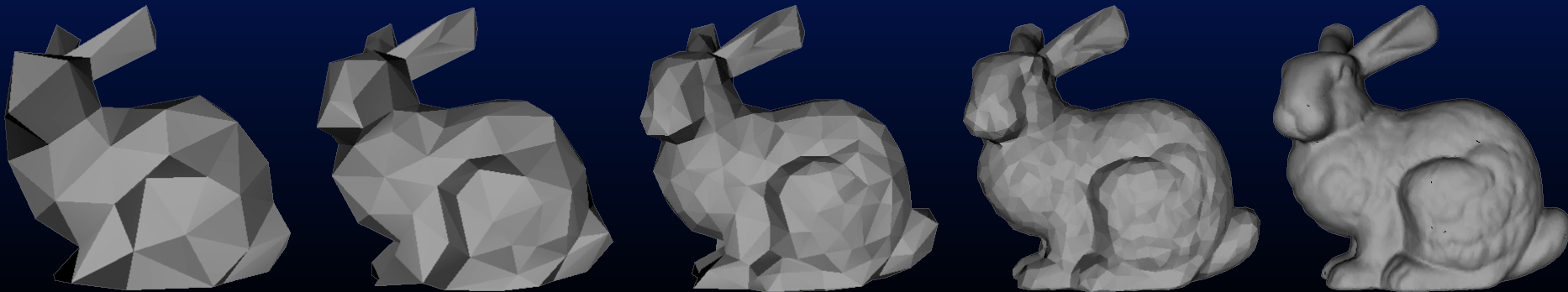


SAN ANTONIO
SIGGRAPH
2002

Terrain Level Of Detail

Martin Reddy





Contents

- Background
 - History, applications, data sizes
- Important Concepts
 - regular grids v TINs, quadtrees v bintrees, out-of-core paging, web streaming
- Implementations
 - Lindstrom 96, Duchaineau 97, Röttger 98, Hoppe 98, DeFloriani 00, Lindstrom 01
- Further resources

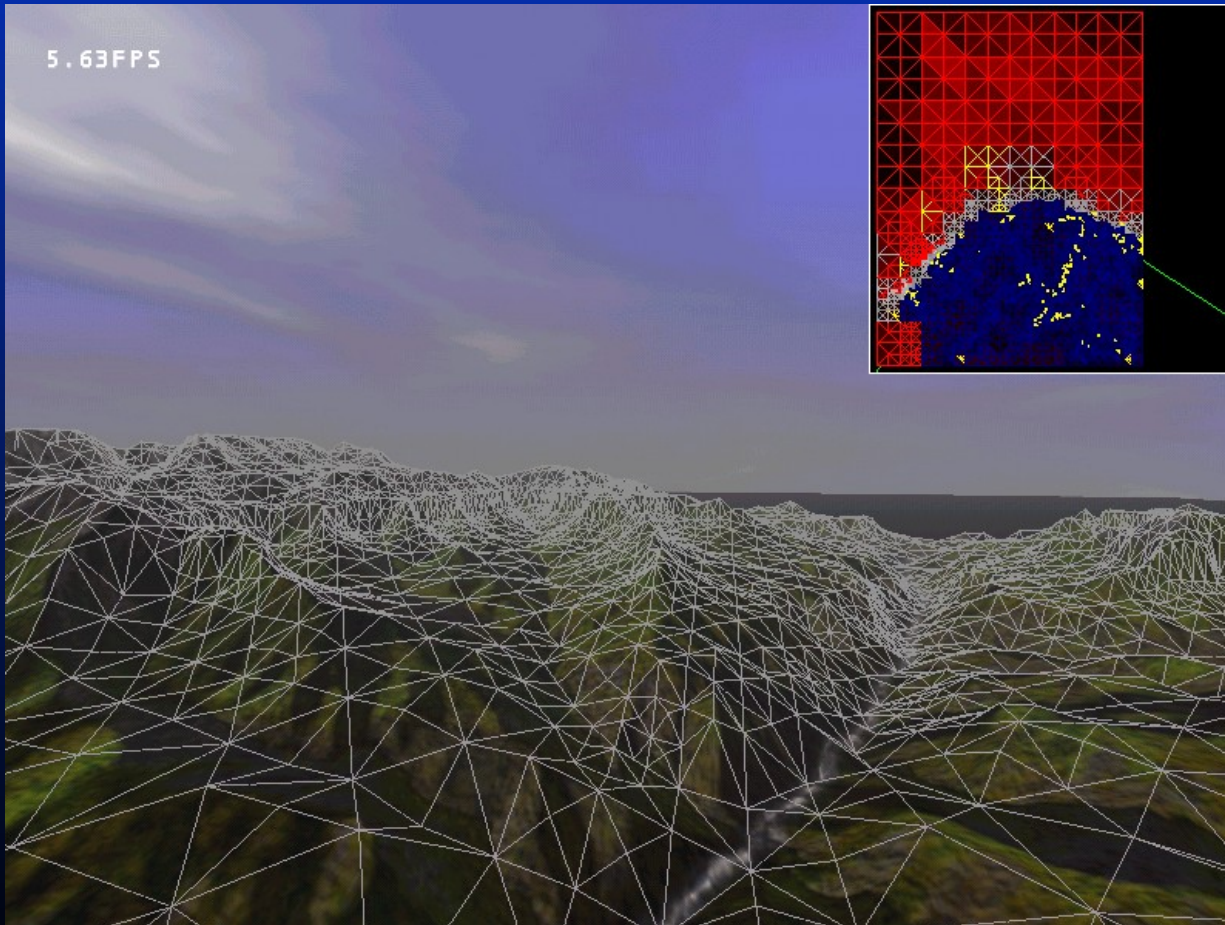


Background

- One of the first real uses of LOD
- Important for applications such as
 - Flight simulators
 - Terrain-based computer games
 - Geographic Information Systems (GIS)
 - Virtual tourism, real-estate, mission planning
- Sustained R&D since the 1970s
- Other terms include
 - *generalization* (GIS)



Terrain LOD Example



Screenshot of the Grand Canyon with debug view using the Digital Dawn Toolkit, now incorporated into Crystal Space



