R.REFINE: Scalable Raster to TIN Simplification

Jonathan Todd   Laura Toma

Bowdoin College

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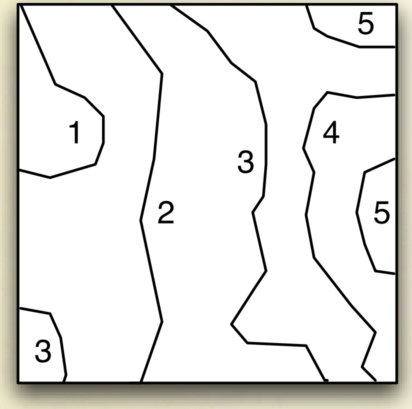
Lausanne, Switzerland

Data is GROWING!!!

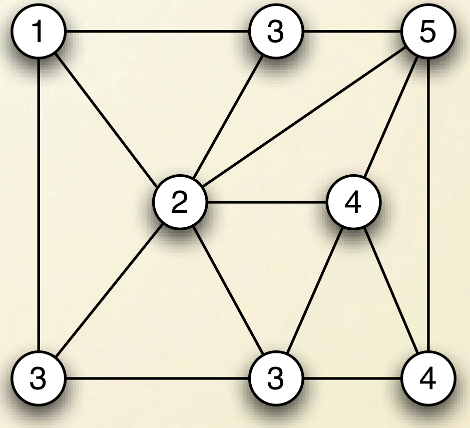
- NASA's SRTM mapped 80% of the earth at 30 meter resolution
    - SRTM data set: 300,000 x 300,000 raster
- USGS & NASA publicly release terabytes of data
- LIDAR data collection produces extremely large data sets at high resolution

DEM Representations

Contour Lines



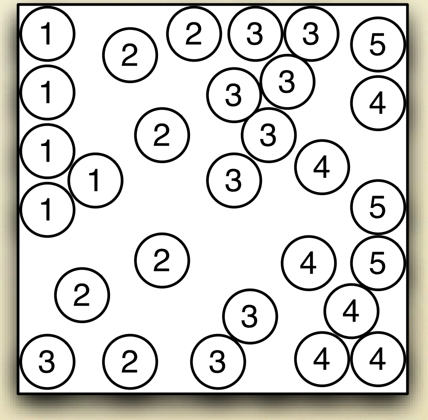
TIN



Raster

1	2	2	3	3	5	5
1	2	2	3	3	4	4
1	1	2	3	3	4	5
1	1	2	2	3	4	5
2	2	2	2	3	4	5
3	2	2	2	3	3	4
3	2	2	3	3	3	4

Sample Points



Raster - TIN Comparison

Rasters

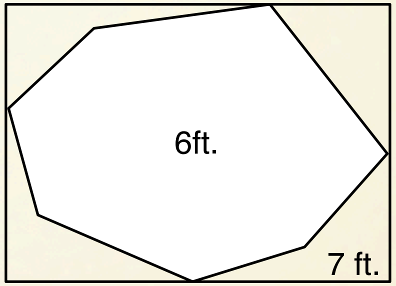
- Fixed Resolution
- Implicit Topology
    - Don’t need to store adjacency explicitly
- Simple algorithms
- Large amount of grid data available
- Most Commonly Used

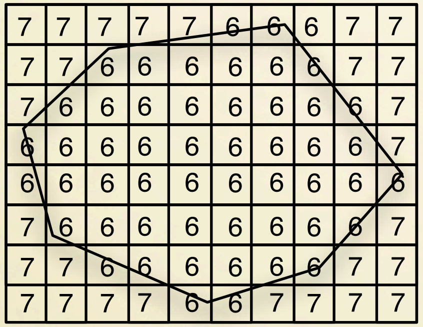
TINs

- Variable resolution
- Topology needs to be stored explicitly
- Algorithms are more complex
- Data needs to be converted into a TIN
- Somewhat less popular than grids

