REAL-TIME FUSION, VISUALIZATION AND ANALYSIS OF HIGH-PRECISION DSM'S AND ORTHO-IMAGERY

REAL-TIME FUSION

Scale and merge *(low res + high res)*

Combine data *(base + detail)*

Adjust and augment *(corrections)*

VISUALIZATION

Consumer level hardware *(CPU, GPU)*

Real-time, interactive 3D

Seamless geometry + textures

ANALYSIS

Visibility determination *(e.g. culling)*

Collision detection *(e.g. physics)*

Obstacle avoidance *(e.g. SDF)*

Path finding / navigation

HIGH-PRECISION

Ground Sample Distance

- 500 m : global data
- 50 cm : local data
- 0.25 mm : surface scans

Digital Elevation Model (DSM, DTM)

- 300 m : GMTED2010
- 30 m : ASTER GDEM 2, SRTMGL1
- 1 m : Elevation1 - Airbus D&S

Satellite Imagery:

- 500 m : BlueMarble2
- 15 m : Landsat
- 50 cm : GeoEye, KOMPSAT, Pleiades, WorldView...

Manual adjustments:

- 0.9 cm : Custom scenery / fixes

Surface Scans:

- 0.25 mm : e.g. Quixel Megascans

REAL-TIME FUSION

Geo-referenced image files:

- GeoTIFF, JPEG2000+WKT...
- Datum (e.g. WGS84/EGM96)
- Projection (e.g. Mercator)
- Parameters (e.g. origin, scale)

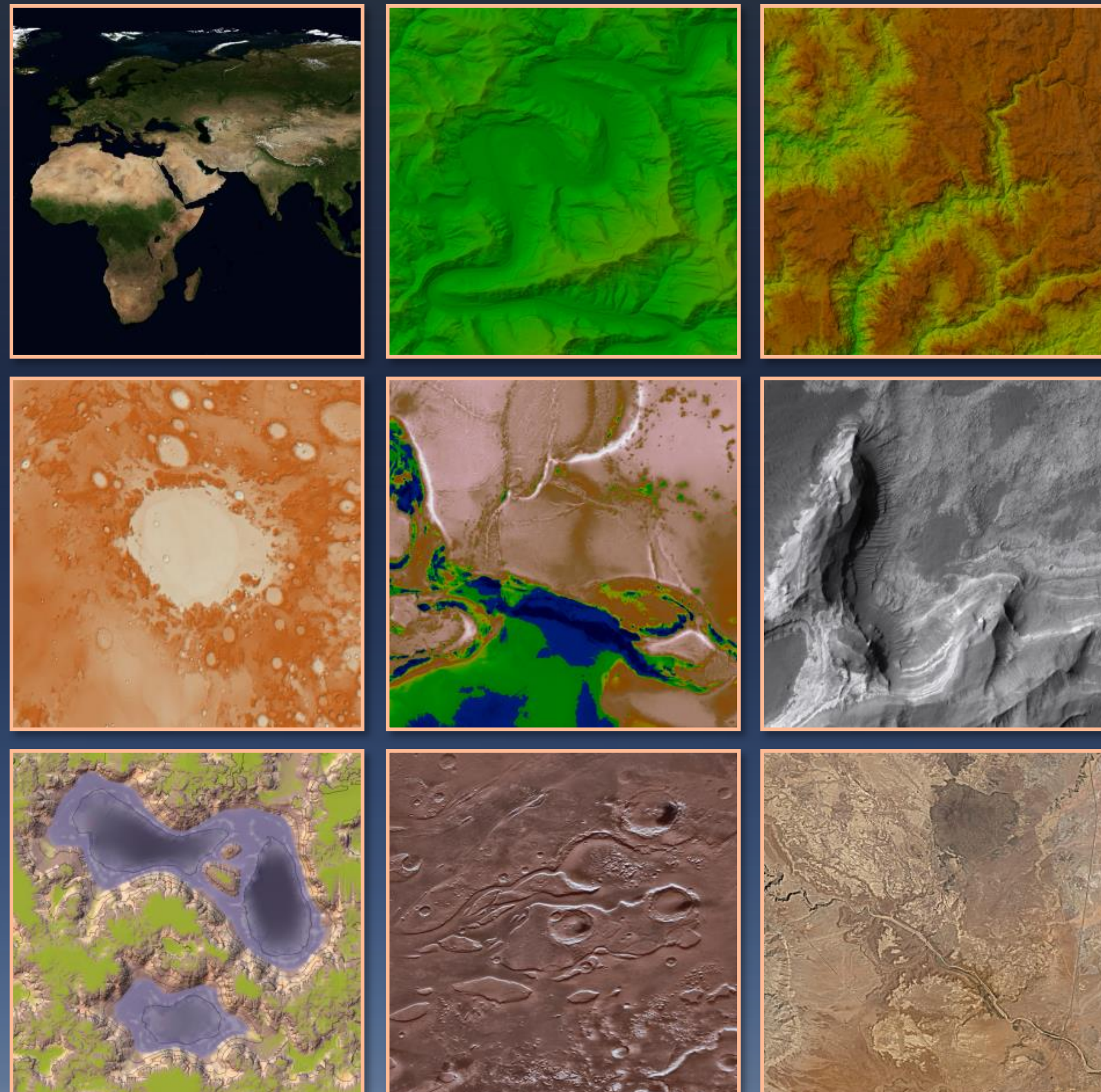
Myriad of possible combinations,
huge amounts of data,
cannot process in real-time!

Example: ASTER GDEM 2

http://asterweb.jpl.nasa.gov/gdem.asp

- Tiles á 3,601 x 3,601 pixels
- over 22,000 tiles
- more than 2.8E+11 pixels

Need uniform basis for geodata,
to enable real-time processing!



REAL-TIME FUSION

Uniform base grid:

