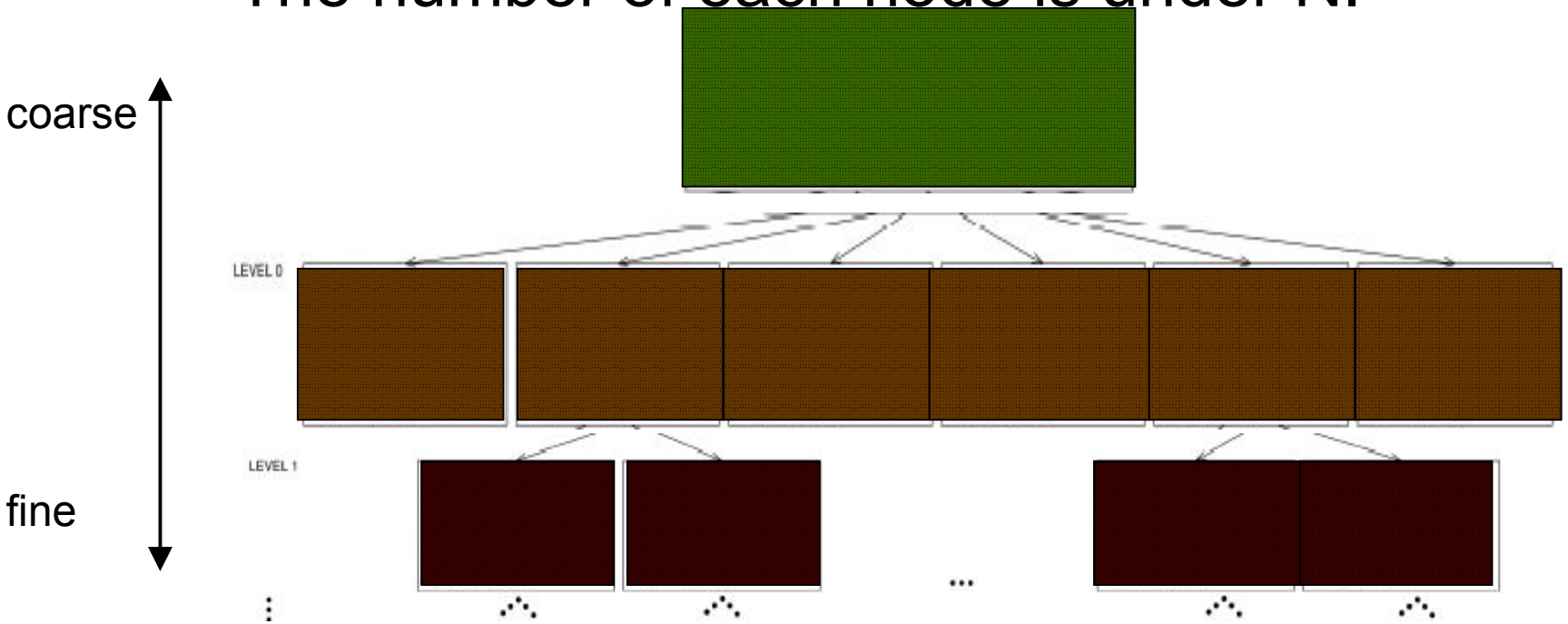
Split at the midpoint of the longest edge