Terrain LOD vs Generic LOD

- Terrain is easier...
 - Geometry is more constrained
 - Normally uniform grids of height values
 - More specialized and simpler algorithms
- Terrain is more difficult...
 - Continuous and very large models
 - Simultaneously very close and far away
 - Often requires paging from disk (out-of-core)
 - Necessitates view-dependent LOD

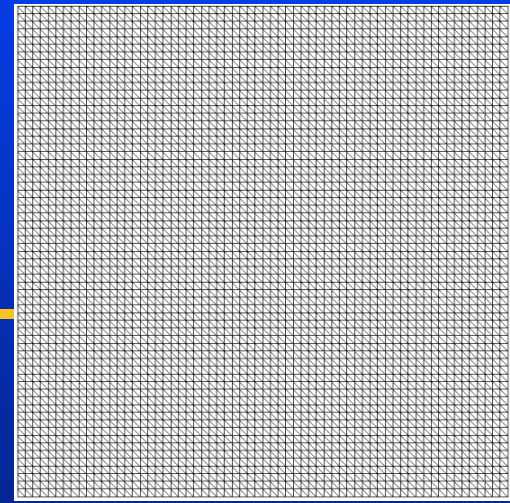


Large Terrain Databases

- USGS GTOPO30
 - 30 arc-second (~1 km) resolution elevation
 - $43,200 \times 21,600 = 1.8$ billion triangles
- NASA EOS satellite ASTER
 - 30-m resolution elevation data
 - from 15-m near infrared stereo imagery
- USGS National Elevation Dataset (NED)
 - 50,000 quads at around 50 GB



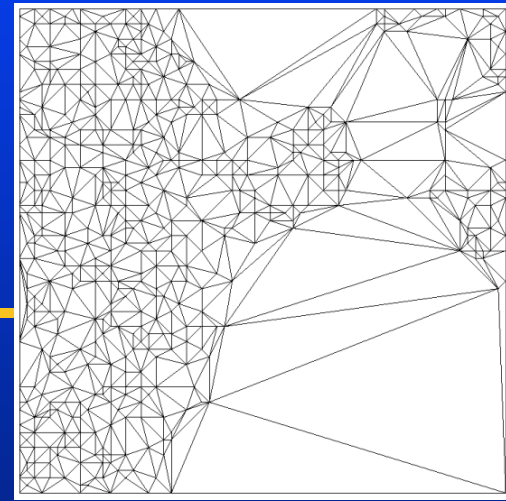
Regular Grids



- Uniform array of height values
- Simple to store and manipulate
- Easy to interpolate to find elevations
- Encode in raster formats (DEM, GeoTIFF)
- Less disk/memory (only store z value)
- Easy view culling and collision detection
- Used by most implementers



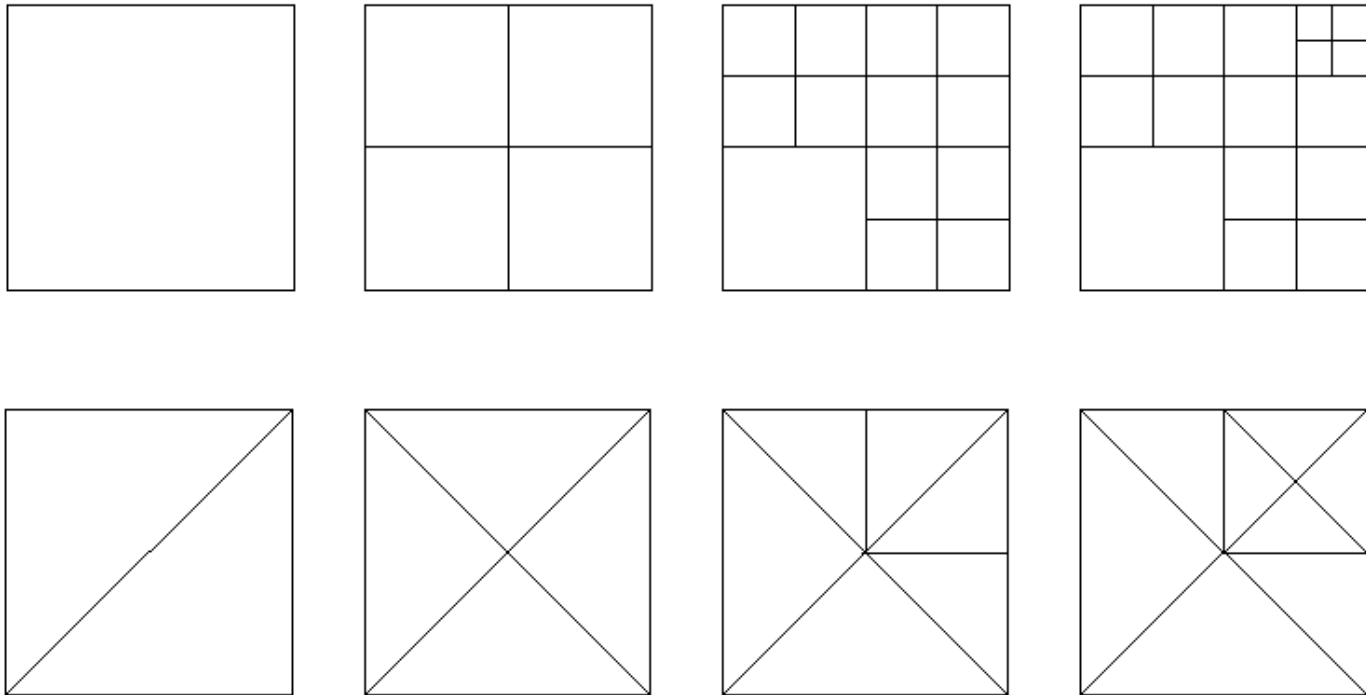
TINs



- Triangulated Irregular Networks
- Fewer polygons needed to attain required accuracy
- Higher sampling in bumpy regions and coarser in flat ones
- Can model maxima, minima, ridges, valleys, overhangs, caves
- Used by Hoppe 98 & DeFloriani 00