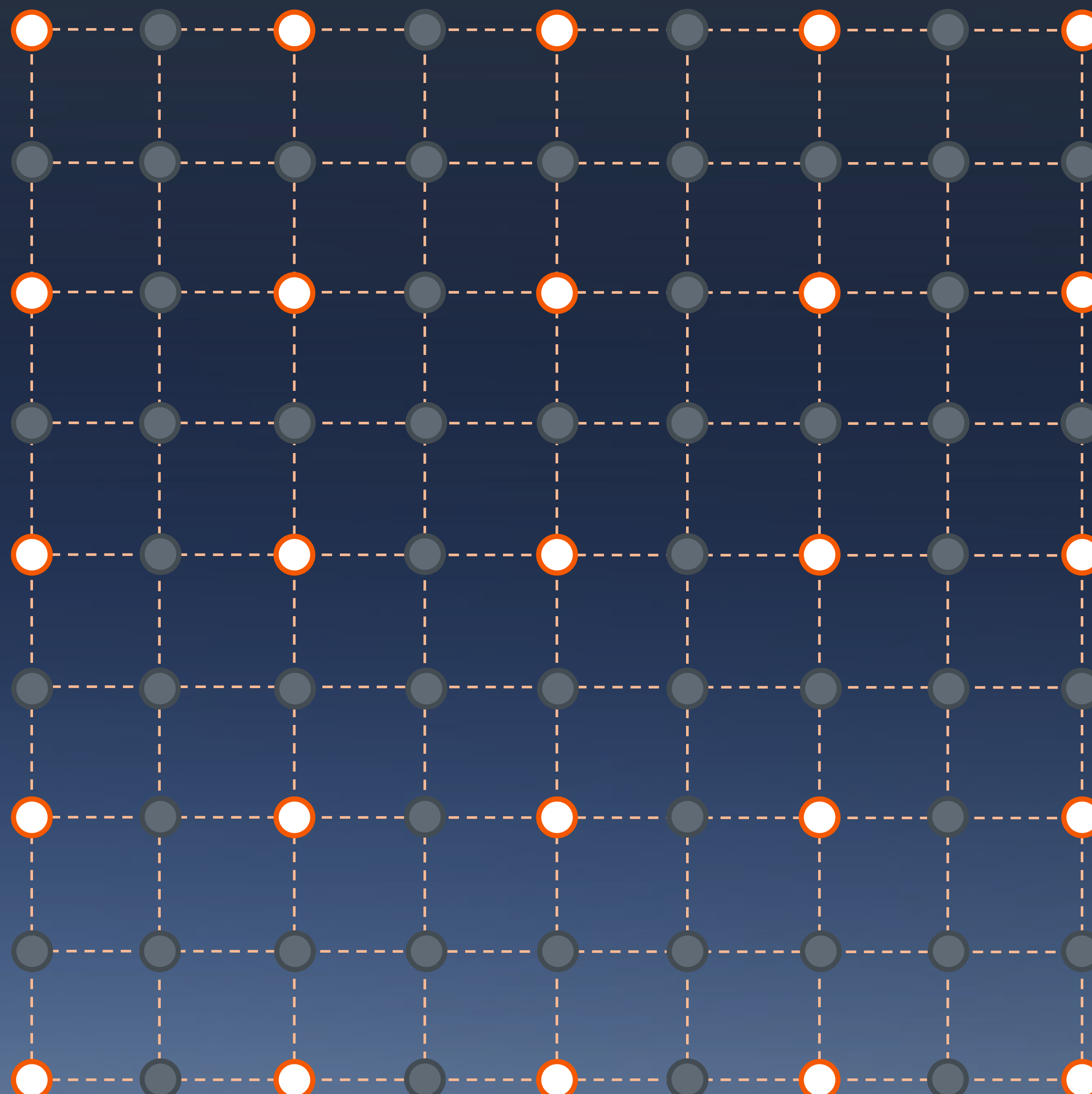
- Square
- Pixel-is-point: 2^n+1
- Pixel-is-area: 2^n
- Uniform datum: e.g. WGS84
- Sparse, i.e. per-pixel coverage
- Easy to scale (power of two)
- Easy to merge / combine

Need to resample geodata to grid, must be done in pre-processing step, using a GIS processing tool.

ArcGIS
https://www.arcgis.com/features/index.html

GDAL
http://www.gdal.org/

Tinman 3D
https://www.tinman3d.com/



REAL-TIME FUSION

Uniform base grid:

- Need to choose a map projection,
- ...that works equally well
- ...everywhere on surface of Earth.

To be used as a storage format:

- Lengths / angles are less important,
- ...heavy resampling at runtime.
- Areas must be preserved (almost),
- ...for high-quality sampling.

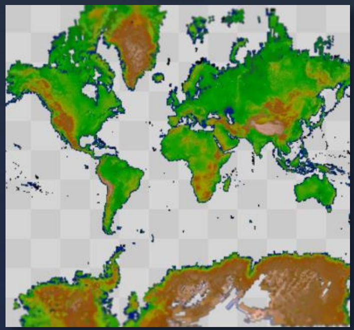
Use 6 base grids instead of one,
assemble as cubemap:

- Per-face projection (e.g. Gnomonic)
- Custom warp to improve GSD,
- ...for example:

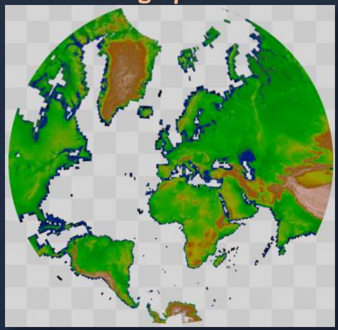
$$\sqrt{2x^2 + 0.5} * x, \ -1 \leq x \leq +1$$

- Works well for real-time processing.

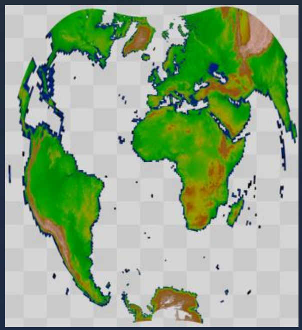
Mercator?

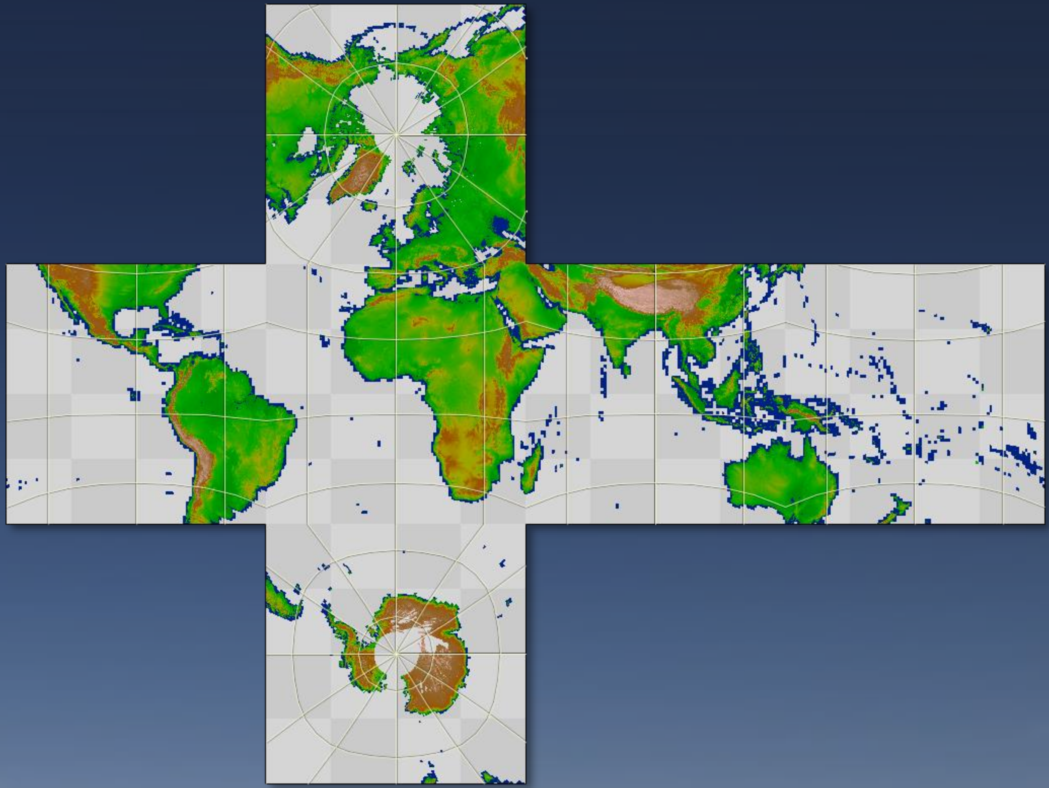


Stereographic?



Cassini?