Refining and coarsening based on a diamond

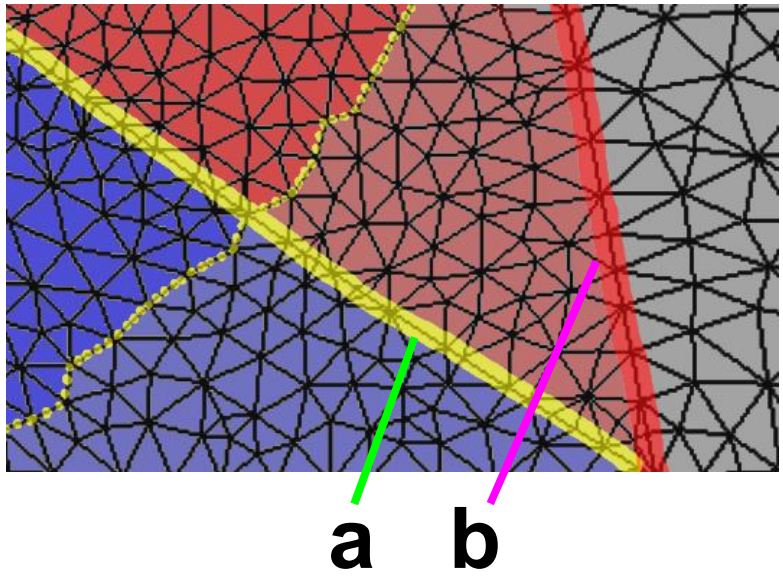
Simplification

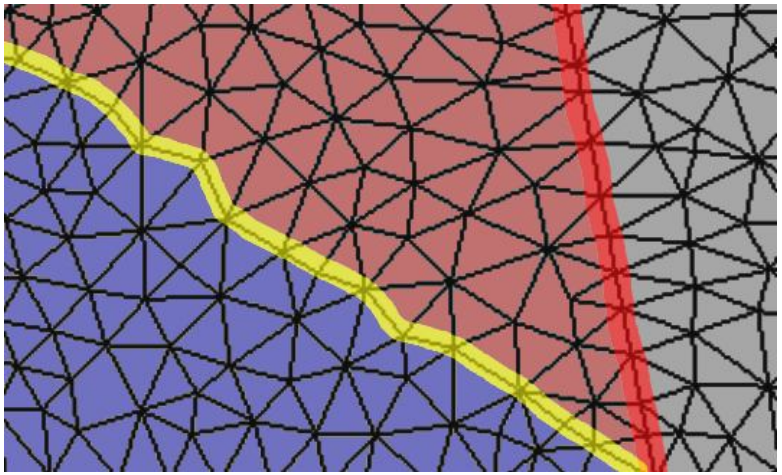
- Simplification in bottom up order after recursive partitioning
- Simplification using quadric error metrics
  - The number of each node is under N.



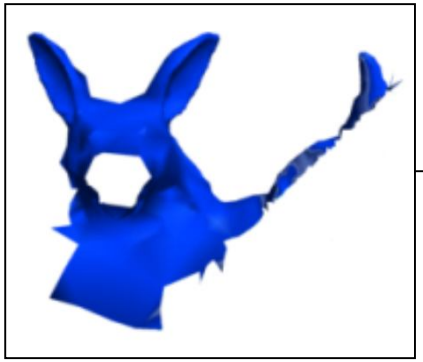
Constraint in simplification

- Constrains simplification on borders
  a. Diamond-internal borders
  b. Diamond-external borders
  c. Original borders





Data format



Patch parameters

- Bounding Sphere
  center(x, y, z), radius r
- Normal cone
  axis (nx, ny, nz), width θ
- Simplification error ε
  $\varepsilon = s\sqrt[3]{\varepsilon_q}$ where ε_q is QEM
- Pointer to children