Quadtrees and bintrees



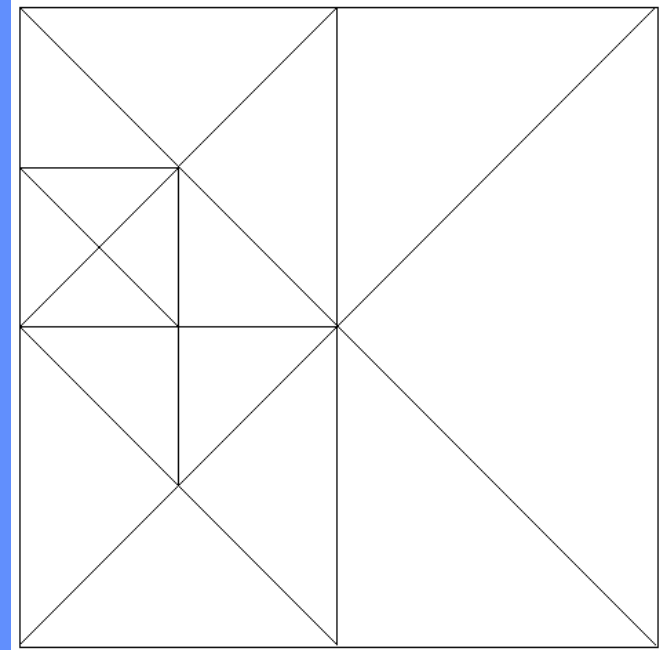
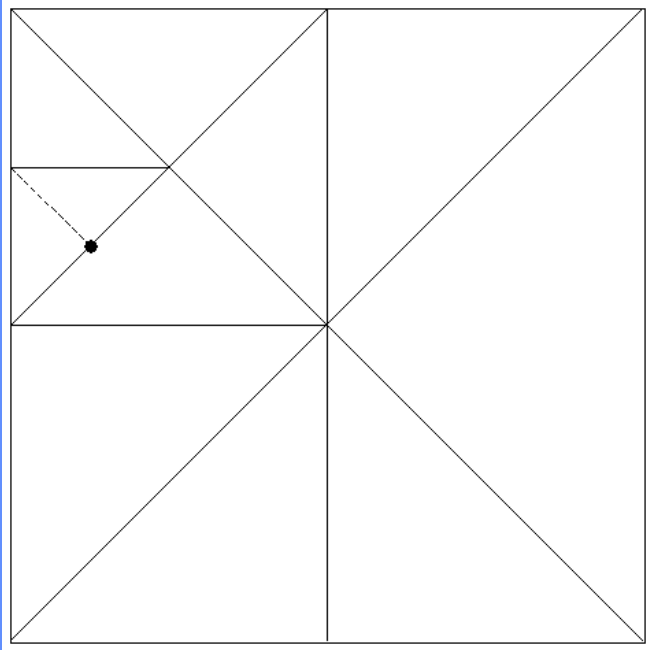


bintrees

- Terminology
 - binary triangle tree (bintree, bintritree, BTT)
 - right triangular irregular networks (RTIN)
 - longest edge bisection
- Easier to avoid cracks and T-junctions
- Neighbor is never more than 1 level away
- Used by Lindstrom 96 & Duchaineau 97



Avoiding T-junctions





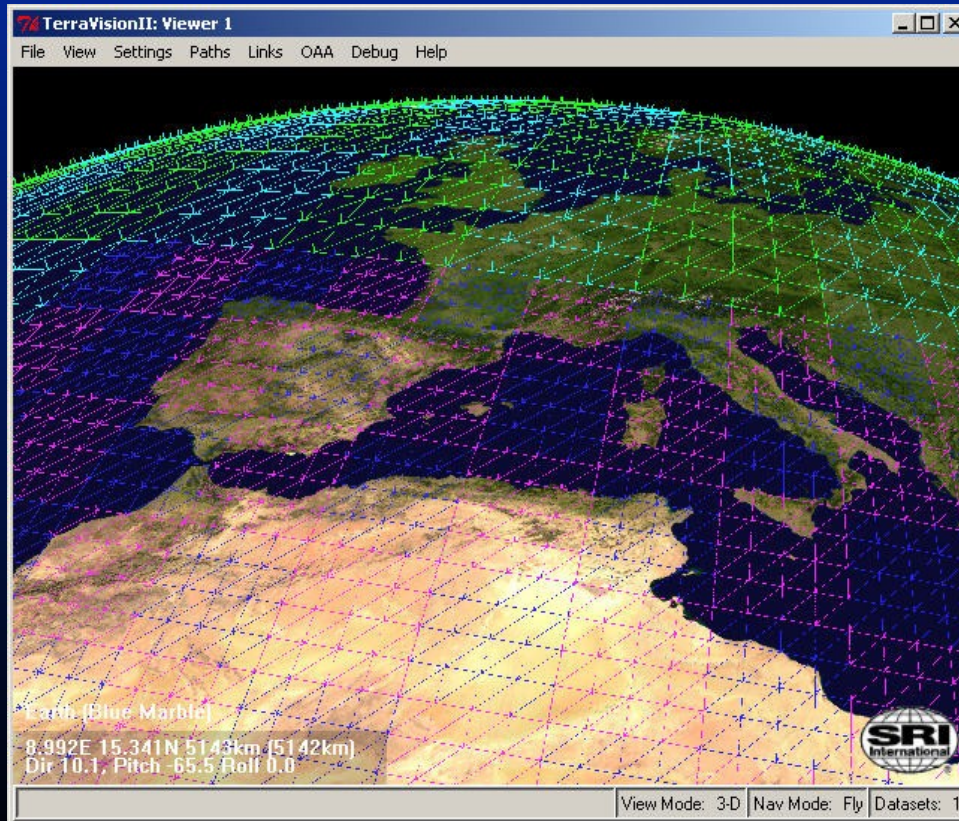
Out-of-core operation

- Virtual memory solutions
 - mmap() used by Lindstrom 01
 - VirtualAlloc() / VirtualFree() used by Hoppe 98
- Explicit paging from disk
 - NPSNET (NPS): Falby 93
 - VGIS (GVU): Davis 99
 - OpenGL Performer Active Surface Def (ASD)
 - SGI InfiniteReality (IR) Clipmapping



Streaming over the Web

- TerraVision (SRI) – Leclerc 94, Reddy 99





Texture issues

- Need to handle paging of imagery as well as geometry (satellite imagery resolution is generally $>$ than elevation resolution)
- Hardware support for paging (clipmaps)
- Detail textures for close-to-ground detail
- Texture compression useful?



