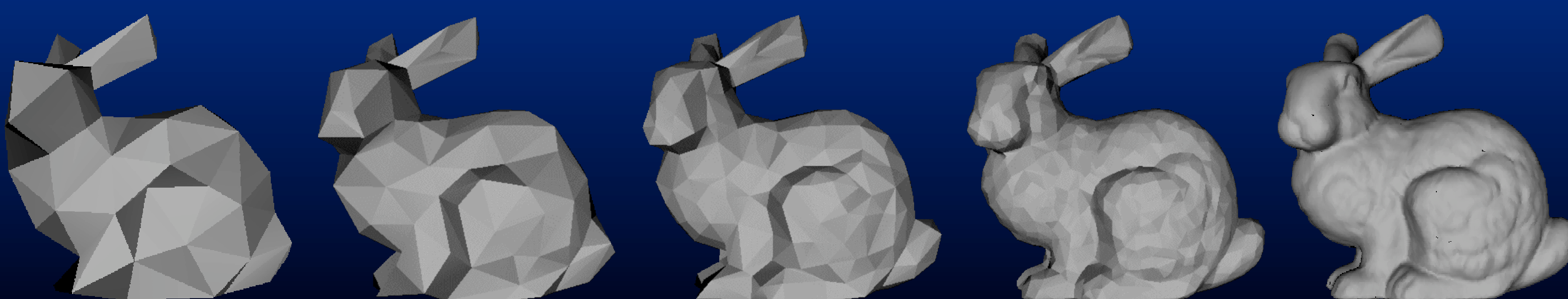
SAN ANTONIO

SIGGRAPH

2002

# Terrain Level Of Detail

Martin Reddy



# Contents

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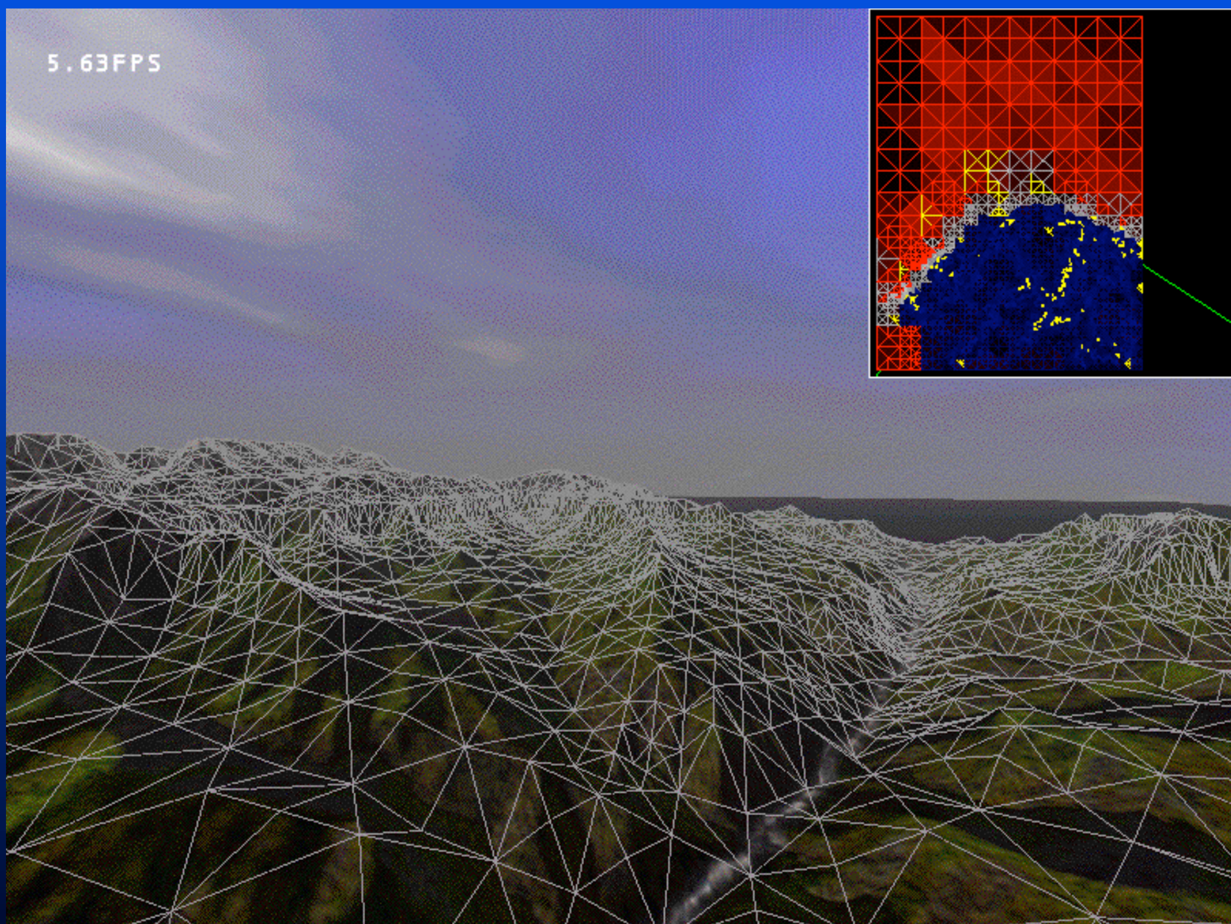
- Important Concepts
  - – regular grids v TINs, quadtrees v bintrees, out-of-core paging, web streaming
- Implementations
  - – Lindstrom 96, Duchaineau 97, Röttger 98, Hoppe 98, DeFloriani 00, Lindstrom 01
- Further resources

# 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

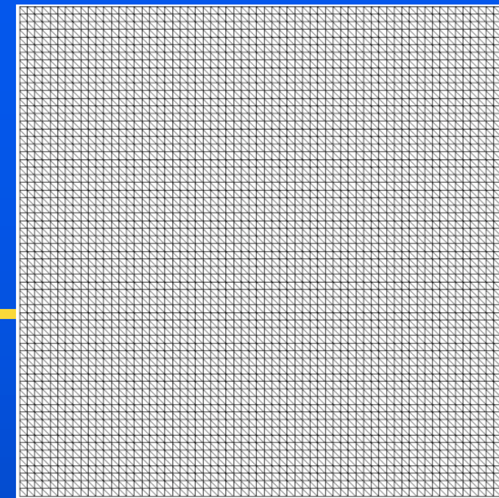
# Terrain LOD vs Generic LOD

- 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
  - Necessitates view-dependent LOD
  - Often requires paging from disk (out-of-core)