REAL-TIME FUSION

Example uniform base grid:

- Grid size: 16 x 16
- Block size: 4 x 4

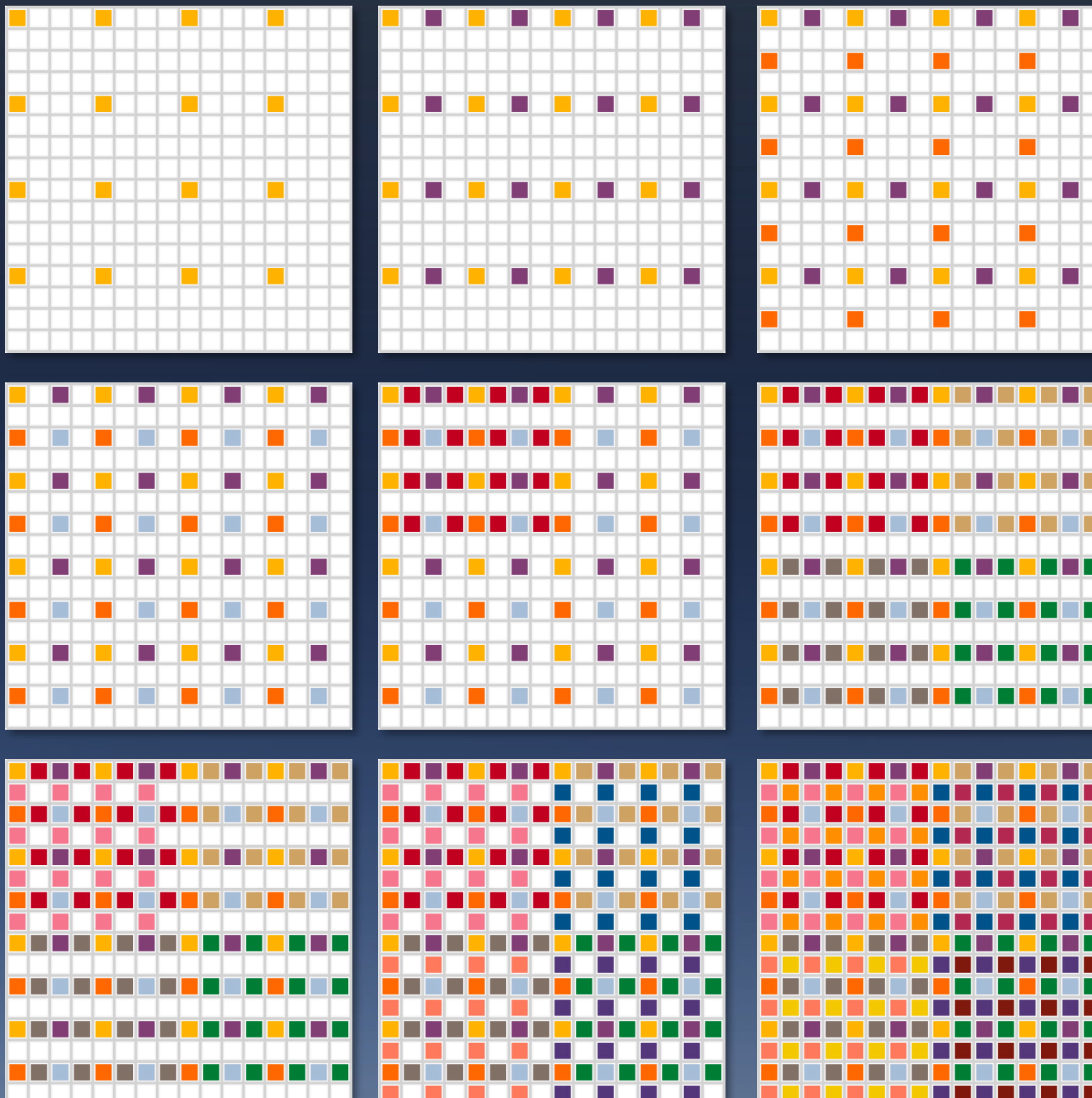
Data management:

- Per-block storage
- Lossless compression
- Random access

Block #0 on level #0
Block #1 on level #1
Block #2 on level #1
Block #3 on level #1
Block #4 on level #2
...
Block #15 on Level #3

Actual uniform base grid: 2^30+1

- 1,073,741,825 x 1,073,741,825
- Block size: 256 x 256

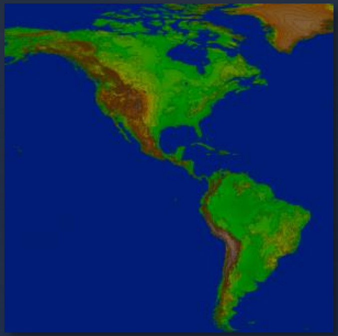


REAL-TIME FUSION

http://manual.tinman3d.com/Geodata_Examples.html

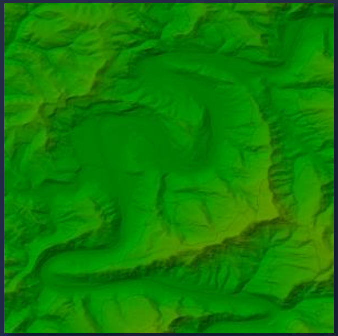
GMTED2010

- Whole dataset
- GSD : 274 m
- File size : 1.84 GB



NED 1/3"

- Whole dataset
- GSD : 8.5 m
- File size : 31.8 GB

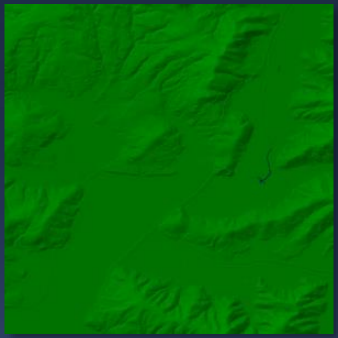


ASTER GDEM 2

- Whole dataset
- GSD : 34 m
- File size : 116 GB

NED 1/9"

- Whole dataset
- GSD : 4.2 m
- File size : 42.5 GB



Landsat 7

- 2 selected scenes
- GSD : 17 m
- File size : 541 MB

BlueMarble 2

- Whole dataset
- GSD : 548 m
- File size : 908 MB

VISUALIZATION

A recipe for real-time 3D terrain:

#1 : Uniform base grid

- Simplifies scaling & merging
- Virtual storage, sparse data
- LOD-based partitioning

#2 : Continuous level-of-detail

- Choose relevant grid points
- Compute optimal triangulation

#3 : Incremental GPU streaming

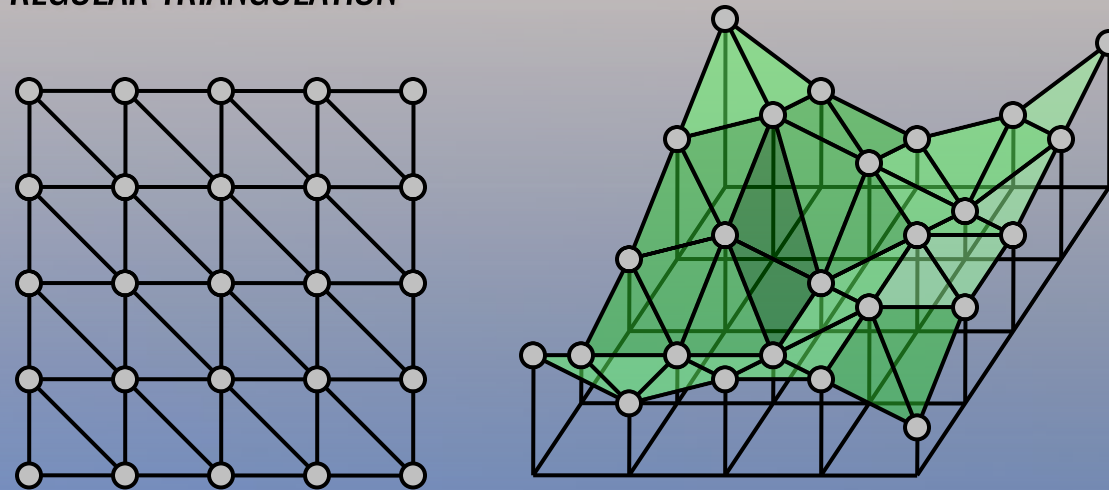
- Exploit frame-to-frame coherence
- Only upload new data to GPU
- Reuse geometry batches (IB + VB)

Well-known recipe, but hard to cook:

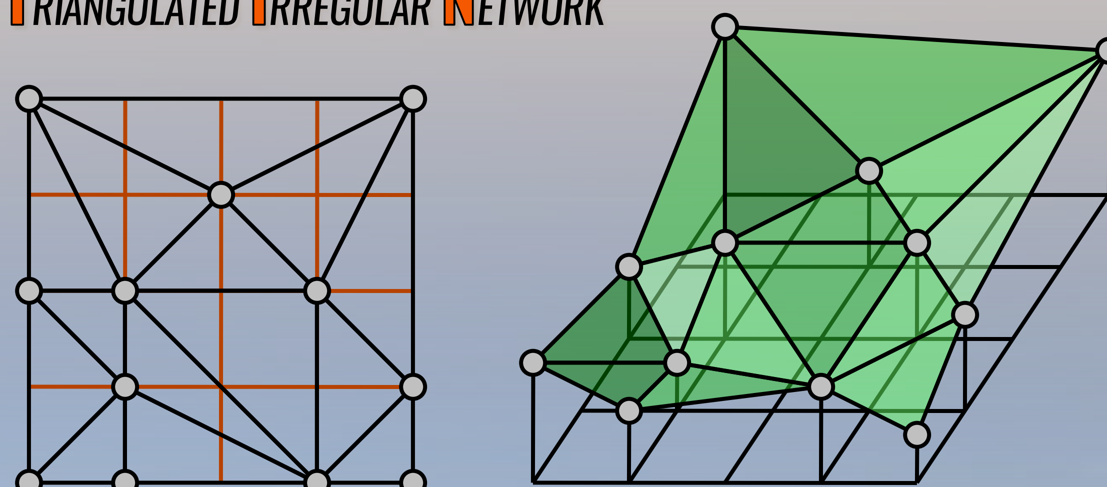
Stateless, One-pass Adaptive Refinement (2002)
https://computation.llnl.gov/casc/SOAR/

Real-time Optimally Adapting Meshes (1997)
http://www.cognigraph.com/ROAM_homepage/

REGULAR TRIANGULATION



TRIANGULATED IRREGULAR NETWORK



VISUALIZATION

GPU's are heavily optimized for geometric processing.

- Vertices
- Triangles
- Textures

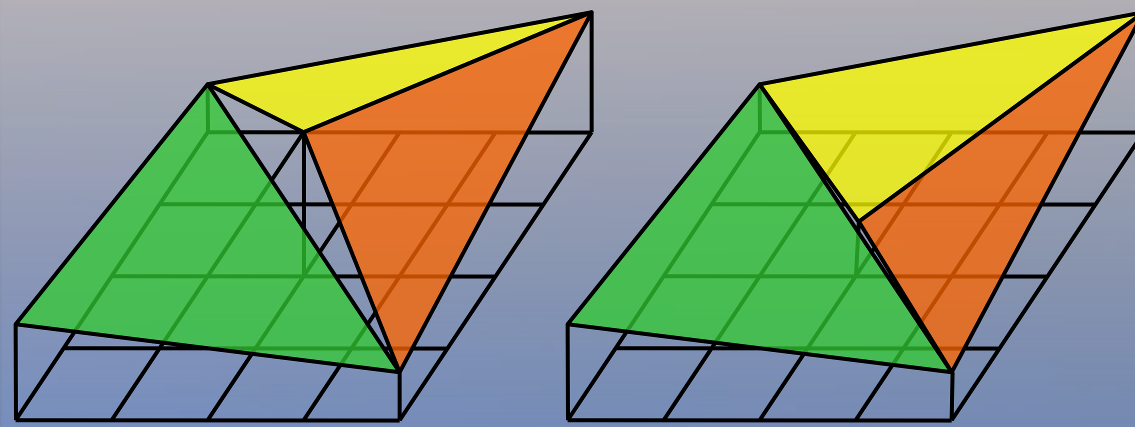
Must be generate efficiently from geodata, according to current view.

- Visibility / LOD computation
- Generate terrain geometry
- Geodata streaming to GPU

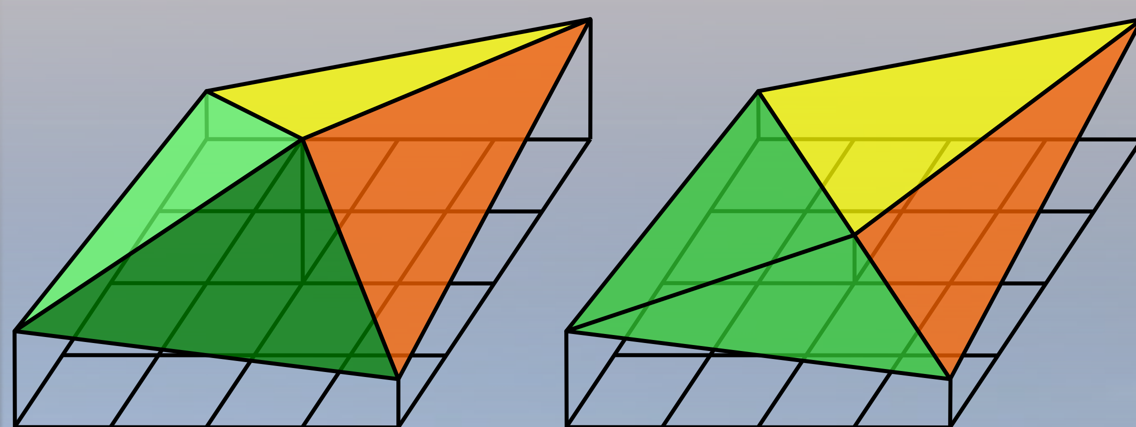
Difficult to achieve in real-time!

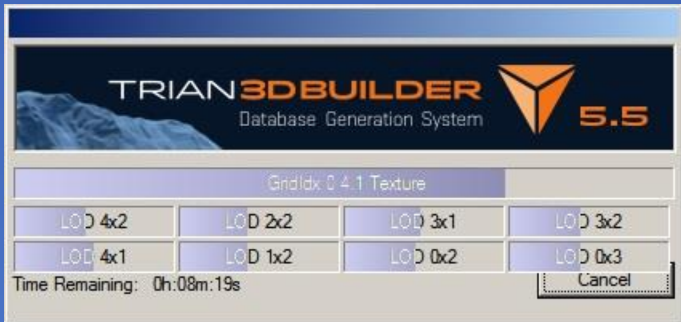
- Pre-process terrain data
- Tolerate blurry textures
- Tolerate inaccurate meshes
- Tolerate defective meshes

DEFECTIVE TERRAIN MESH – GAPS AND T-JUNCTIONS



VALID TERRAIN MESH – CLOSED SURFACE EVERYWHERE





VISUALIZATION

Pre-processing yields optimal results for selected region of interest:

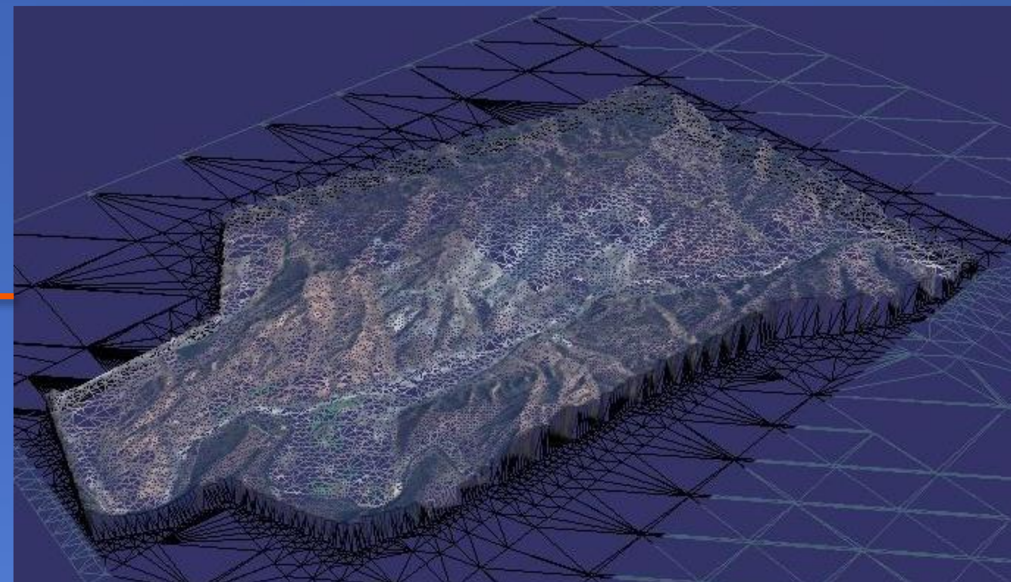
- *Valid terrain mesh*
- *Optimal triangle count*
- *High-quality textures*