Geometric information

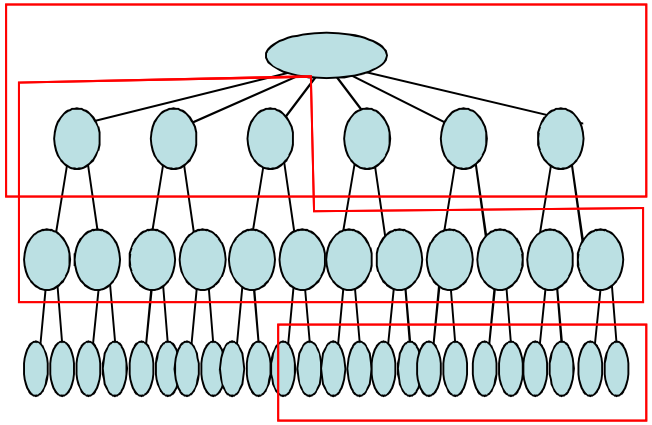
- Vertex array
- Index array

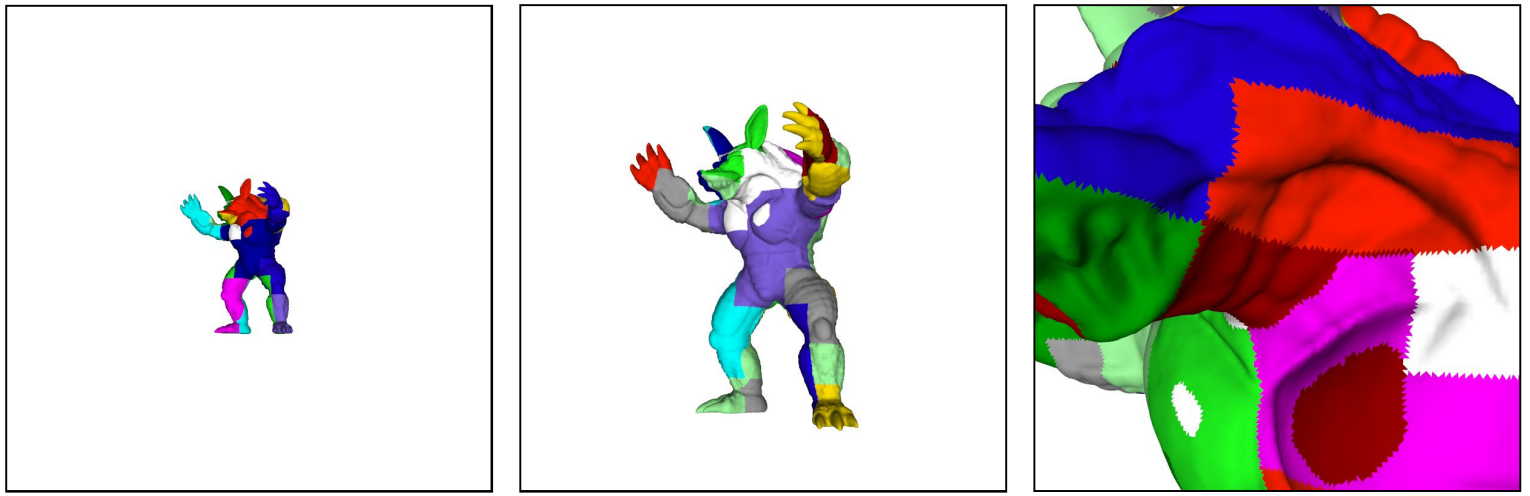
Data format

- Geometric data compression
  - Quantize vertices' parameters
    - Vertex position (px, py, pz) -> 24bit * 3
    - Normal vector (nx, ny, nz) -> 32bit
  - Index parameters
    - Triangle strips compression [Isenburg01]