# Large Terrain Databases

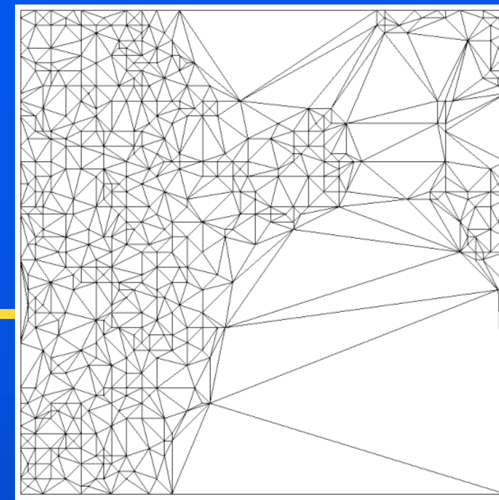
- USGS GTOPO30
  - 30 arc-second (~1 km) resolution elevation
  - 43,200 x 21,600 = 1.8 billion triangles
- NASA EOS satellite ASTER
  - 30-m resolution elevation data
  - from 15-m near infrared stereo imagery
- USGS National Elevation Dataset (NED)
  - 50,000 quads at around 50 GB

# Regular Grids



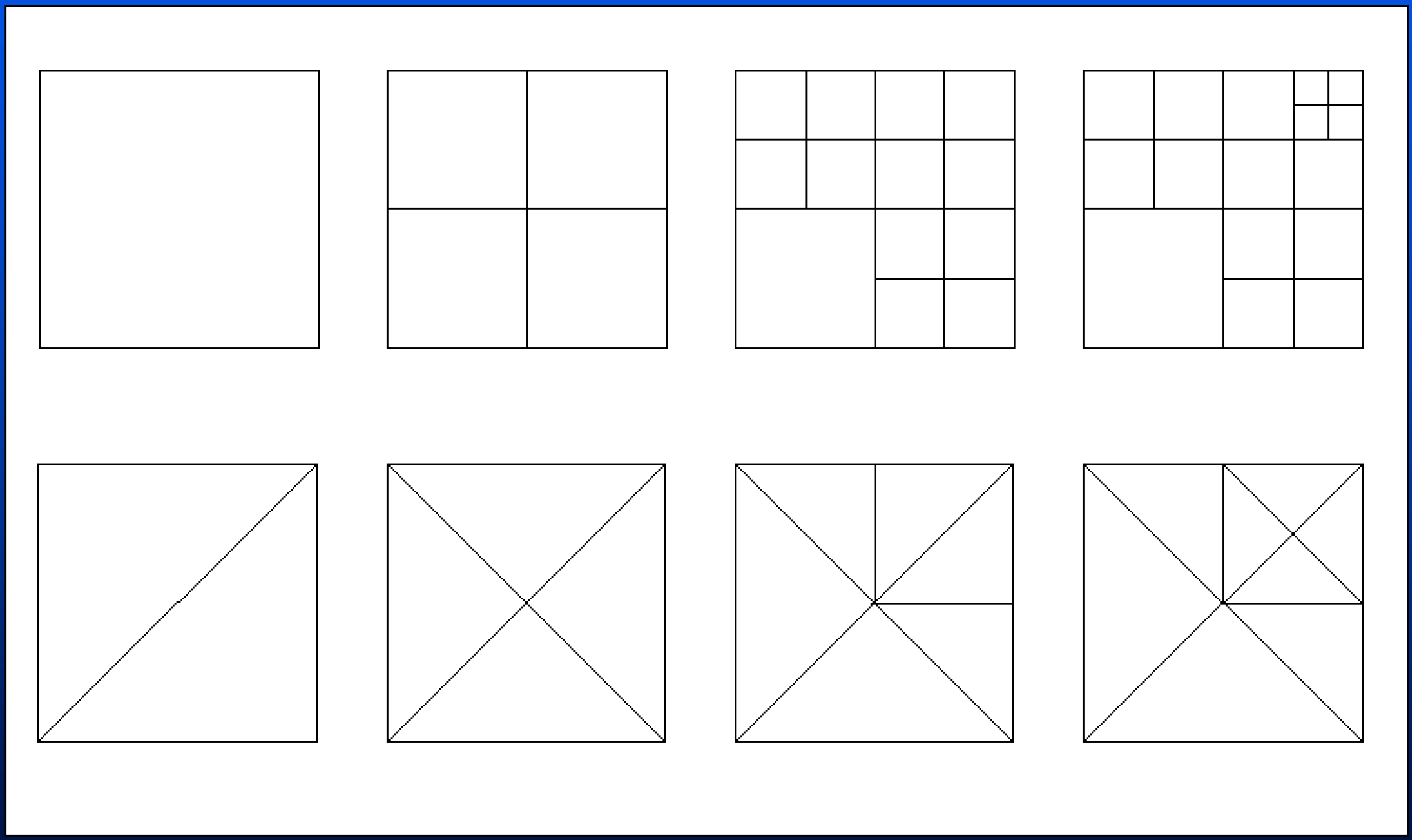
- Uniform array of height values
- Simple to store and manipulate
- Encode in raster formats (DEM, GeoTIFF)
- Easy to interpolate to find elevations
- Less disk/memory (only store z value)
- Easy view culling and collision detection
- Used by most implementers