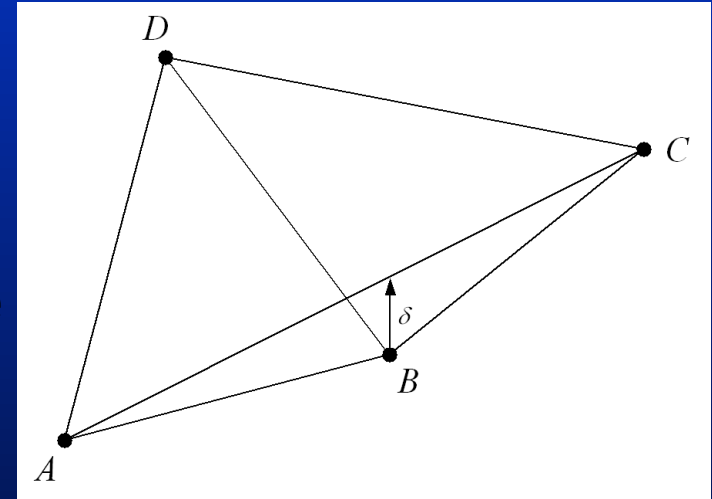
Lindstrom et al. 1996

- One of first real-time continuous LOD (CLOD) algorithms
- Regular grid, bintree, quadtree blocks
 - Mesh broken into rectangular blocks with a top-down coarse-grained simplification
 - Then per-vertex simplification performed within each block
- Frame-to-frame coherence:
 - Maintain an active cut of blocks
 - Only visit vertices if could change in frame



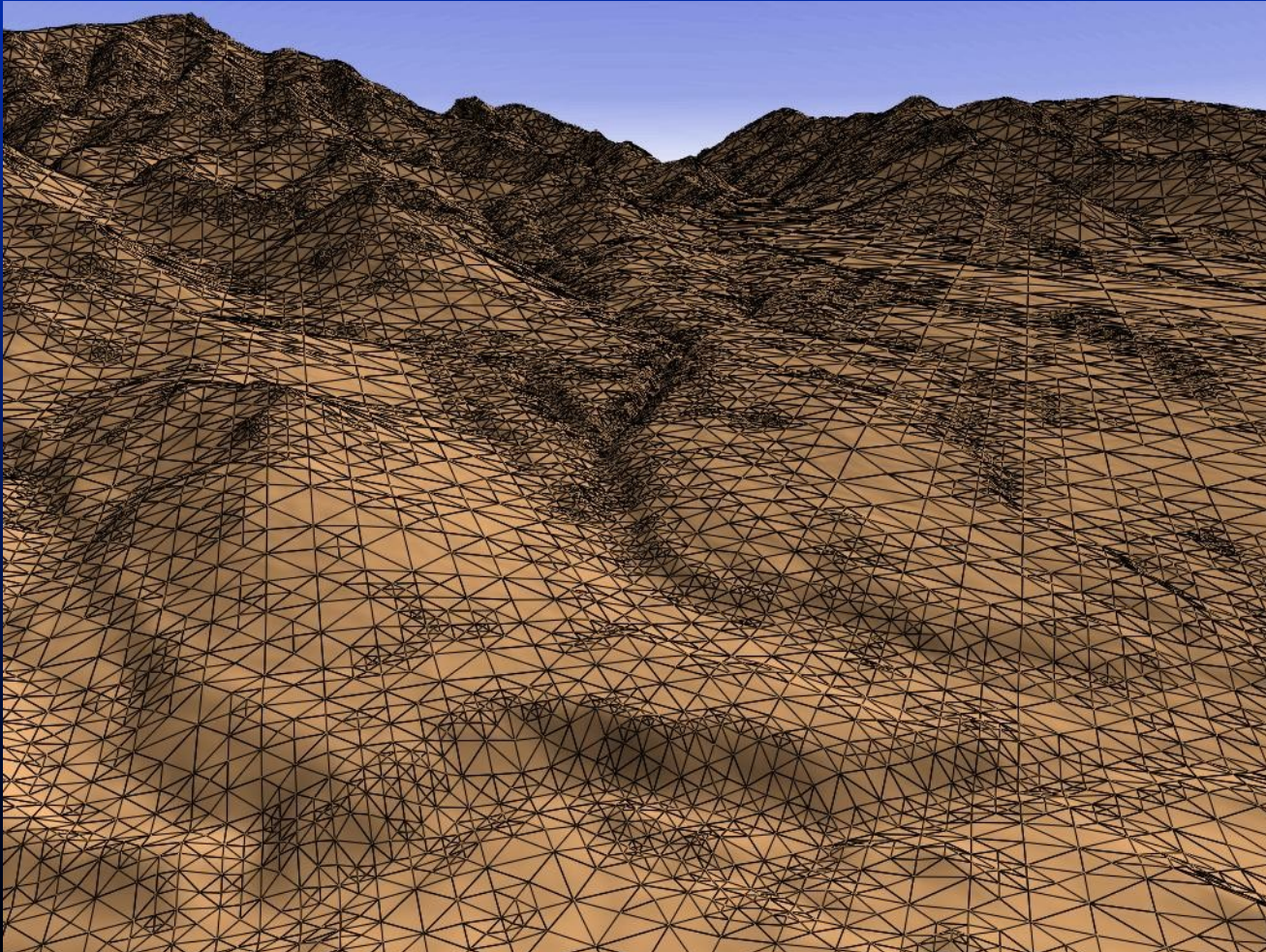
Lindstrom et al. 1996

- Vertex removal scheme
- Merge based upon a measure of screen-space error between the two surfaces, δ
- Used nonlinear mapping of δ to represent 0..65535 in only 8-bits