Variable Resolution

Flat Area

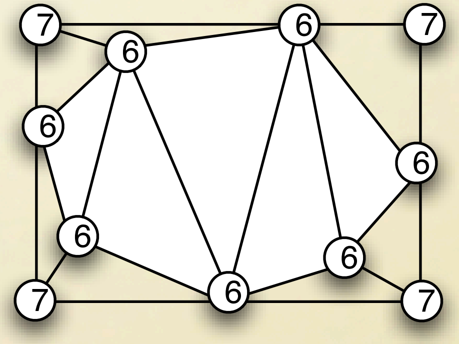




7	7	7	7	7	6	6	6	7	7
7	7	6	6	6	6	6	6	7	7
7	6	6	6	6	6	6	6	6	7
6	6	6	6	6	6	6	6	6	7
6	6	6	6	6	6	6	6	6	6
7	6	6	6	6	6	6	6	6	7
7	7	6	6	6	6	6	6	7	7
7	7	7	7	6	6	7	7	7	7

Raster - 80 pts

TIN -11 pts, 12 tris



Representing Massive data

- With rasters, the same amount of space is used to represent
  - a mountainous region (Himalayas)
  - a flat area (Mohave desert)
- Space efficiency becomes more important for massive data!
- Increased space efficiency can significantly reduce run time

Scalable raster-to-TIN Simplification

- raster-to-TIN simplification
  - simplify raster to TIN which approximates the raster within a user specified error threshold
  - intuitively: drop points in the raster that are redundant
- Scalable raster to TIN simplification
  - efficient when size of input raster becomes very large

R.REFINE

- Scalable raster-to-TIN simplification module
    - Input: raster, error threshold e
    - Output: simplified TIN
- Based on an I/O efficient algorithm

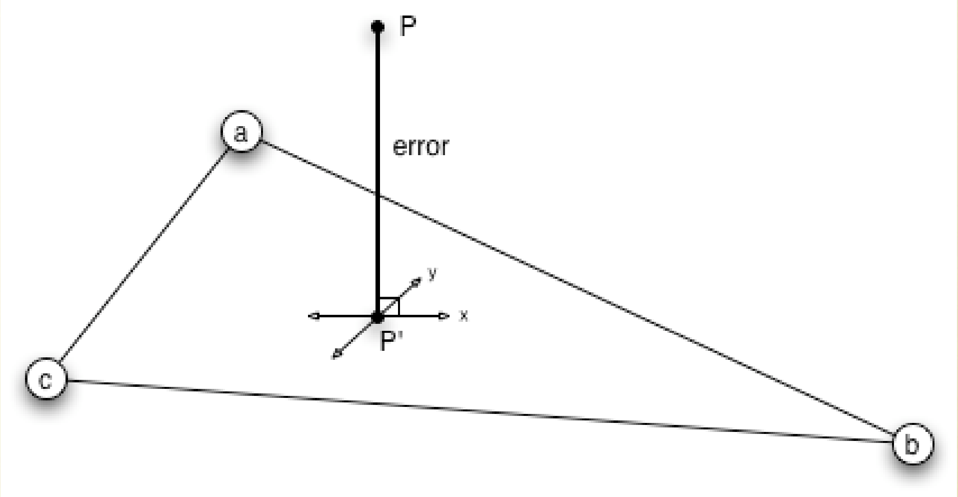
Outline

- [Introduction]
- Raster simplification
- r.refine
- Results
  - Scalability
  - Space efficiency
- Conclusion & Future Work