# 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

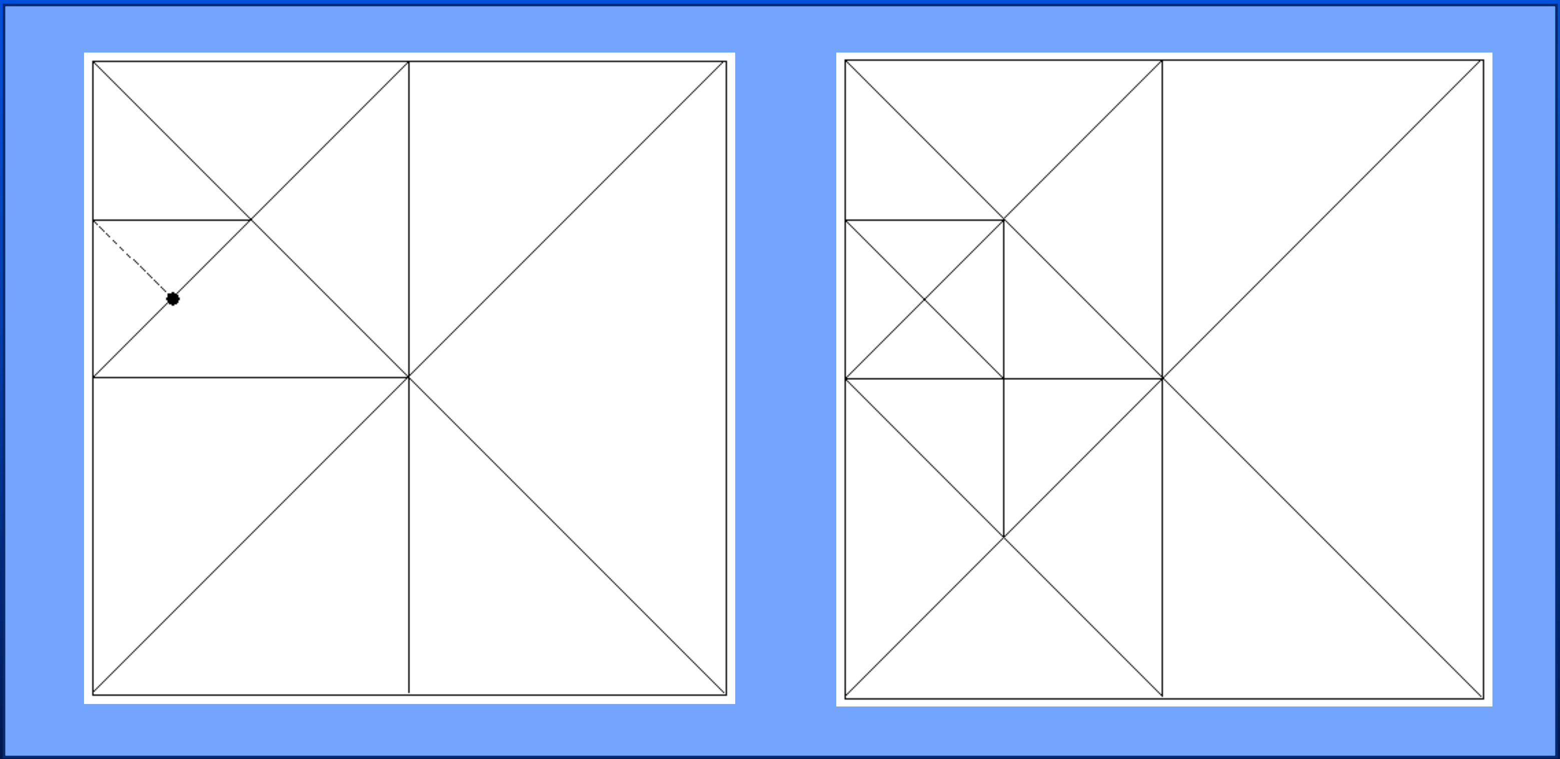
# Quadtrees and bintrees



# 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

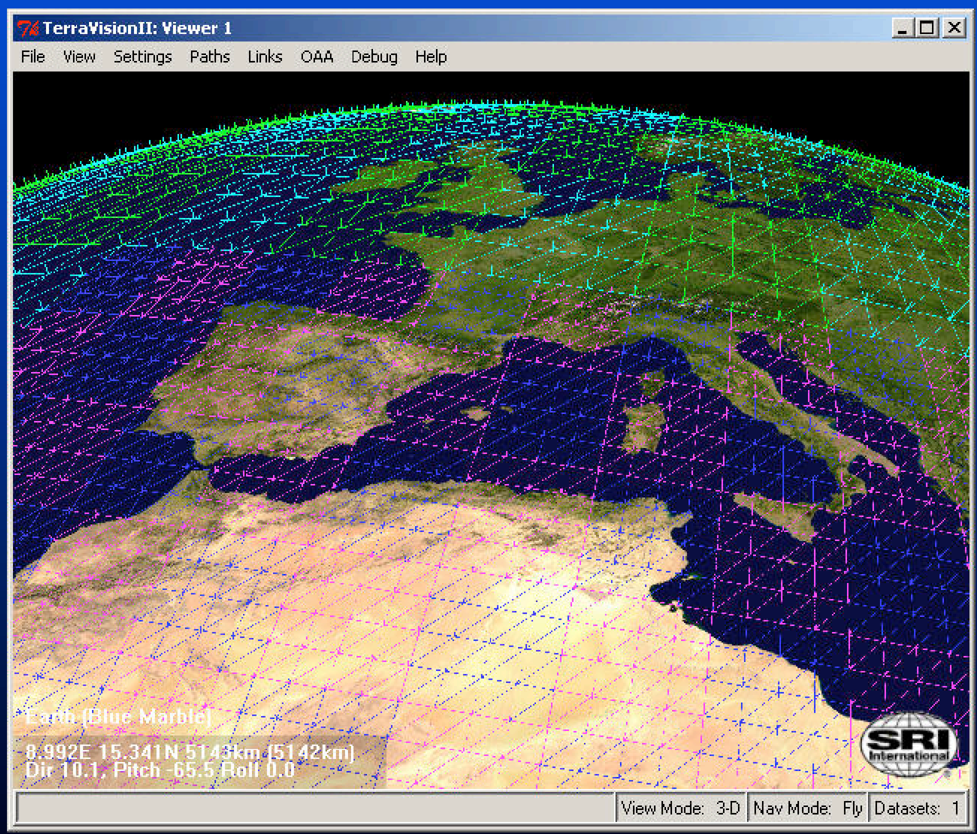


# Out-of-core operation

- 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

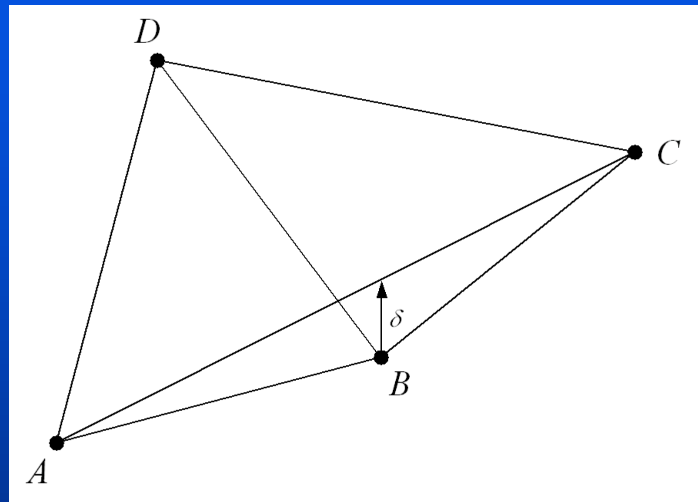
- Need to handle paging of imagery as well as geometry (satellite imagery resolution is generally > than elevation resolution)
- Hardware support for paging (clipmaps)
- Detail textures for close-to-ground detail
- Texture compression useful?