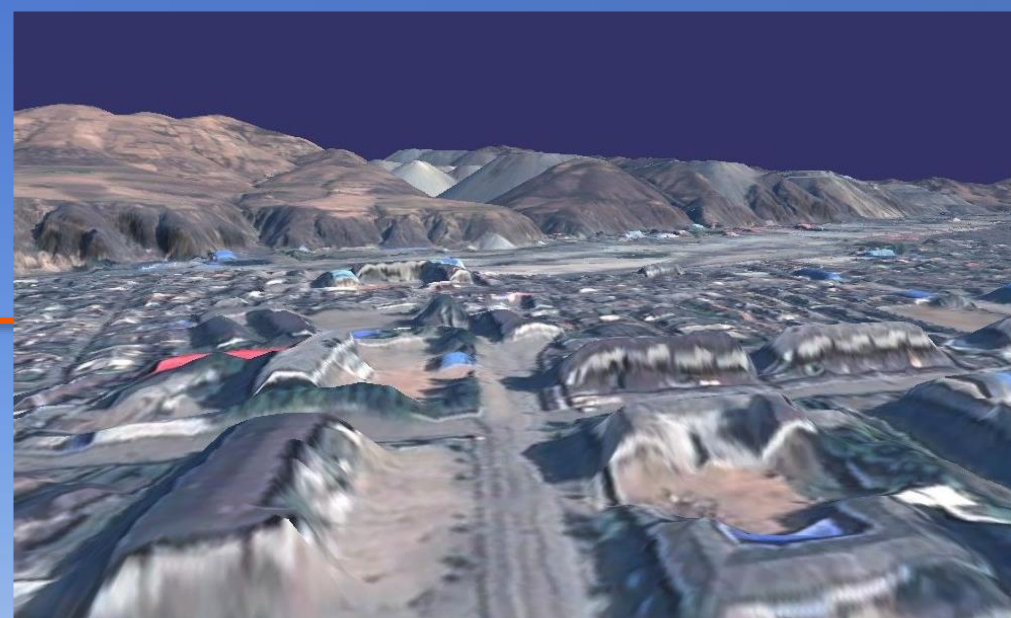
Generated terrain is static:

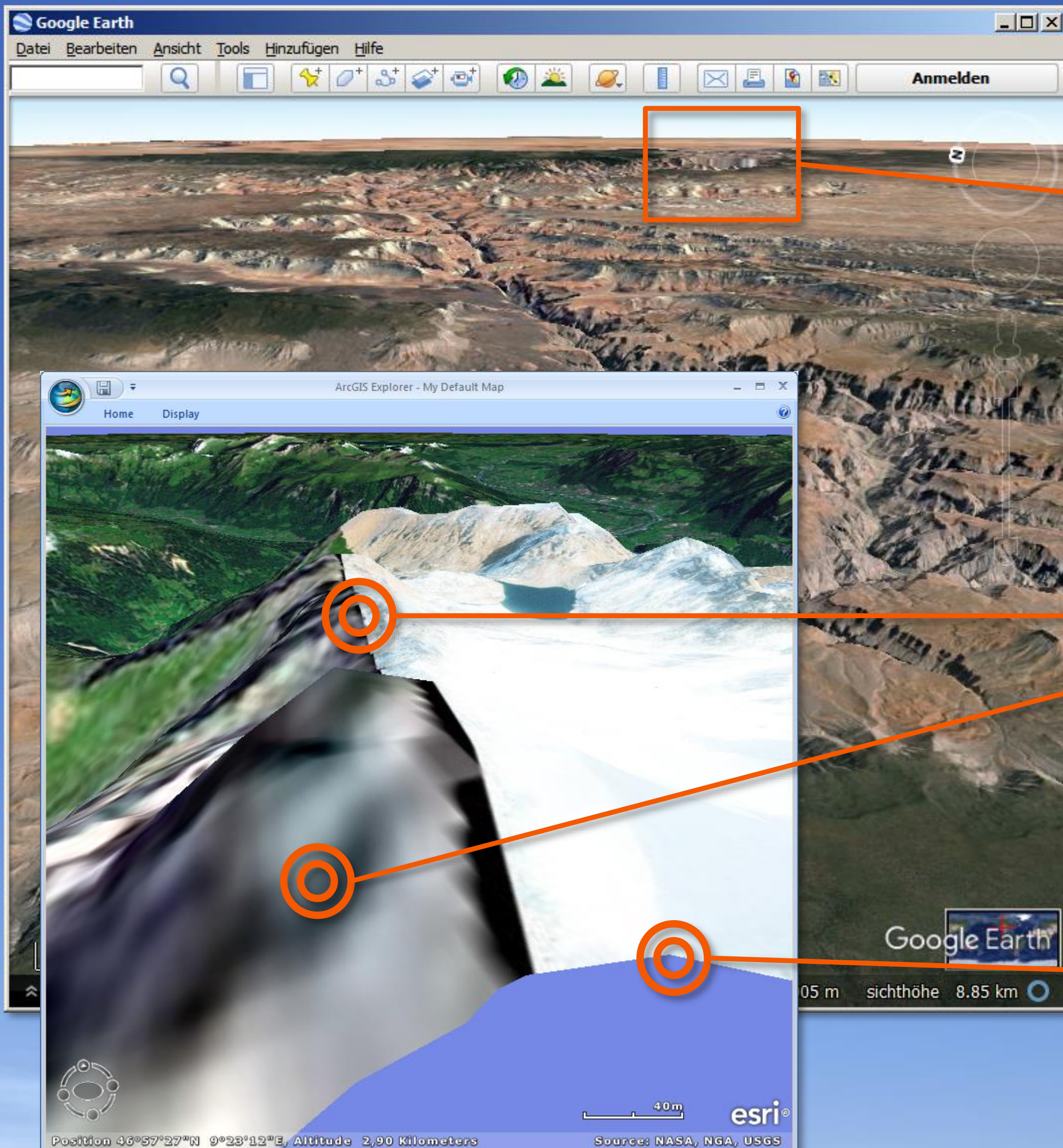
- *Cannot edit after creation*
- *Difficult to merge / adjust*

Trian3DBuilder
http://www.triangraphics.de/

Elevation1 by Airbus Defence & Space
http://www.geo-airbusds.com/







Visualization

Performance vs. texture quality:

- Texture seams
- Blurry textures

Performance vs. vertices / triangles:

- Inaccurate geometry
- Fake geometry
- Low quality geometry

Challenging to implement a general-purpose 3D terrain solution!

https://www.google.com/intl/de/earth/
http://www.esri.com/software/arcgis/explorer/

Visualization

Continuous level-of-detail (CLOD):