Raster Simplification

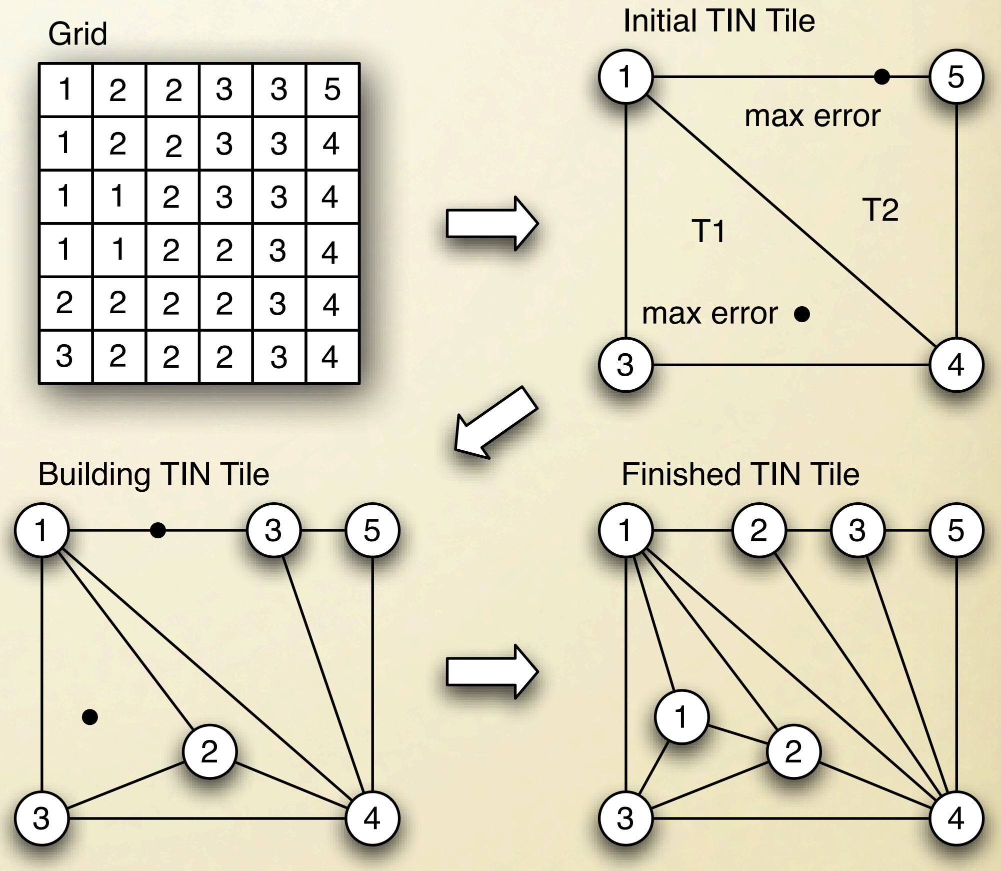
Raster Simplification

- Problem:
  - Given a raster with points ***P*** and an error ε, find ***S*** ∈ ***P*** which approximates ***P*** within ε: that is, every point in ***S*** is within distance ε of ***P***.



Refinement Heuristics

- Start with 4 corner pts of raster
- Repeat:
  - Find point with largest error
  - Add point to triangulation
  - If no more points with error > ε Then break;



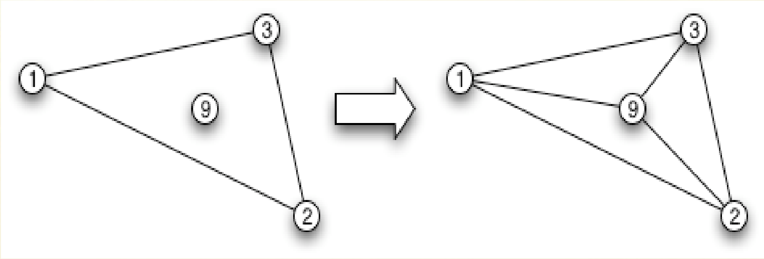
Grid

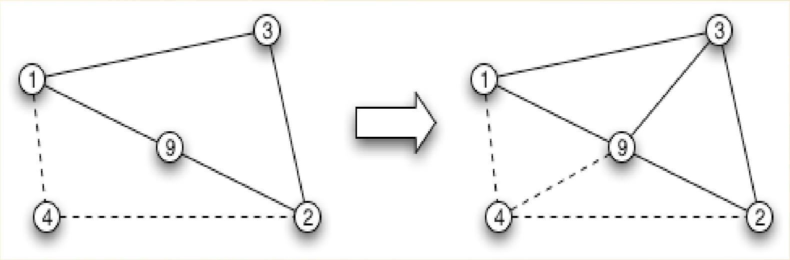
1	2	2	3	3	5
1	2	2	3	3	4
1	1	2	3	3	4
1	1	2	2	3	4
2	2	2	2	3	4
3	2	2	2	3	4