# Lindstrom et al. 1996

- One of first real-time view-dependent algorithms, referred to as continuous LOD (CLOD)
- 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

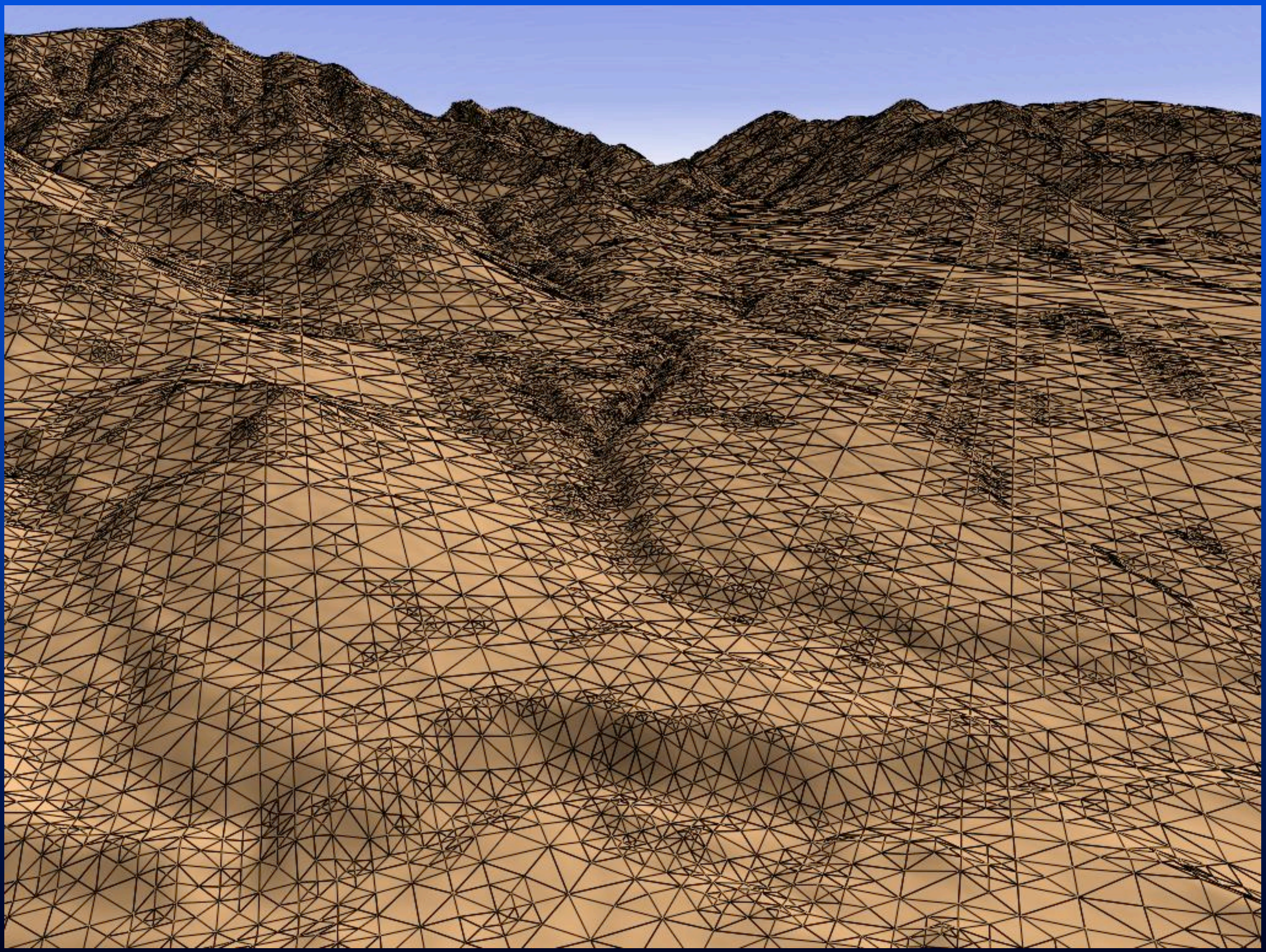
# Lindstrom et al. 1996

- 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



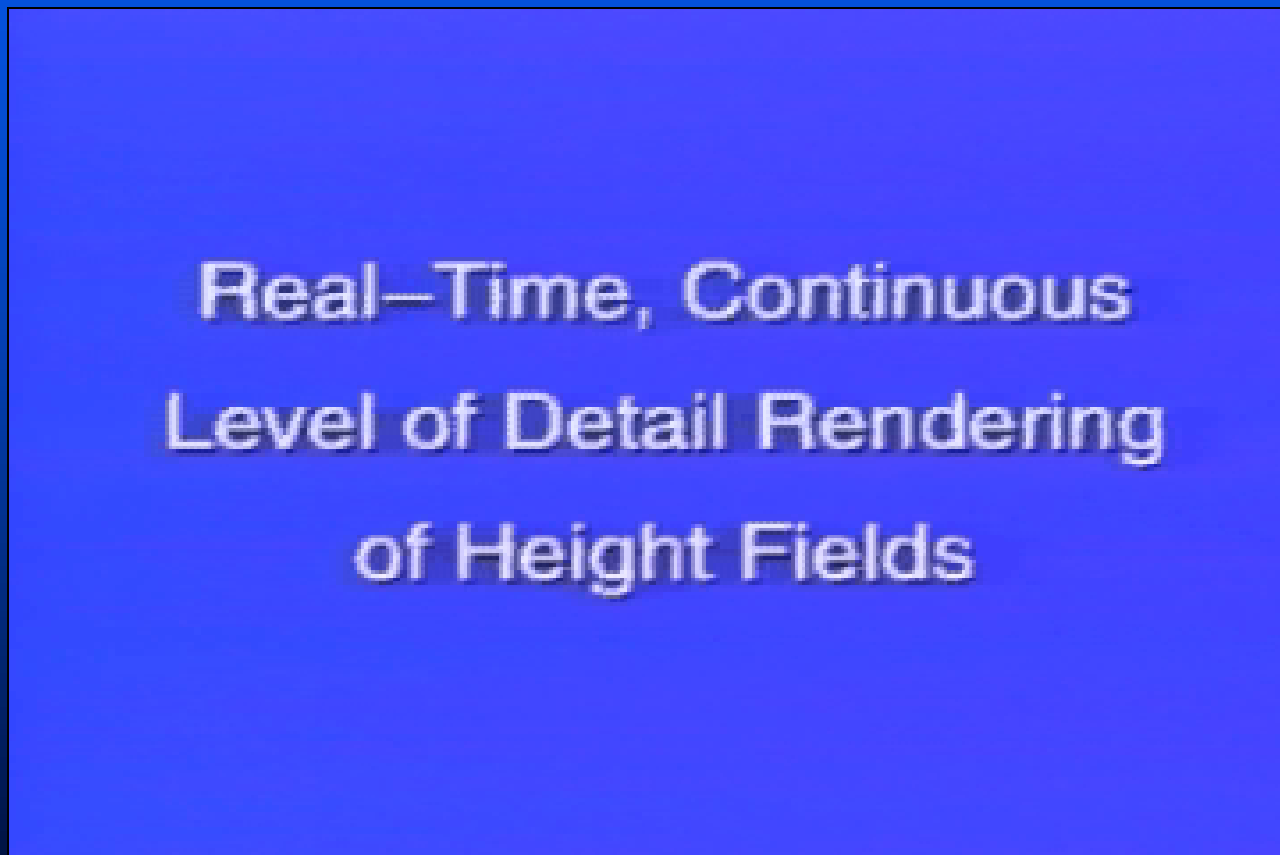
Hunter-Liggett
US Army base

2-m res

8 x 8km

32 M polys

# Lindstrom et al. 1996

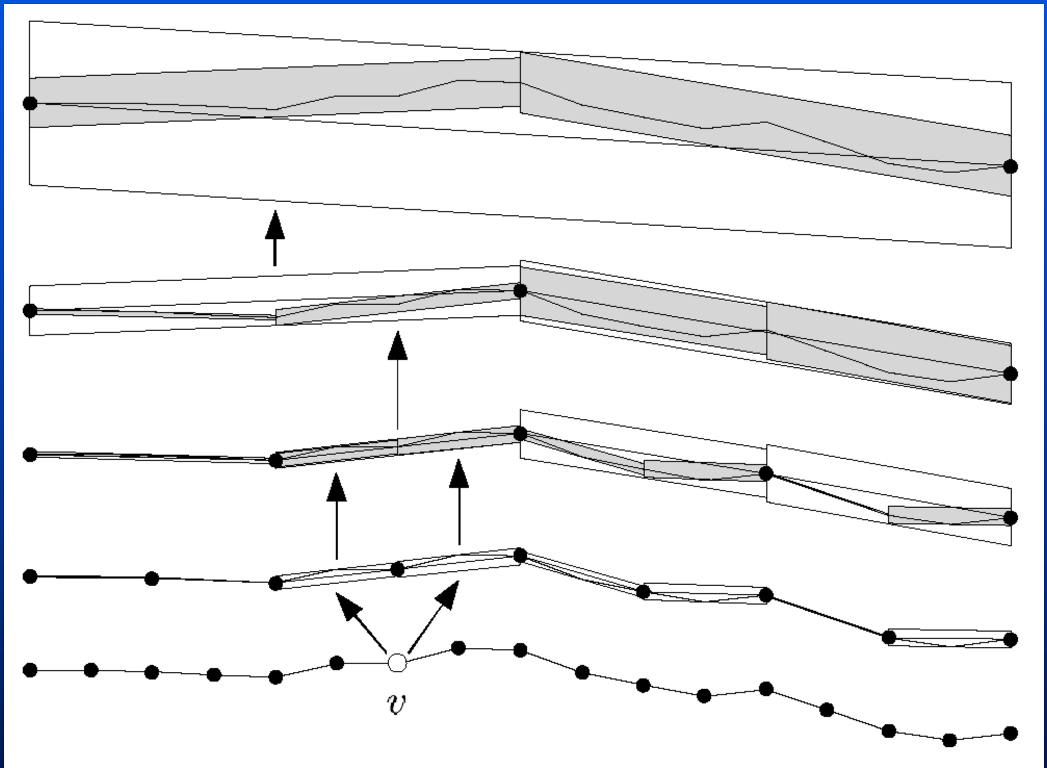