View-dependent rendering

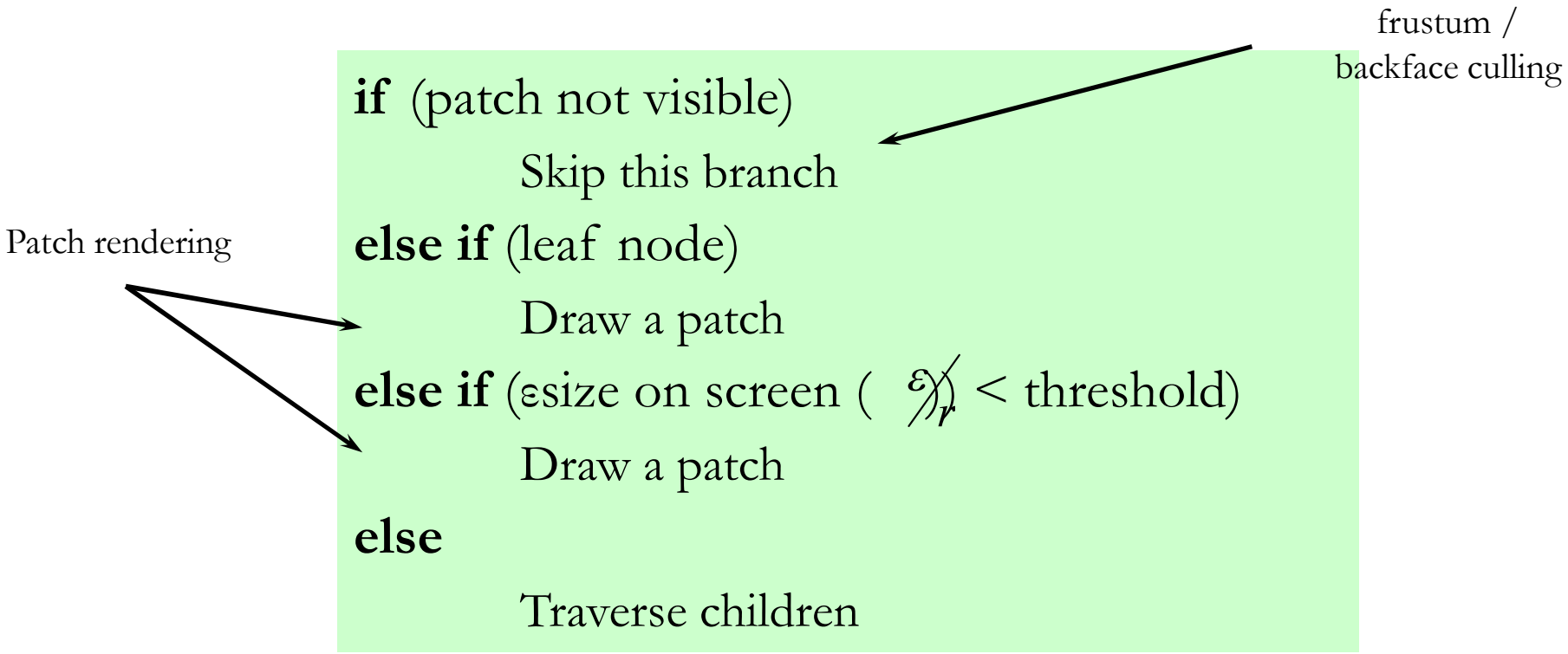
- Traverse, select, and render patches





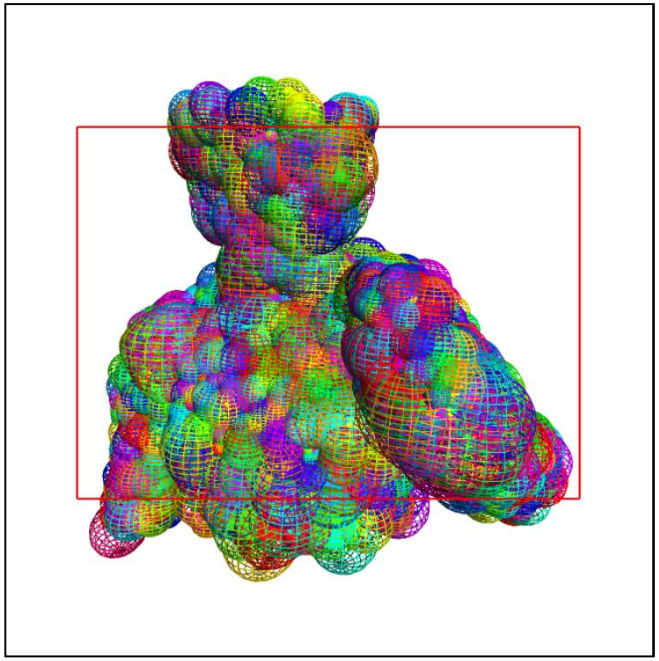
Rendering algorithm

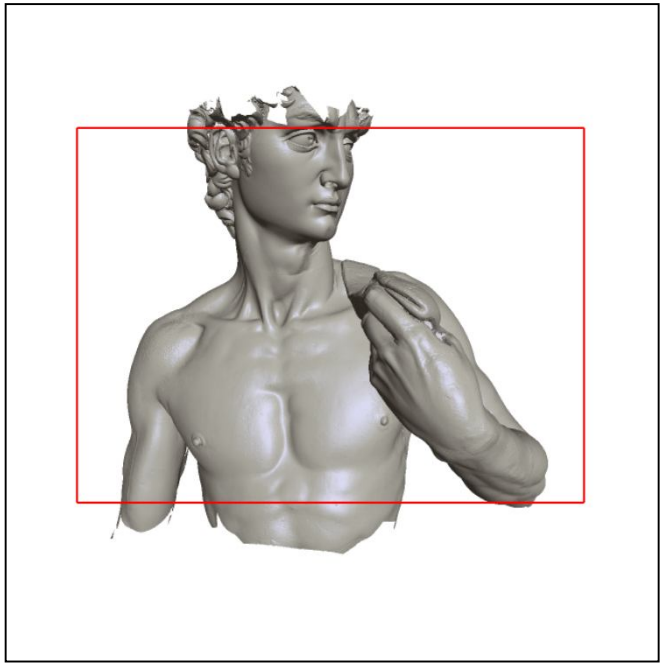