Lindstrom et al. 1996



Hunter-Liggett
US Army base

2-m res

8 x 8km

32 M polys



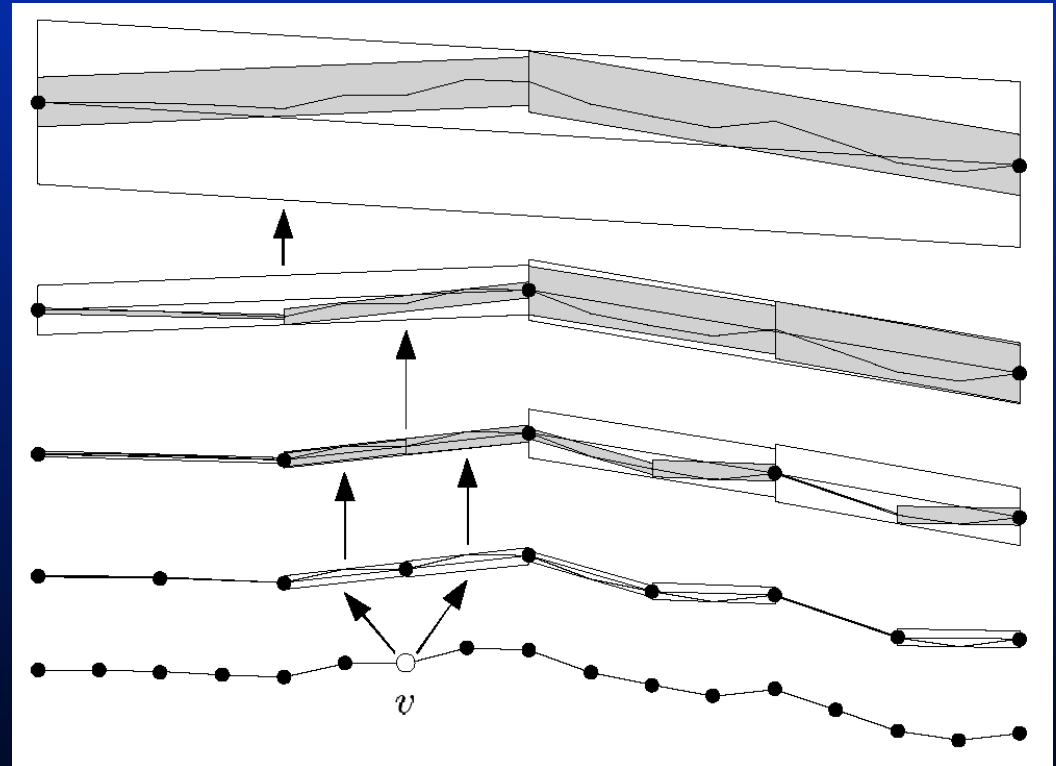
Duchaineau et al. 1997

- Real-time Optimally Adapting Meshes (ROAM)
- Regular grid, bintree, 2 priority queues:
 - 1 priority-ordered list of triangle splits
 - 1 priority-ordered list of triangle merges
- Frame coherence
 - pick up from previous frame's queue state
- Very popular with source code and implementation nodes available



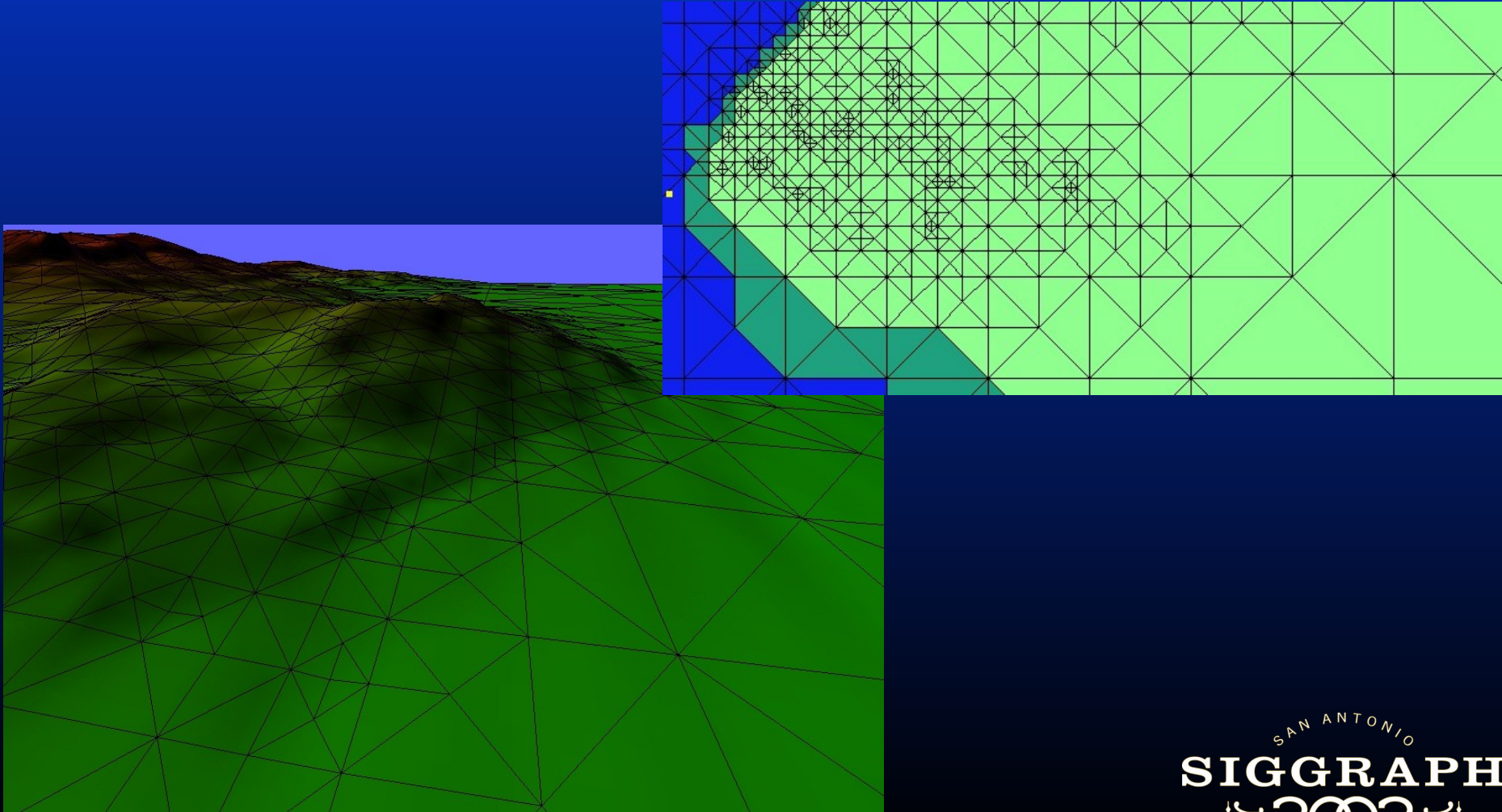
Duchaineau et al. 1997

- Principal metric was screen-based geometric error with guaranteed bound on the error
- Hierarchy of volumes called *wedgies*