# Duchaineau et al. 1997

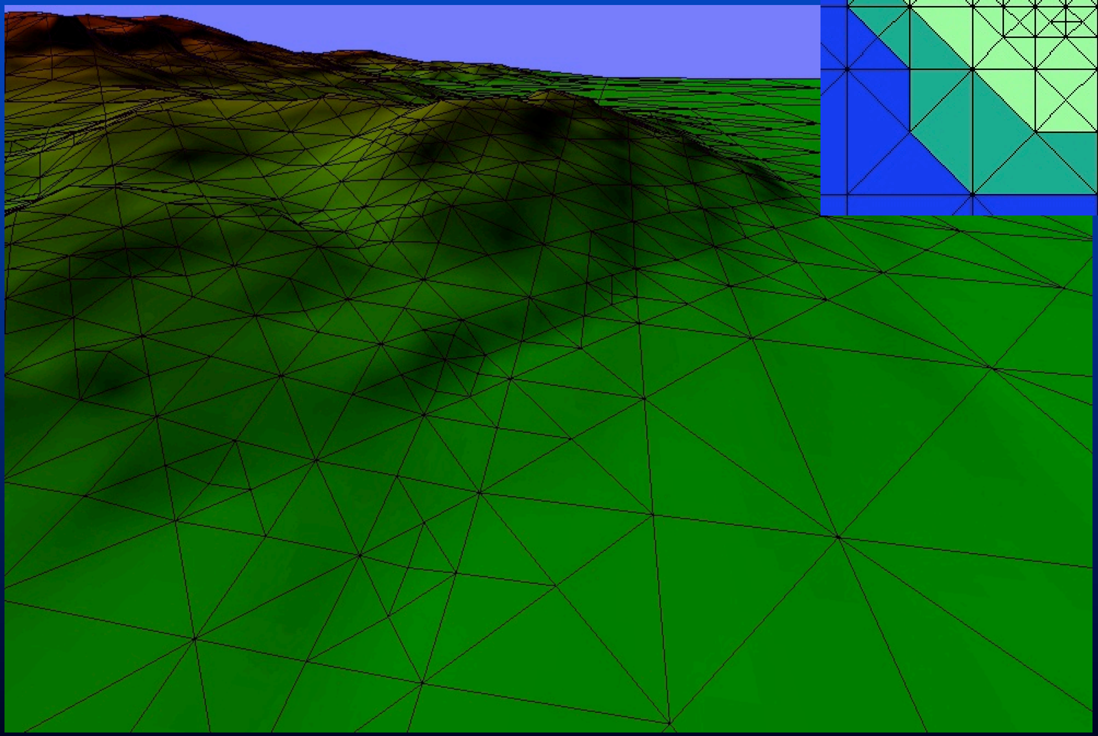
- Real-time Optimally Adapting Meshes (ROAM)
- Regular grid, bintree, 2 priority queues:
  - 1 priority-ordered list of triangle splits
  - 1 priority-ordered list of triangle merges
- Frame coherence
  - pick up from previous frame’s queue state
- Very popular with source code and implementation nodes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