- Traverse hierarchy recursively



Frustum culling

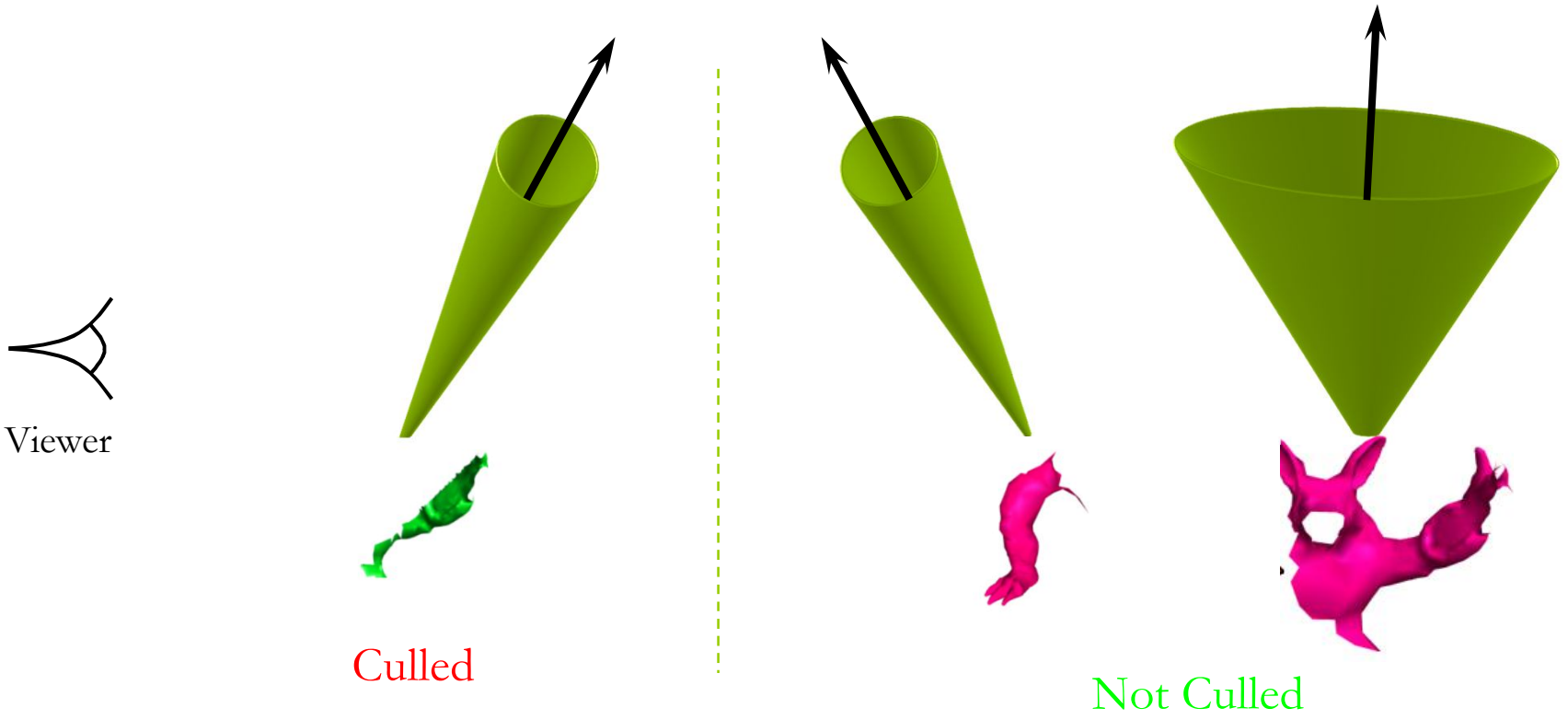
- View-frustum culling
  - If the bounding sphere is out of screen, cull and backtrack.