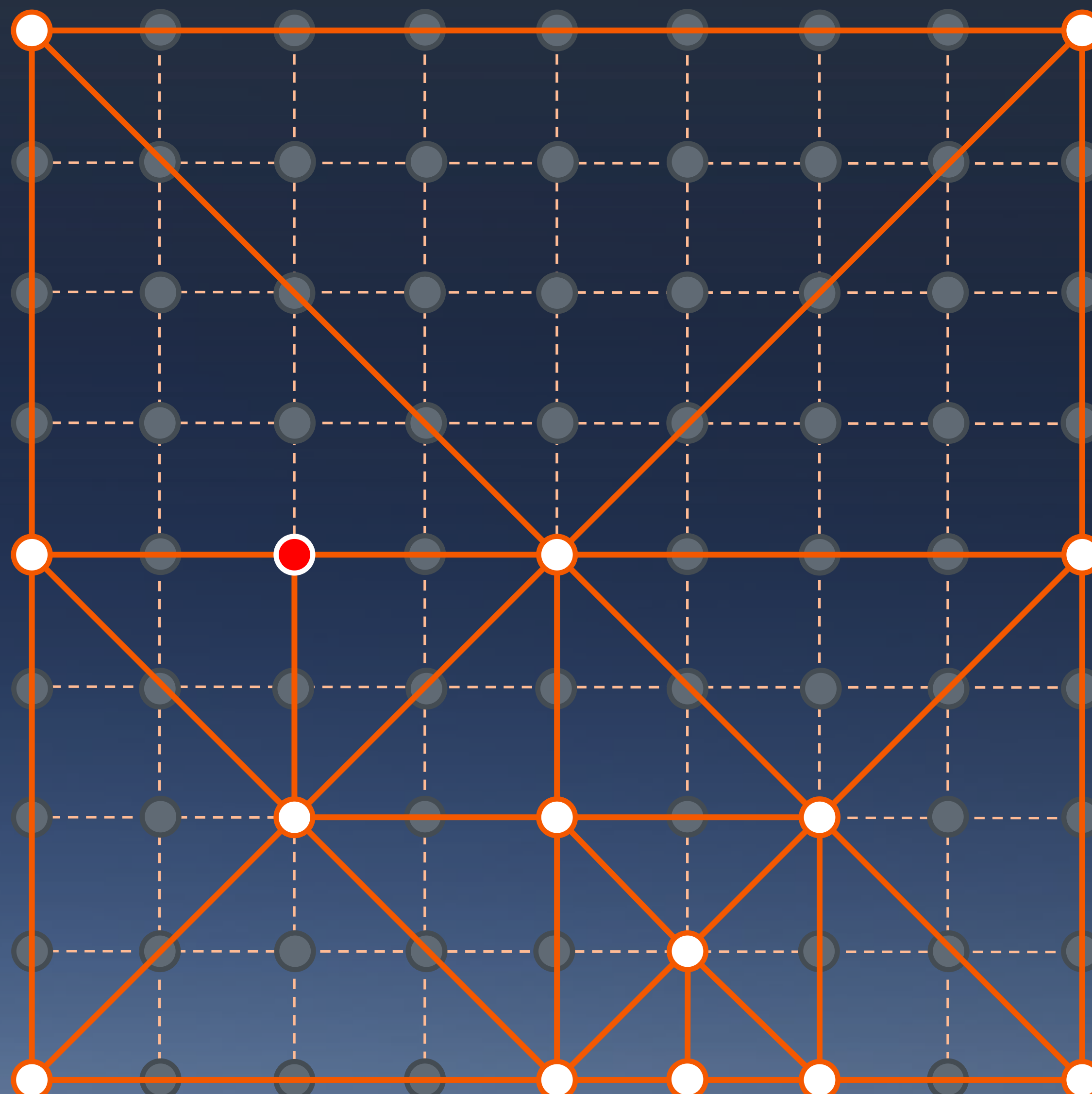
- Based on uniform grid
- Grid points → vertices
- Grid cells → textures
- Right isosceles triangles → RTIN
- Start with 2 triangles → root sector
- Split triangles at longest edge
- Fix T-junctions → forced split
- Load new grid points only
- Merge leaf triangles

Split & merge anywhere, any time:

- Dynamic and adaptive mesh
- Terrain mesh is always valid

Uniform cubemap grid, size 2^30+1:

- Global coverage
- ~9 mm GSD for Earth



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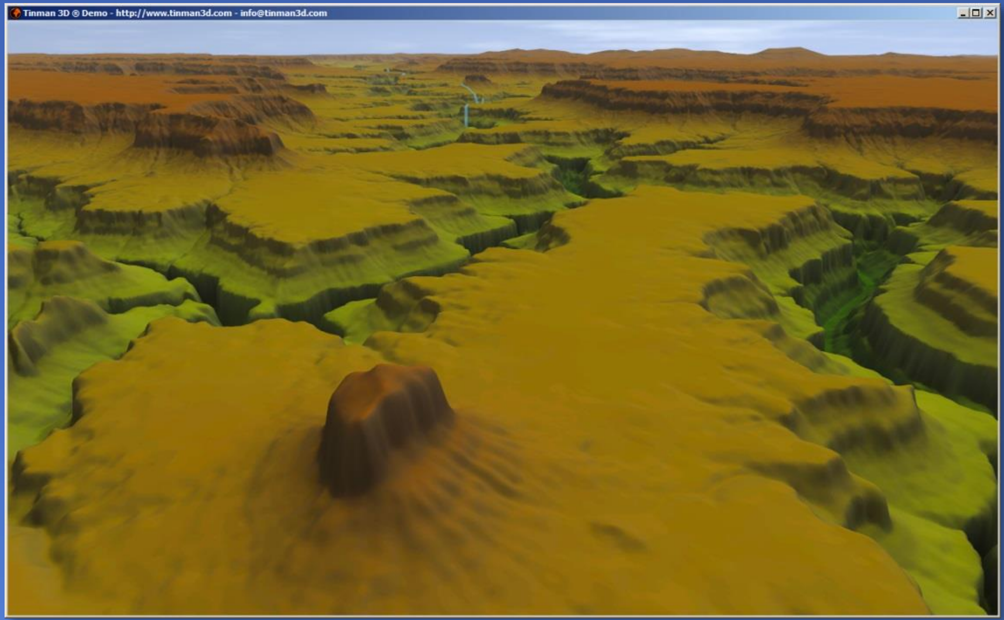
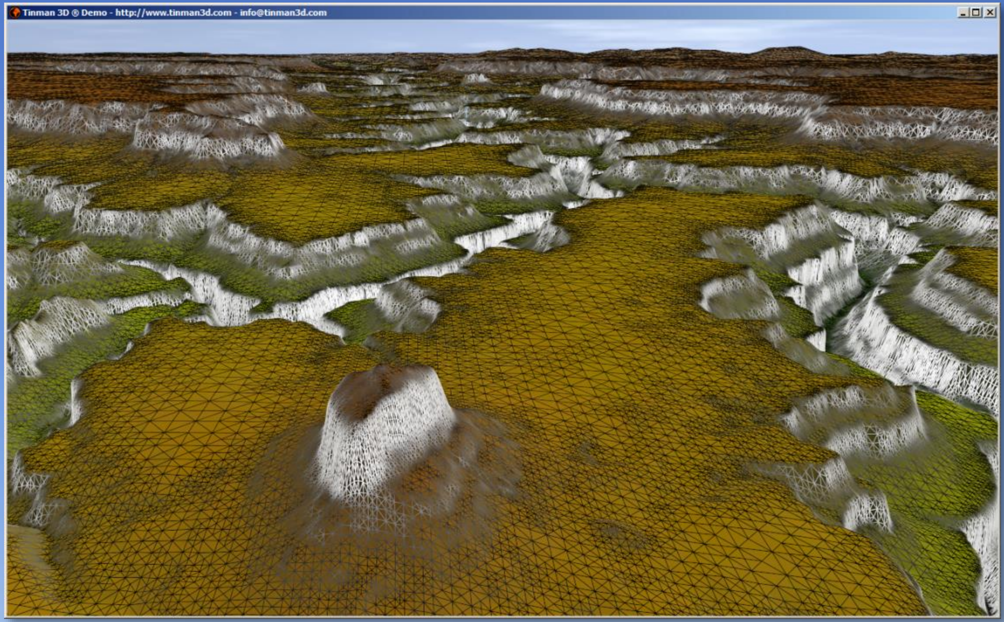