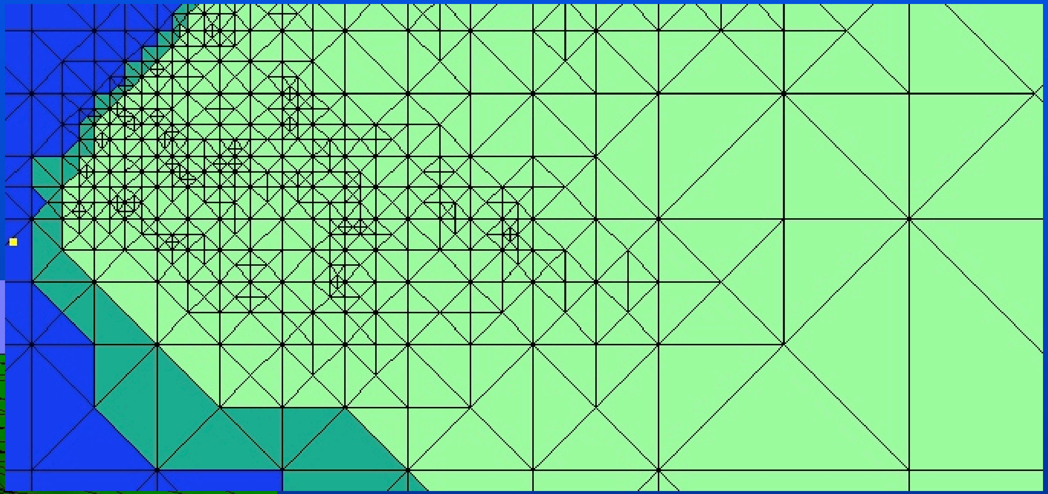
# Duchaineau et al. 1997

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



# Duchaineau et al. 1997

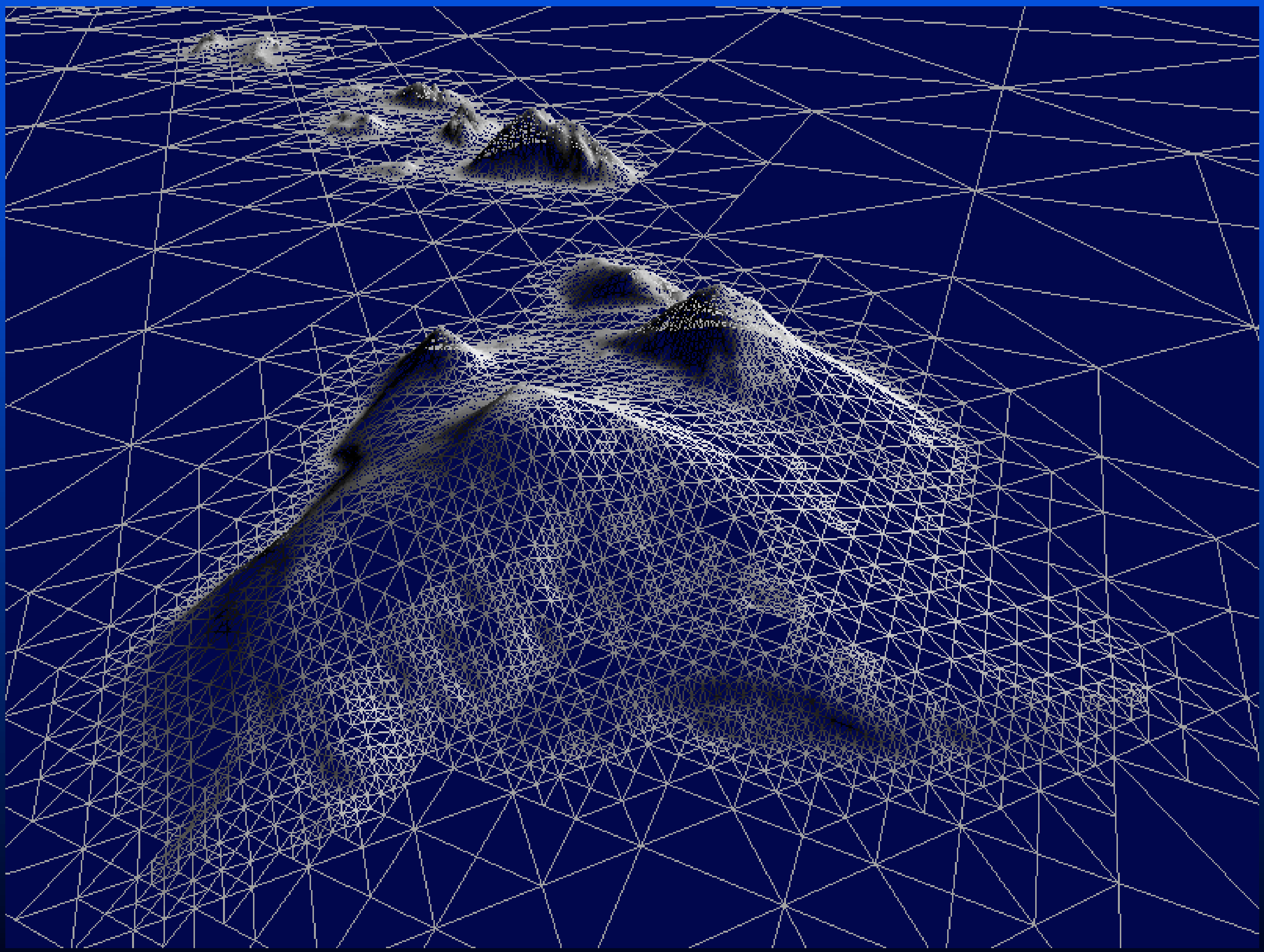




# Röttger et al. 1998

- 