Duchaineau et al. 1997



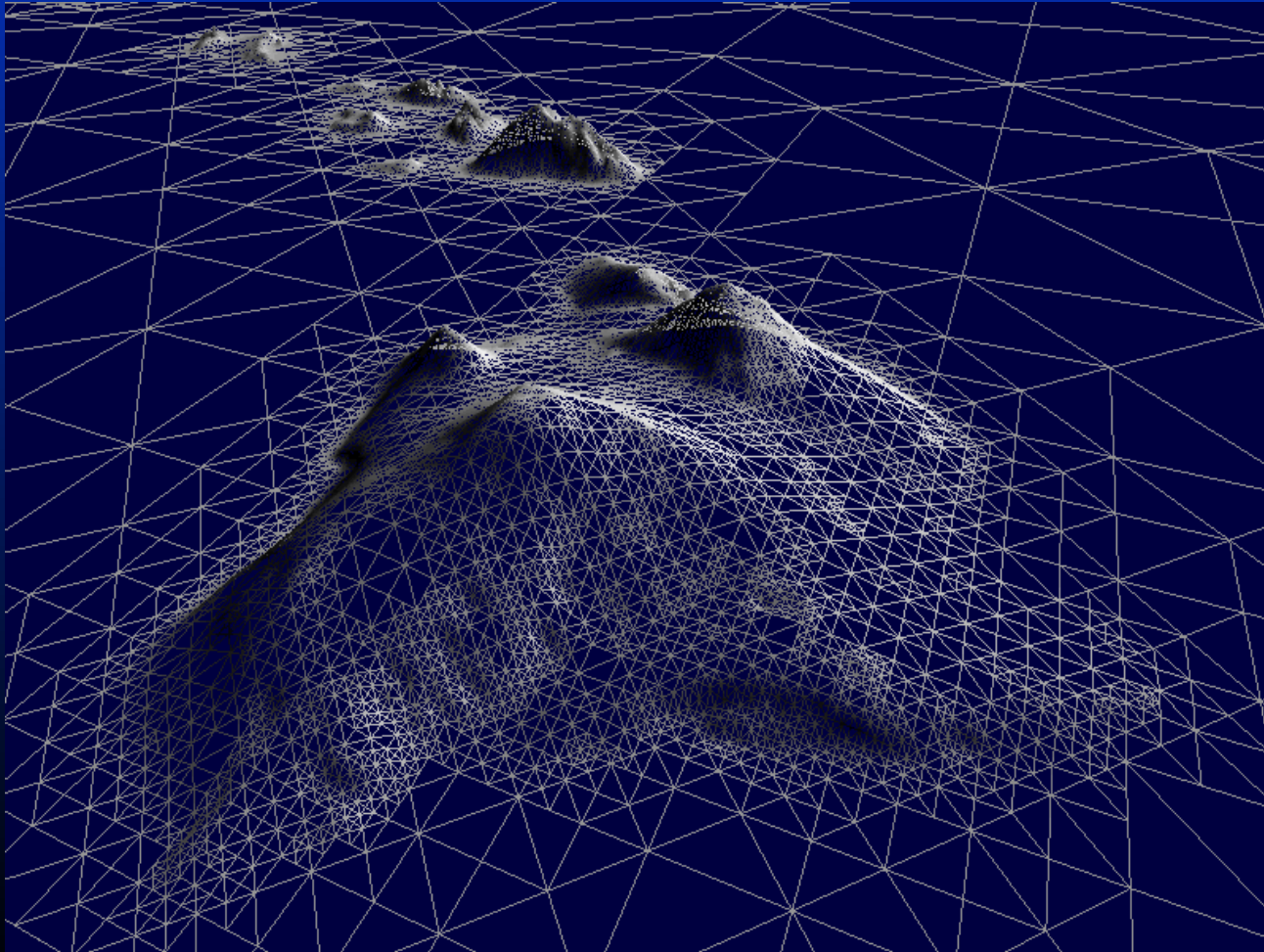


Röttger et al. 1998

- Extended Lindstrom's CLOD work
- Regular grid, quadtree, top-down
- World space metric considered:
 - viewer distance & terrain roughness
- Integrated vertex geomorphing
- Deal with tears by skipping center vertex of higher resolution adjacent edge