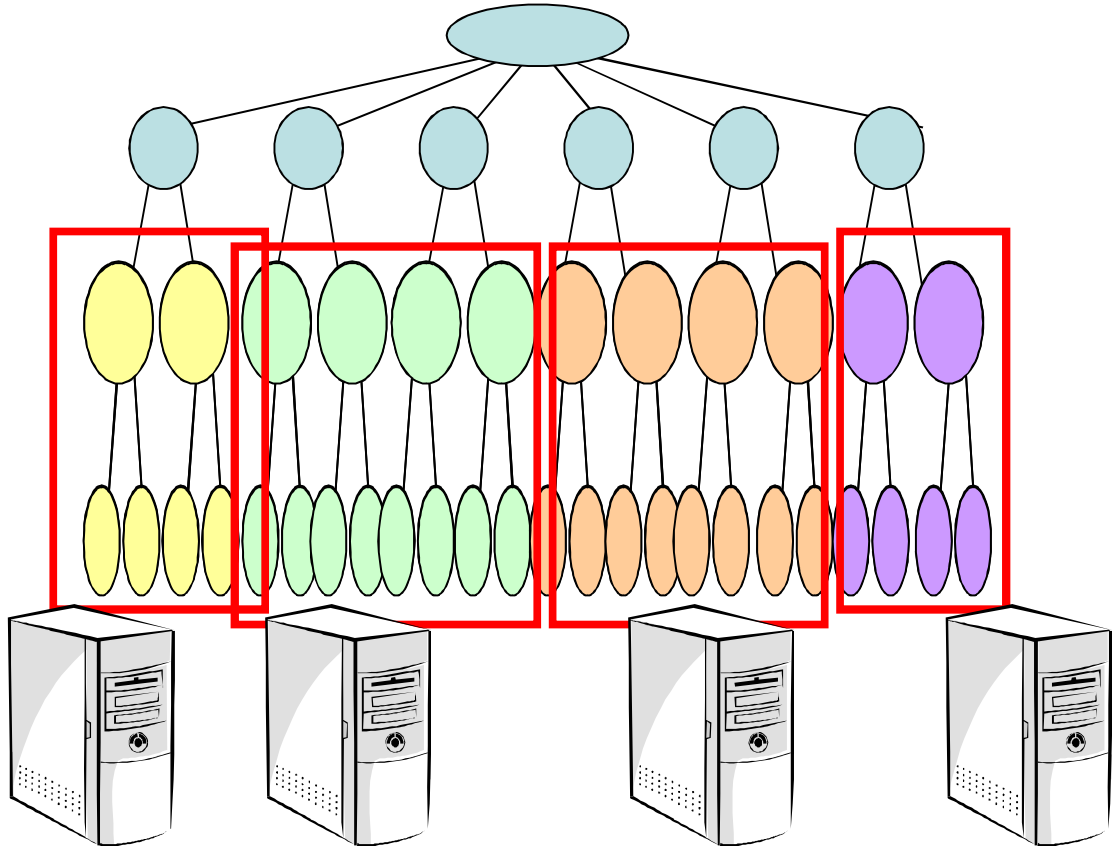
Backface culling

- If the cone faces entirely away from the viewer, cull and backtrack.



Details

- Parallel data construction
  - Partitioning and simplification of subtrees can be done independently