ε = 1

Refinement: Adding Points

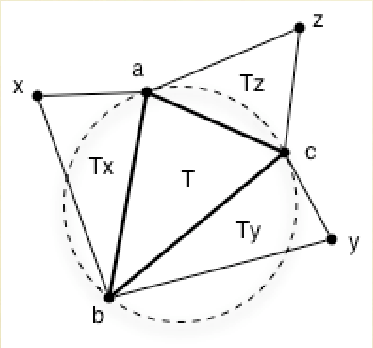
- If point not collinear add 3 triangles
- If collinear add 4 triangles



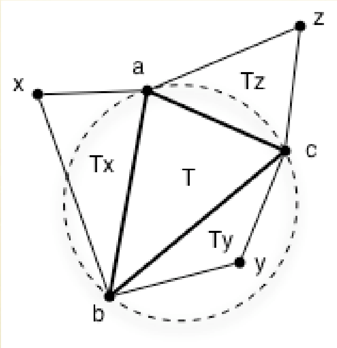


Delaunay Triangulation

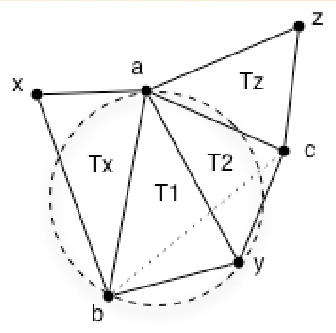
- Delaunay is a type of triangulation which has the property of maximal minimum angle. (Triangles are fat)
- A triangle is locally Delaunay if its circum-circle does not contain any other points in the triangulation
- Delaunay is desirable because it reduces rounding errors and has shown to reduce triangles in a TIN



Delaunay



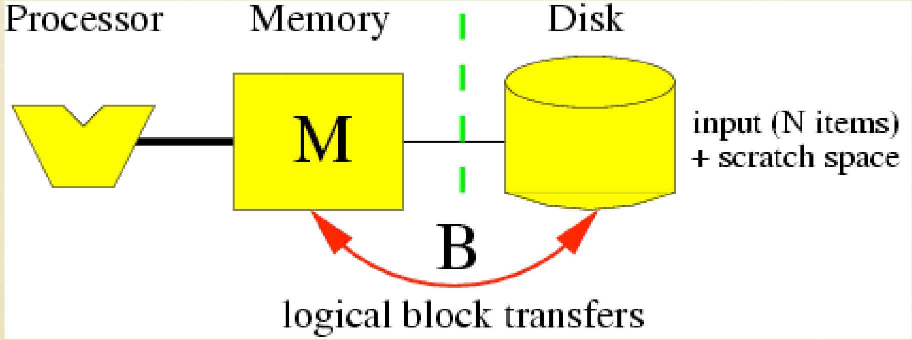
Not Delaunay



Edge flipping

Scalability

- Refinement is not scalable
- Refinement requires random access to data
    - If data-size > mem-size run time is very long
    - GRASS segment library does not fix this
- Large data-sets necessitate scalability



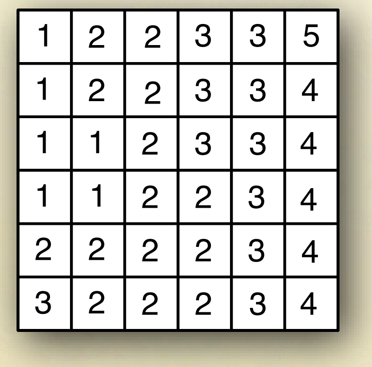
R.REFINE

A scalable approach for raster-to-TIN simplification

Tiling for I/O-Efficiency

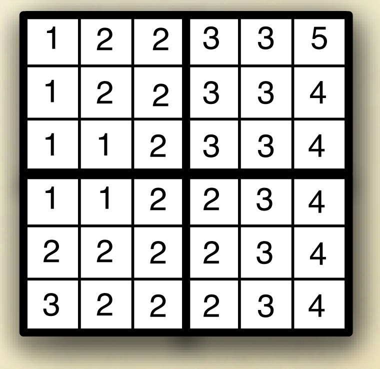
- Tiling is a common I/O optimization technique
  - Take size of memory as parameter
  - Separate large grid into tiles
  - Each tile is small enough to fit in memory
  - Refine each tile individually then write to disk