Röttger et al. 1998



Hawai'i

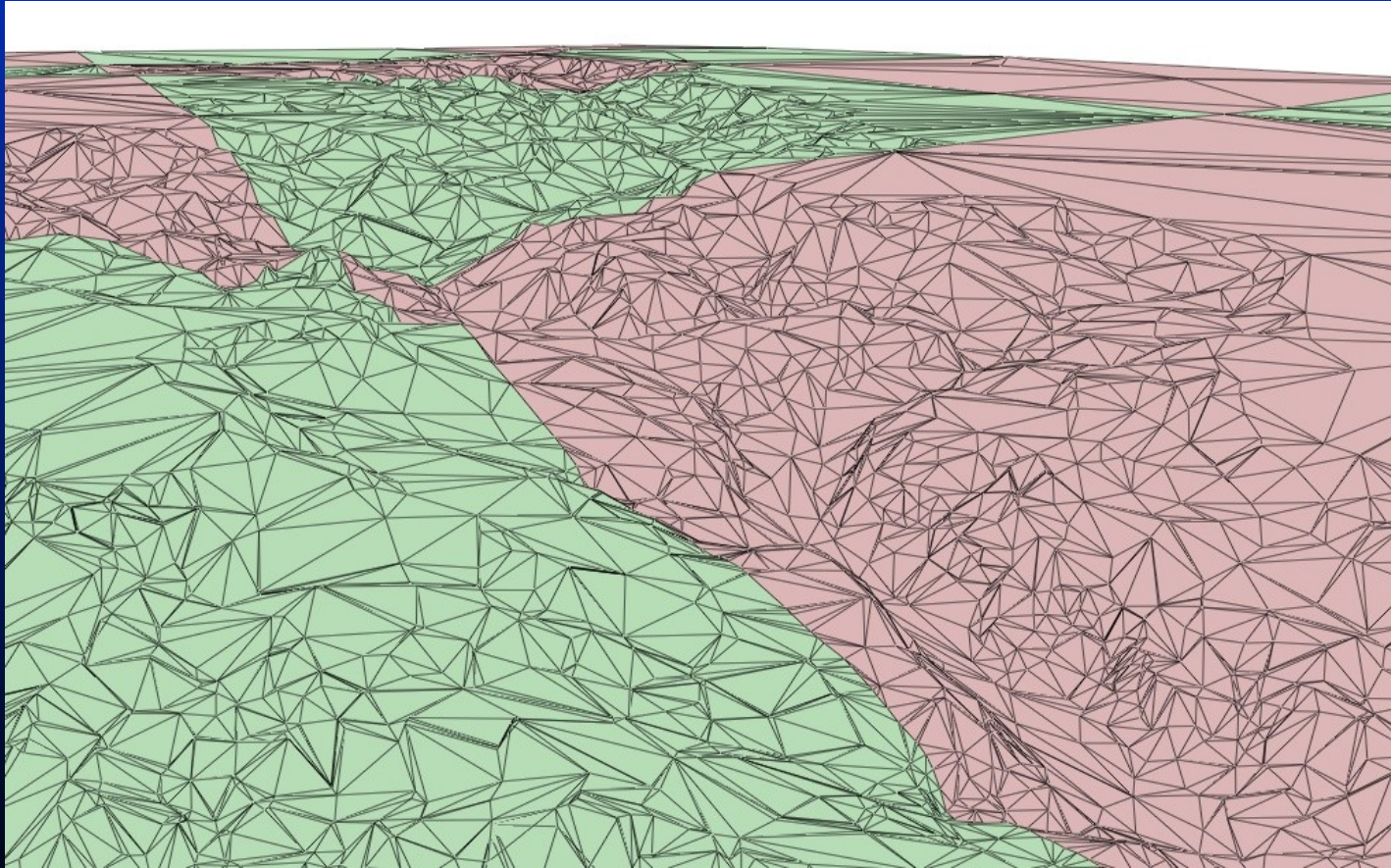


Hoppe 1998

- View-Dependent Progressive Meshes (VDPM) from Hoppe 97 applied to terrain
- TIN-based, out-of-core (VirtualAlloc/Free)
- Integrated vertex geomorphing
- Tears between blocks avoided by not simplifying at block boundaries
- Notes that larger errors can occur between grid points and precomputes maximum height deviations



Hoppe 1998



Grand
Canyon,
Arizona

4,097 x 2,049

8 x 4 blocks
of 513 x 513

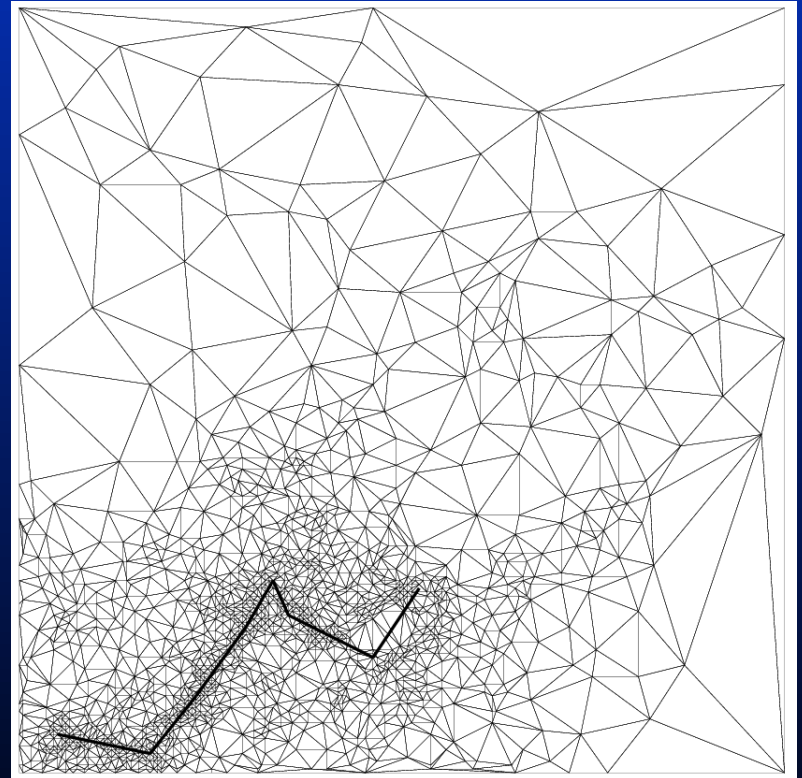
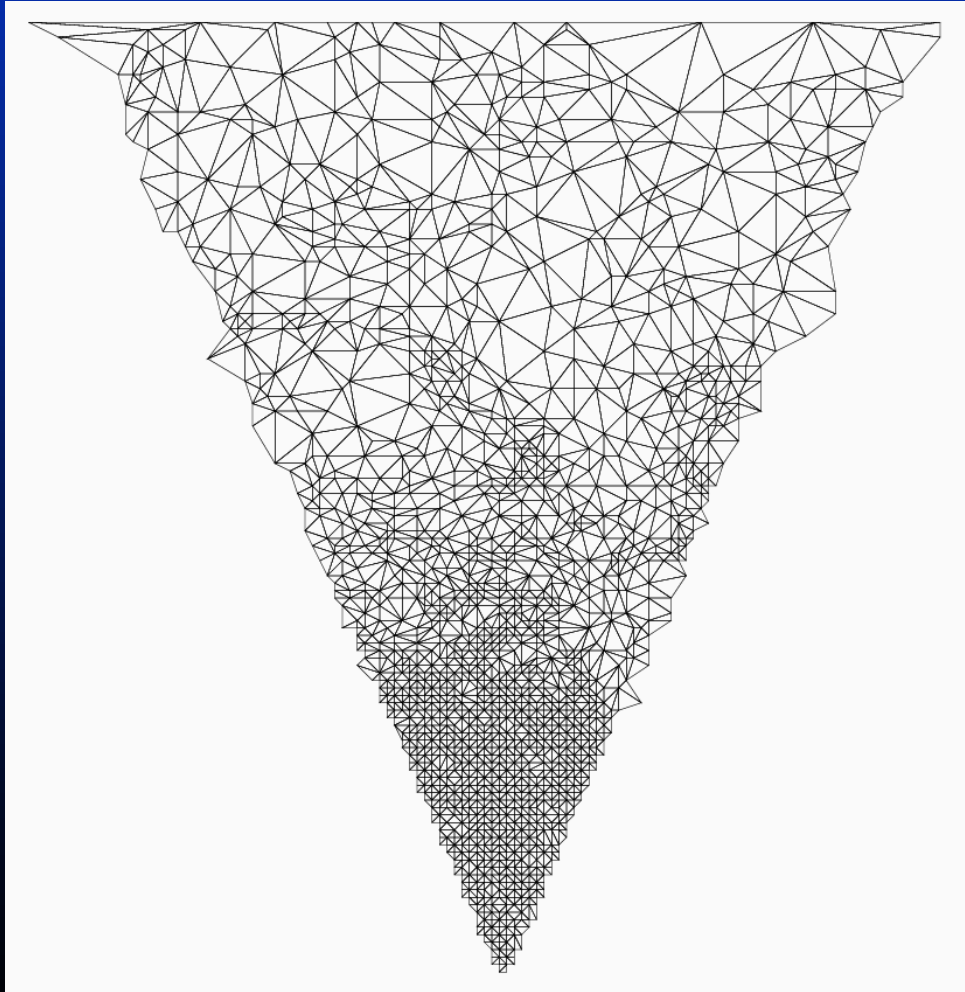