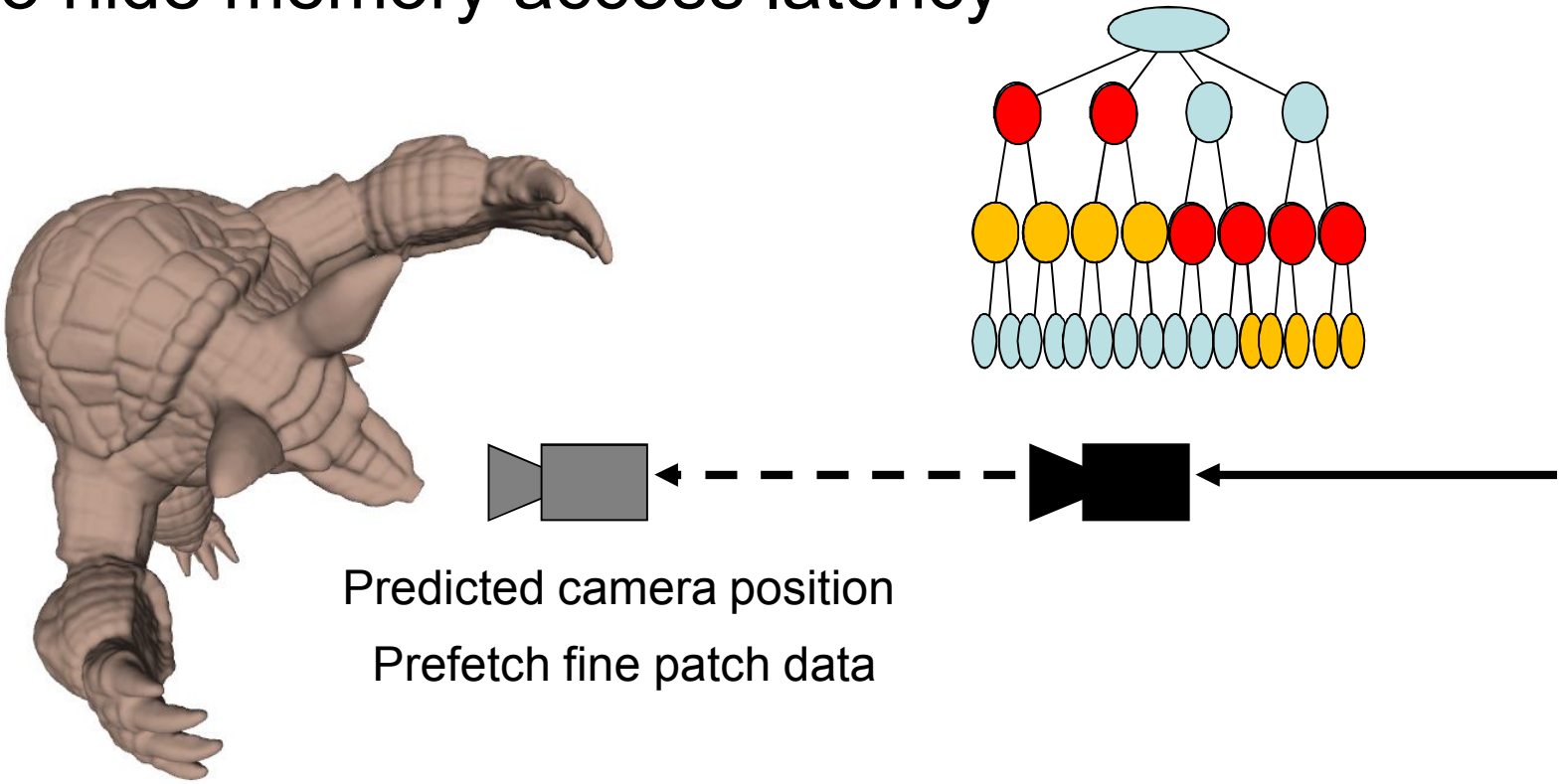


Details

- Memory coherency
  - Write patch data in the depth first order
  - rearrange triangles into the triangle strips
  - Memory management on VRAM
    by LRU strategy