Too big for memory



1	2	2	3	3	5
1	2	2	3	3	4
1	1	2	3	3	4
1	1	2	2	3	4
2	2	2	2	3	4
3	2	2	2	3	4

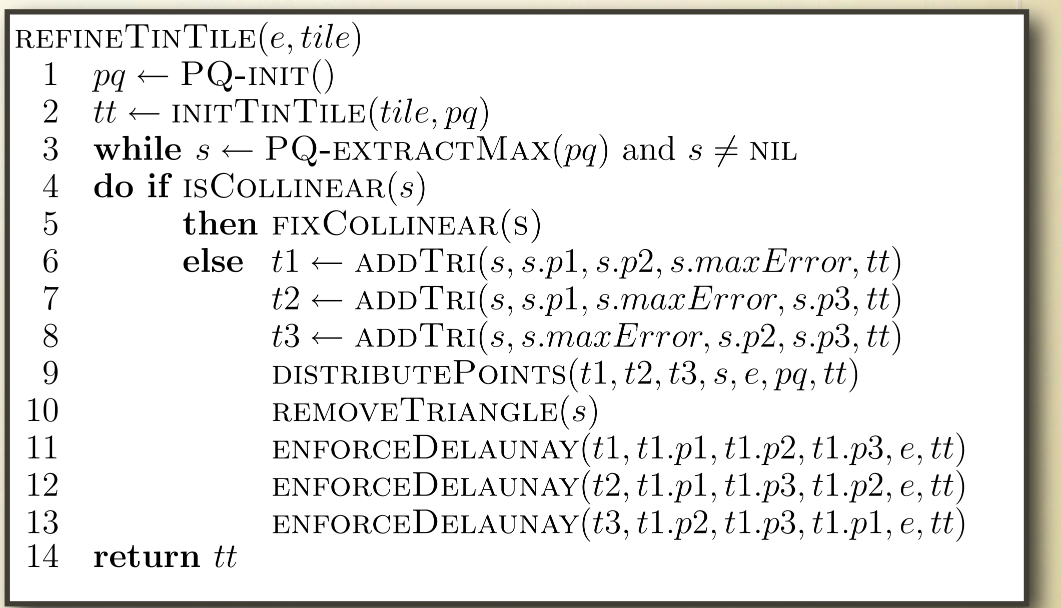
Tiled Raster



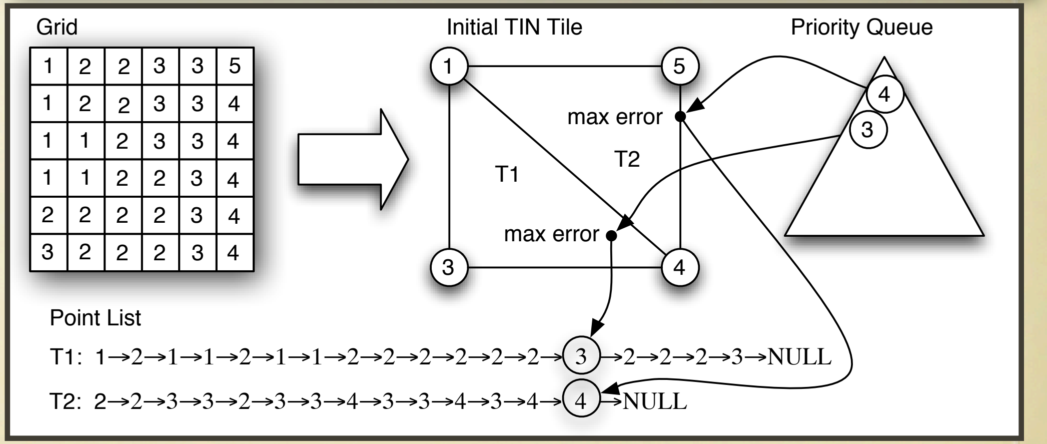
1	2	2	3	3	5
1	2	2	3	3	4
1	1	2	3	3	4
1	1	2	2	3	4
2	2	2	2	3	4
3	2	2	2	3	4