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

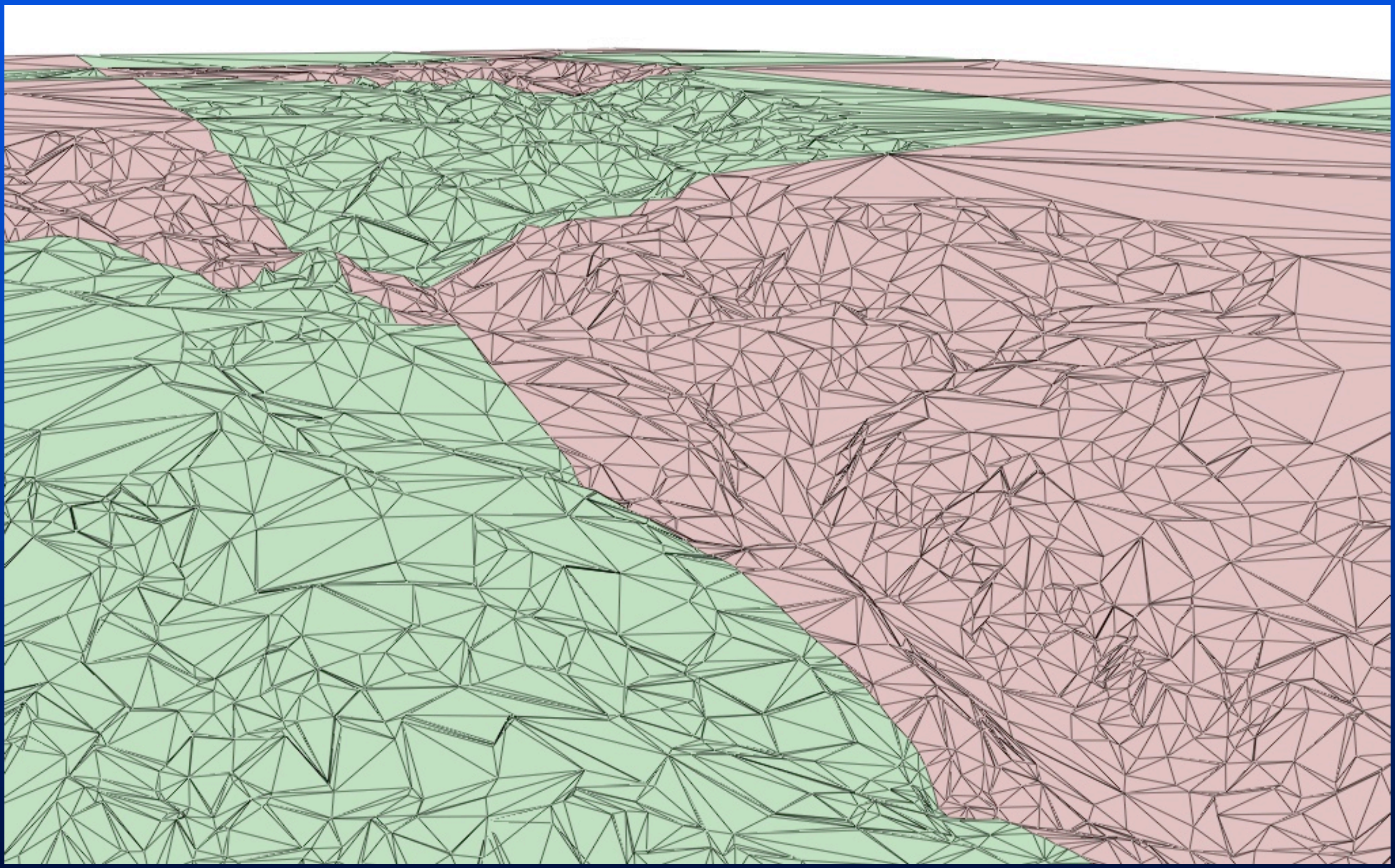


Hawai'i

# 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

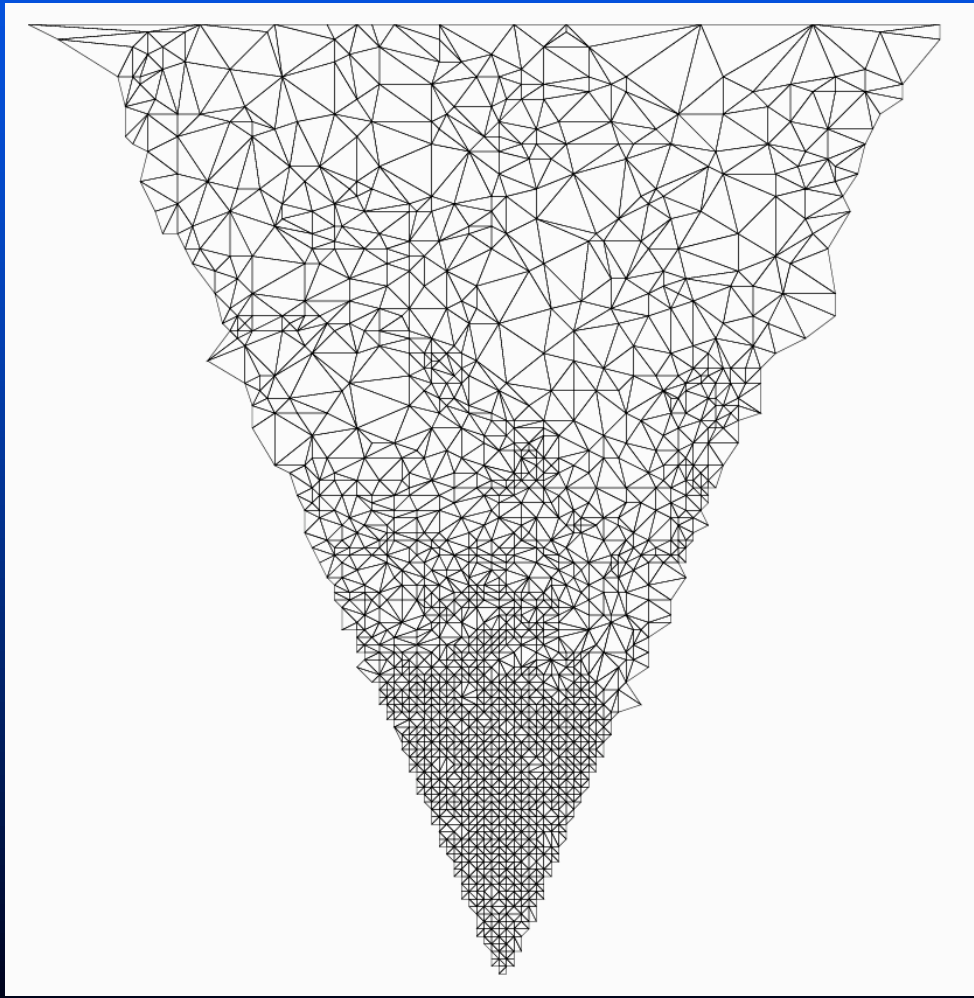
4,097 x 2,049

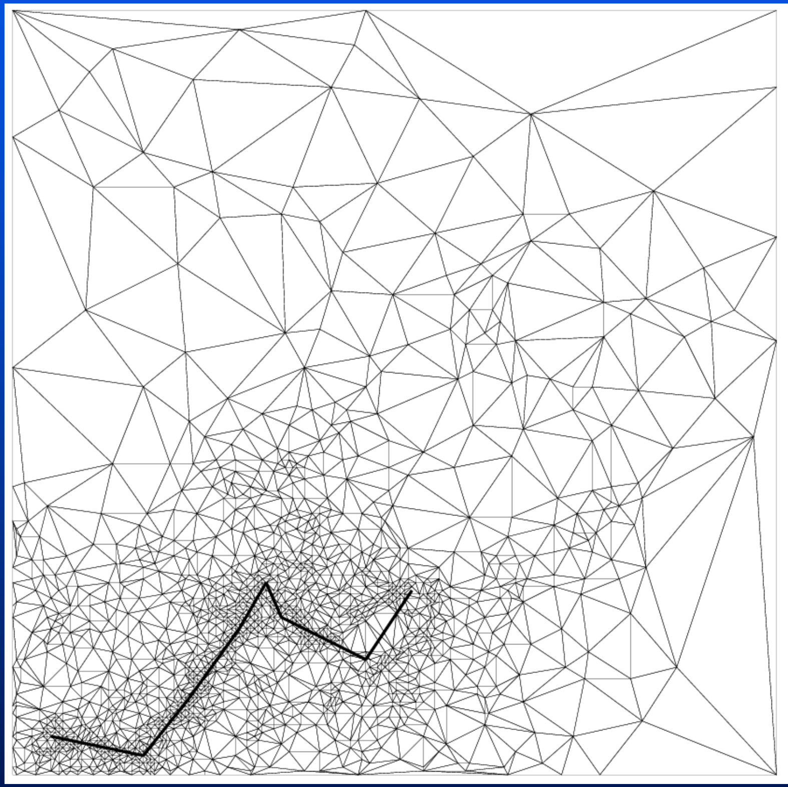