Details

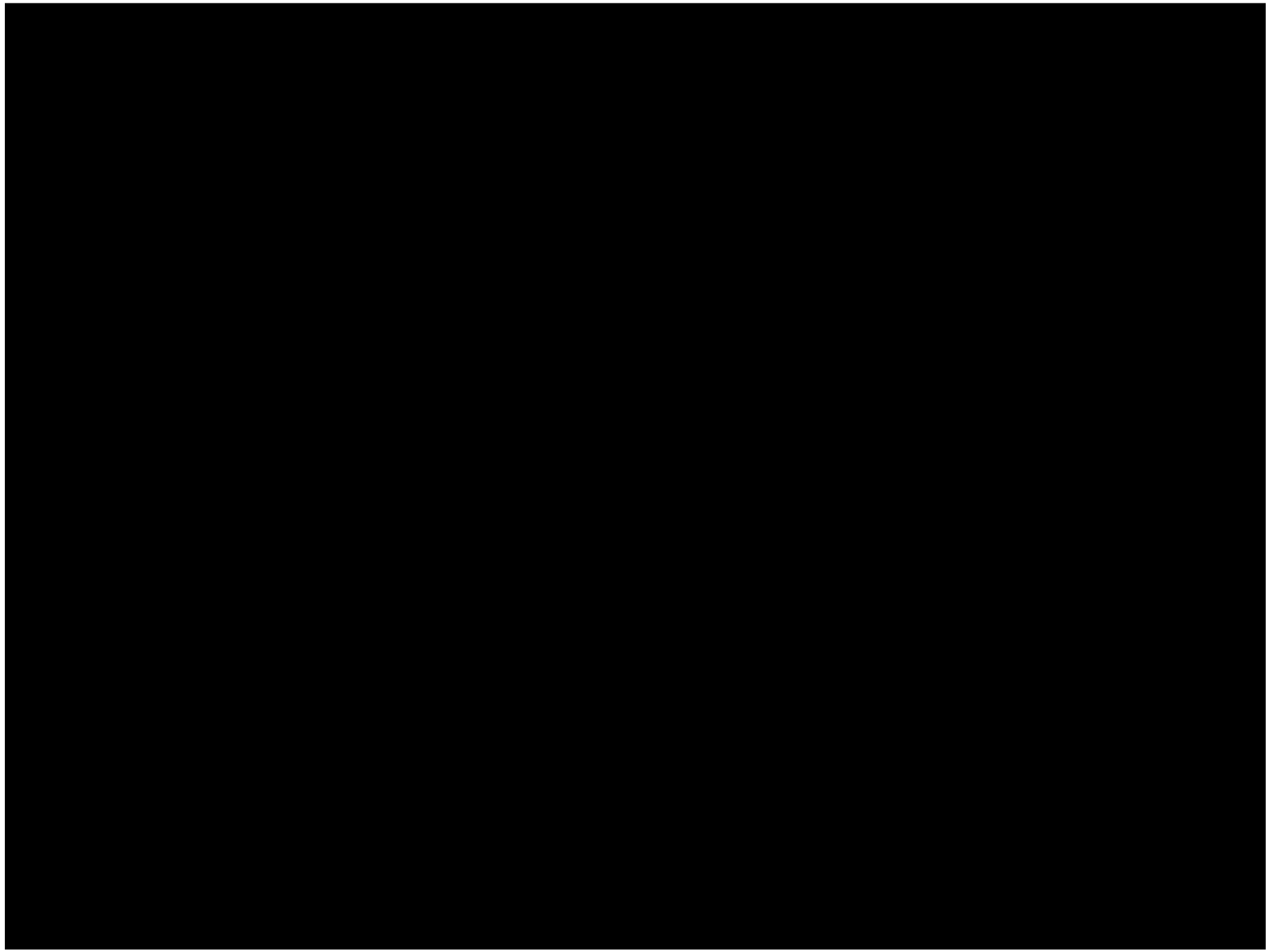
- Speculative prefetching
  - To hide memory access latency



Results

Model	Triangles	CPU	Data construction (sec)	Input size (MB)	Output size
Bonsai	6,317,116	2 15	1,741 219	289	76
David (2mm)	8,277,479	2 15	3,735 426	379	158
David (1mm)	56,230,343	2 15	24,499 3,594	2,574	967
St. Matthew	372,767,445	2 15	92,255 27,790	17,063	5,887

Demonstration video



Summary of ATP

- Patch-based LOD data structure
  - Small size of the hierarchy
  - Good approximation by constraints
  - Parallel data construction
- Some technical tunings
  - Memory coherency
  - Data compression
  - Prefetch

Today's papers

- "Surface Simplification Using Quadric Error Metrics", M. Garland, P. Heckbert, SIGGRAPH97
- "Proggressive Meshes", H. Hoppe, SIGGRAPH96
- "Adaptive TetraPuzzles –Efficient Out-of-Core Construction And Vizualization of Gigantic Polygonal Models", P. Cignoi, et al., SIGGRAPH2004