VISUALIZATION

Spatial quad-tree data structure:

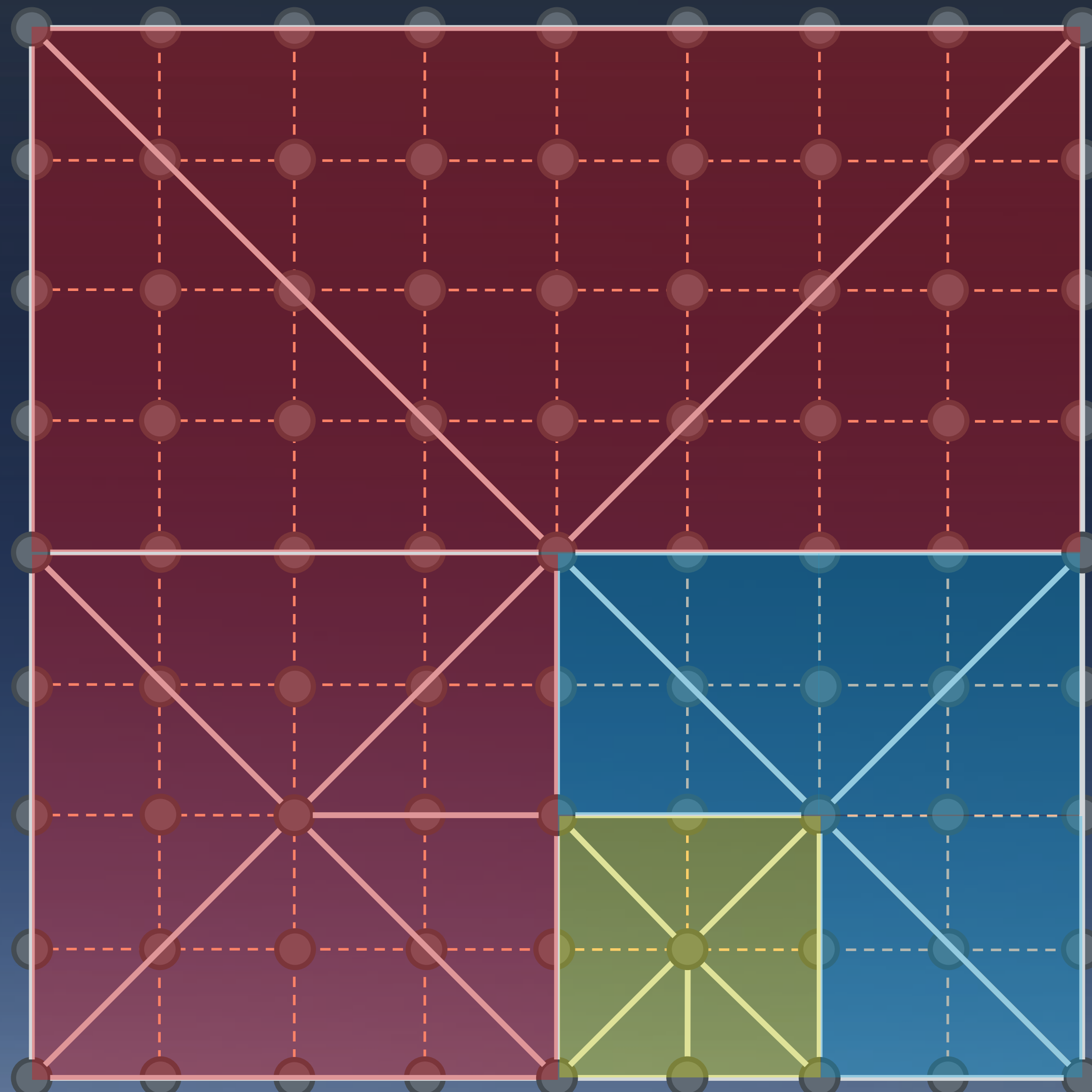
- Root sector spans whole grid
- Split recursively → 4 sub-sectors
- Can be inferred from CLOD,
- ... no extra work necessary!

Attach textures to sectors:

- e.g. 256 x 256 texture per-sector,
- ... as done by GoogleMaps et al.
- to avoid texture seams,
- ... add blend weights to vertices:

f : blend factor child → parent
u, v : texture coordinates [0..1]
B_0, B_1 : precomputed coefficient vectors
x : distance to point of view

$$f = \begin{pmatrix} 1 \\ u \\ v \\ u * v \end{pmatrix} * \left(\overrightarrow{B_0} * \frac{1}{x} + \overrightarrow{B_1}\right)$$



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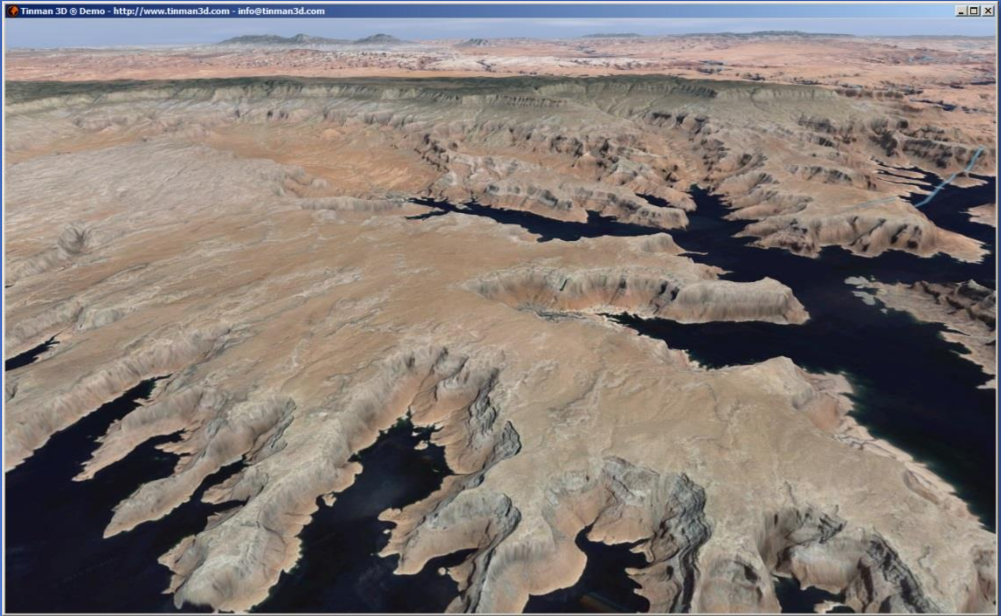
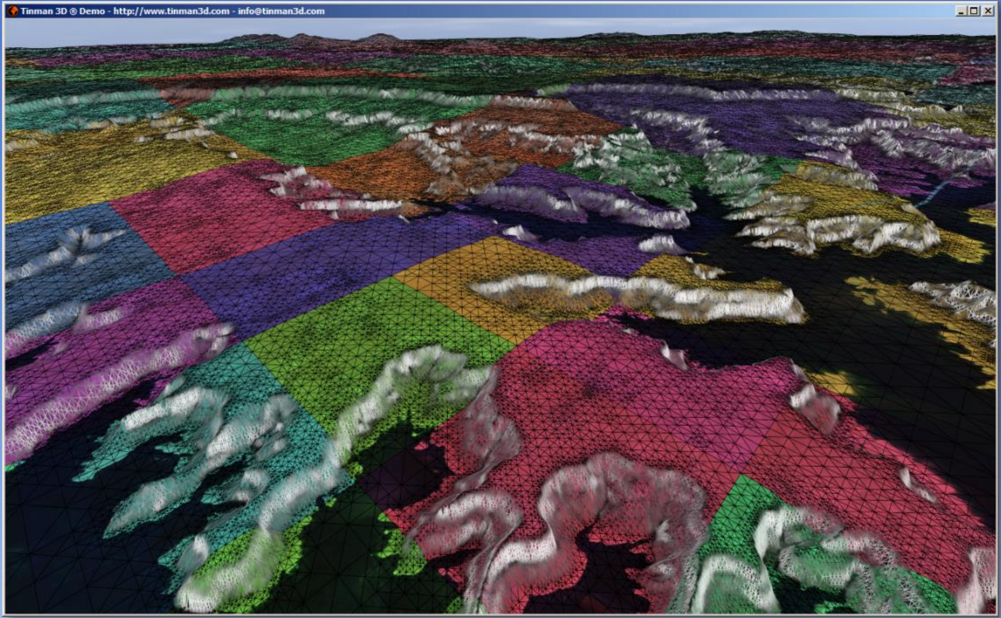