8 x 4 blocks of 513 x 513

# 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

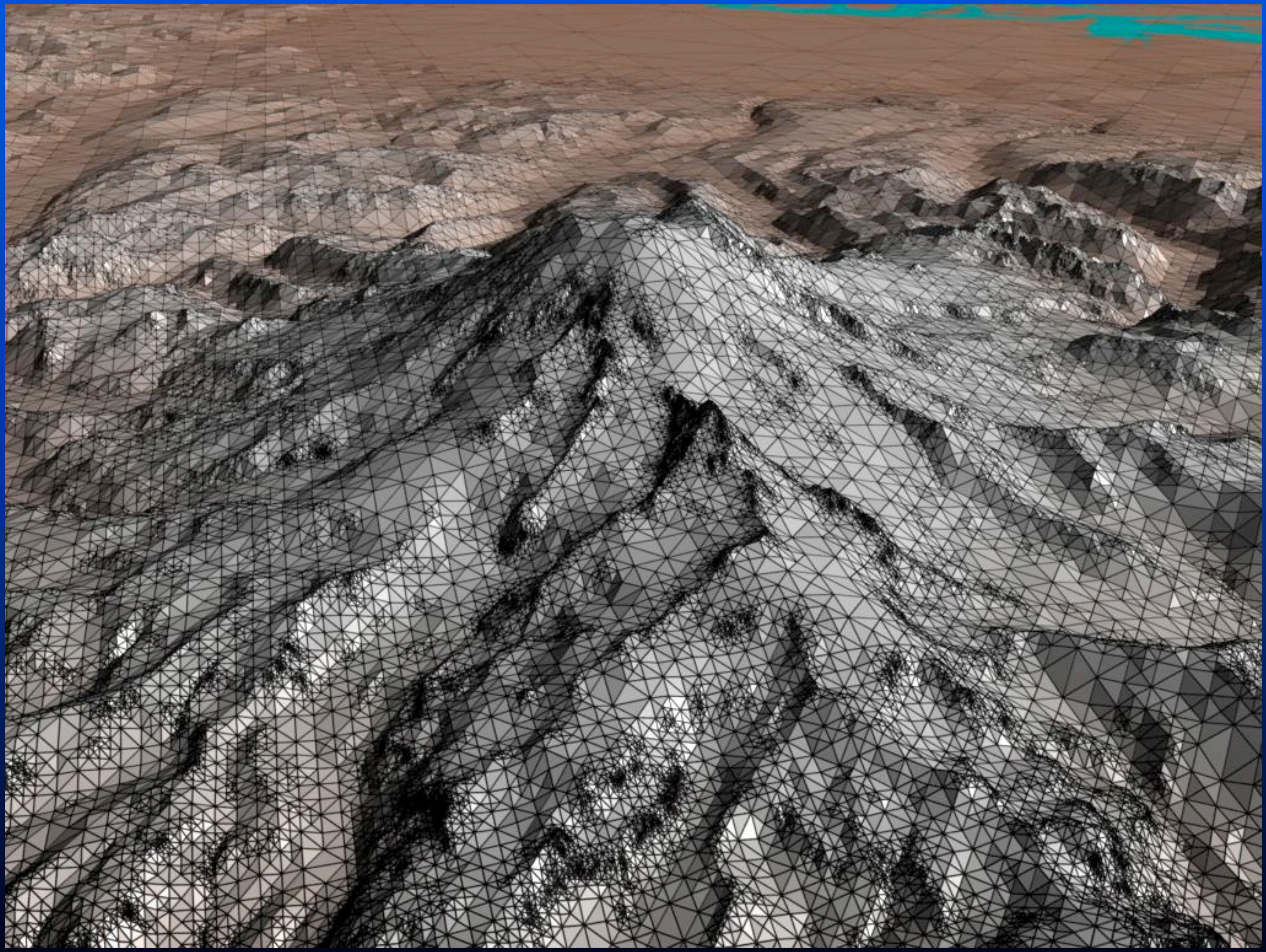




# Lindstrom & Pascucci 2001

- 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