DeFloriani et al. 2000

- VARIANT. Uses Multi-Triangulation (MT)
- General TIN approach applied to terrain
- Plug in different simp. & error routines
- Supports analyses: visibility, elevation along a path, contour extraction, viewshed
- Frame coherence (use previous state)
- Freely available C++ library for MT



DeFloriani et al. 2000



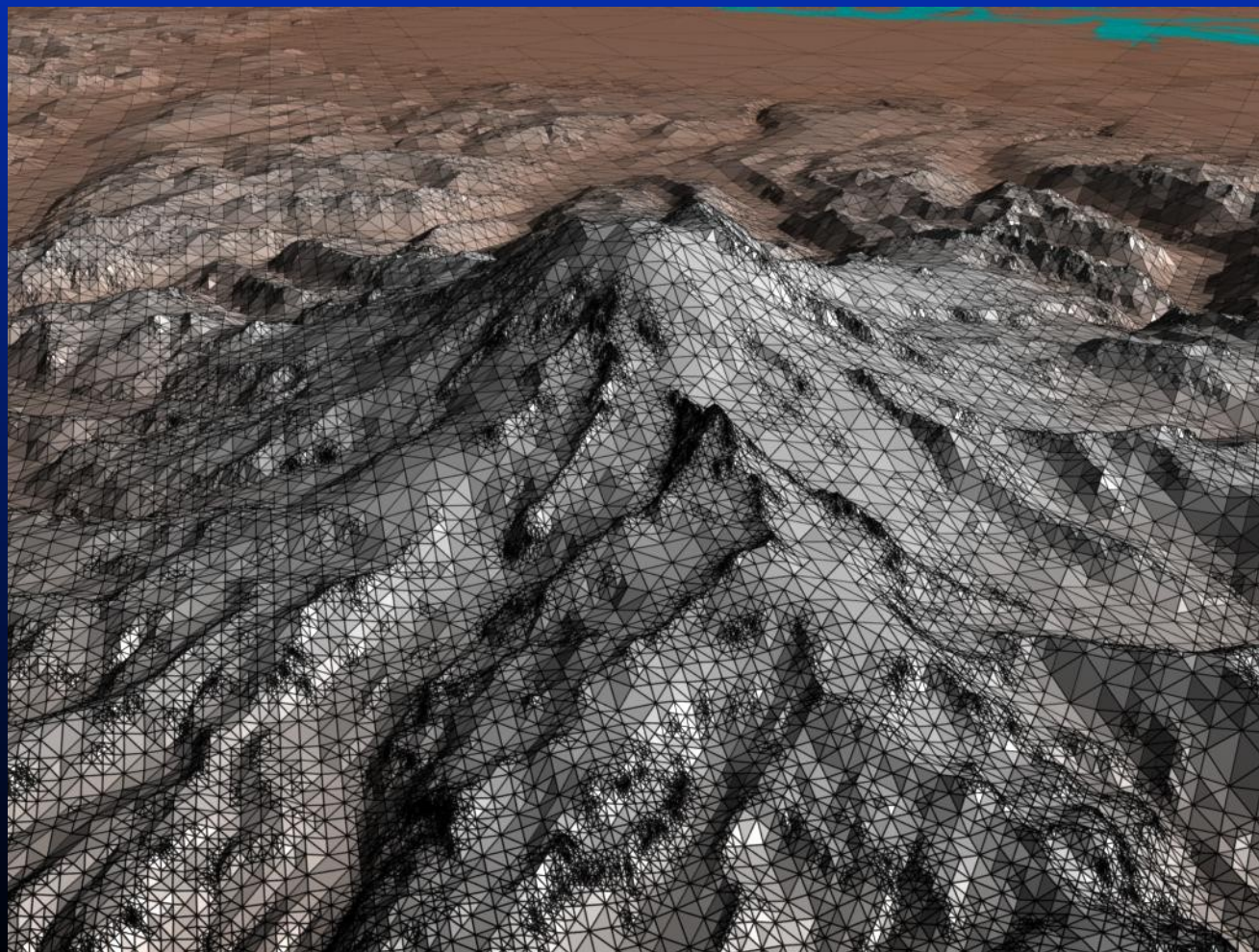


Lindstrom & Pascucci 2001

- Visualization of Large Terrains Made Easy
- Regular gridded, top-down, bintree
- Out-of-core with mmap() and spatial org.
- Fast hierarchical culling, triangle stripping, and optional multithreading of refinement and rendering tasks
- Uses a nesting of error metric terms (bounding spheres)



Lindstrom & Pascucci 2001



Puget Sound,
Washington

16,385 x 16,385

512 MB



Further Resources

- Virtual Terrain Project (VTP)
 - <http://www.vterrain.org/>
- Large terrain databases:
 - http://www.cc.gatech.edu/projects/large_models/
- Source code links (ROAM, VTP, MT, etc.)
 - <http://www.LODBook.com/>
- “LOD for 3D Graphics” Chapter 7