VISUALIZATION

Augment with artificial detail:

- We have a smooth CLOD mesh,
- ... based on accurate geodata
- ... and / or authored content.
- Add per-vertex material weights,
- ... to enhance visual output.

Augmented surface materials:
https://megascans.se/

- Obtained from real-world scans
- ... at very high resolution: < 1 mm.
- Using standard PBR workflow
- ... albedo / ambient occlusion
- ... reflectivity / gloss
- ... normal / displacement

Can be used to dramatically increase the perceived resolution of geodata.

VISUALIZATION

Dynamic editing at runtime:

- We have a global uniform grid,
- ... at 9 mm GSD.
- Can add data anywhere,
- ... with arbitrary resolution.
- The CLOD mesh will adapt,
- ... so will the spatial quad-tree.

Real-time editing workflow:

- Modify grids directly,
- ... or use separate grid for deltas.
- Correct bad data, e.g. spikes.
- Adjust inaccurate data, e.g. roads.
- Author custom scenery.
- WYSIWYG

Can provide editing facilities, without compromise or restrictions!

ANALYSIS

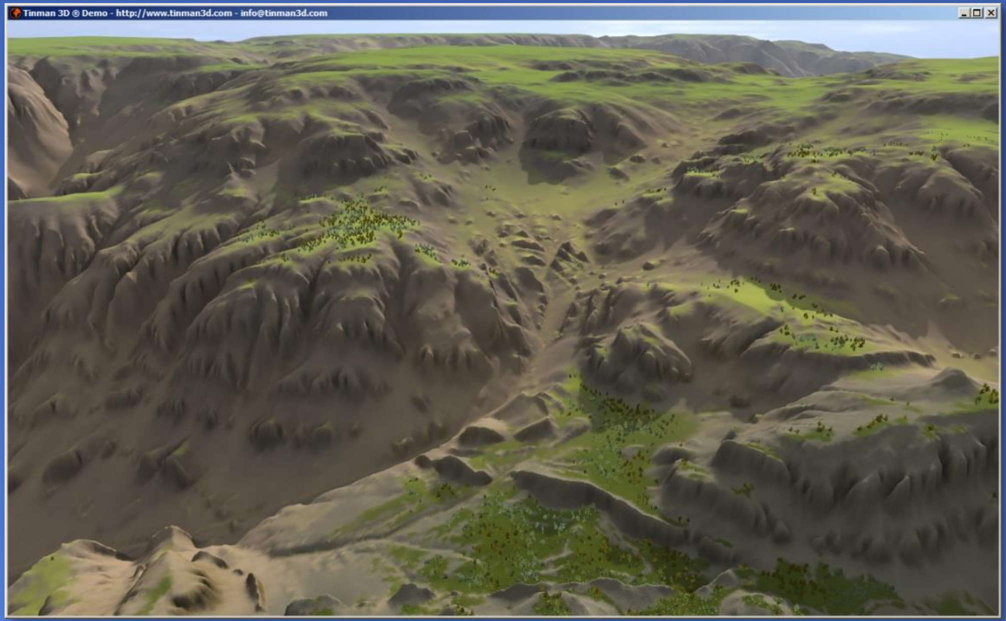
Need a spatial data structure,
to perform queries efficiently:

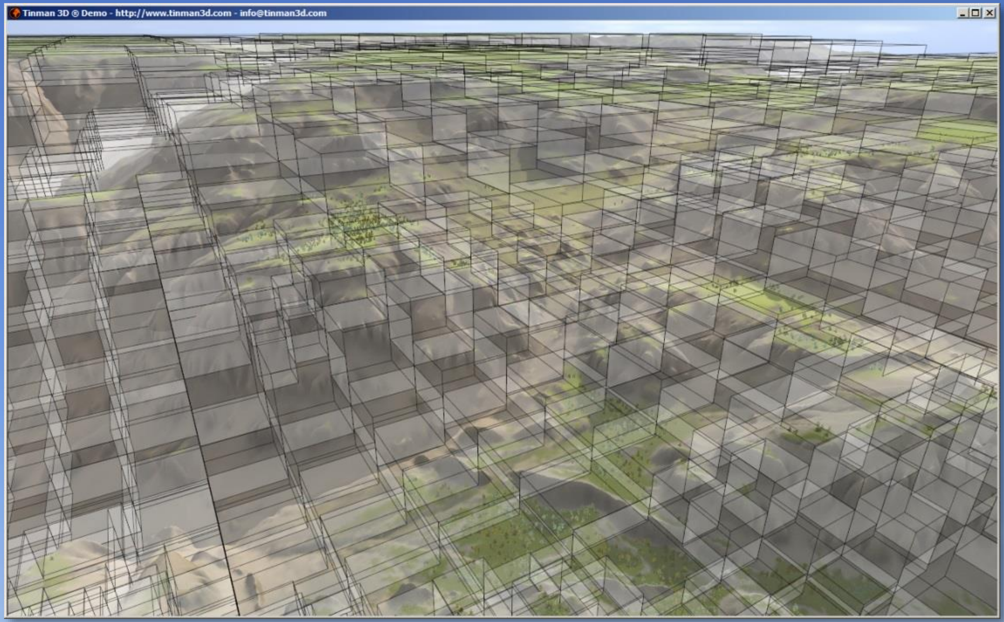
- Collision test
- Visibility test
- Intersection test
- Signed distance field
- Nested data

CLOD mesh already has quad-tree:

- Attach per-vertex bounding spheres
- Attach per-vertex AABB's
- Add nested data to quad-tree,
- ... bounding sphere radii
- ... min / max elevation
- ... material mask

Augmented quad-tree can be used for many kinds of spatial queries!





Thank you!

Matthias Englert - me@tinman3d.com

AABB	- Axis Aligned Bounding Box
ASTER GDEM 2	- Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model
CLOD	- Continuous Level Of Detail
CPU	- Central Processing Unit
CRS	- Coordinate Reference System
DSM, DTM	- Digital Surface Model, Digital Terrain Model
GDAL	- Geospatial Data Abstraction Library
GMTED 2010	- Global Multi-resolution Terrain Elevation Data 2010
GPU	- Graphics Processing Unit
GSD	- Ground Sample Distance
IB, VB	- Index Buffer, Vertex Buffer
LOD	- Level Of Detail
NED	- National Elevation Dataset
PBR	- Physically Based Rendering
ROAM	- Real-time Optimally Adapting Meshes
SDF	- Signed Distance Field
SOAR	- Stateless, One-pass Adaptive Refinement
SRTMGL1	- Shuttle Radar Topography Mission Global DEM 1"
TIN, RTIN	- (Right) Triangulated Irregular Network
WGS84, EGM96	- World Geodetic System, Earth Gravitational Model
WKT	- Well Known Text
WYSIWYG	- What You See Is What You Get

Demo & Questions