Our Refinement

- We use the standard refinement algorithm within each tile
- We maintain Delaunay triangulation while building the TIN



```
REFINETINTILE$(e, tile)$
  $pq \leftarrow$ PQ-INIT()
  $tt \leftarrow$ INITTINTILE$(tile, pq)$
  while $s \leftarrow$ PQ-EXTRACTMAX$(pq)$ and $s \neq$ NIL
  do if ISCOLLINEAR$(s)$
        then FIXCOLLINEAR(S)
        else $t1 \leftarrow$ ADDTRI$(s, s.p1, s.p2, s.maxError, tt)$
             $t2 \leftarrow$ ADDTRI$(s, s.p1, s.maxError, s.p3, tt)$
             $t3 \leftarrow$ ADDTRI$(s, s.maxError, s.p2, s.p3, tt)$
             DISTRIBUTEPOINTS$(t1, t2, t3, s, e, pq, tt)$
             REMOVETRIANGLE$(s)$
             ENFORCEDELAUNAY$(t1, t1.p1, t1.p2, t1.p3, e, tt)$
             ENFORCEDELAUNAY$(t2, t1.p1, t1.p3, t1.p2, e, tt)$
             ENFORCEDELAUNAY$(t3, t1.p2, t1.p3, t1.p1, e, tt)$
  return $tt$
```



Grid

1	2	2	3	3	5
1	2	2	3	3	4
1	1	2	3	3	4
1	1	2	2	3	4
2	2	2	2	3	4
3	2	2	2	3	4

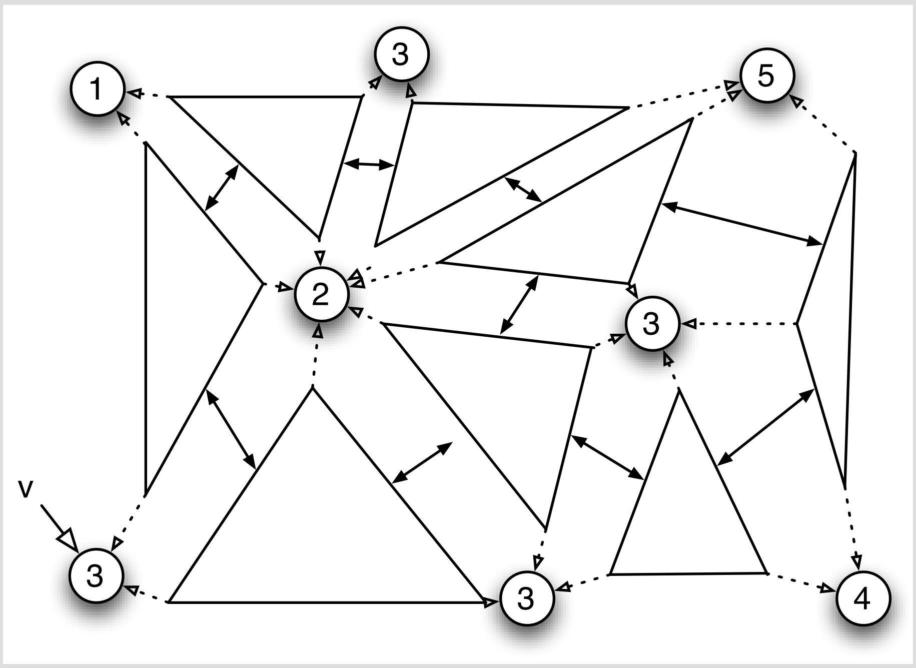
Point List

T1: 1→2→1→1→2→1→1→2→2→2→2→2→2→ 3 →2→2→2→3→NULL

T2: 2→2→3→3→2→3→3→4→3→3→4→3→4→ 4 →NULL

TIN Structure

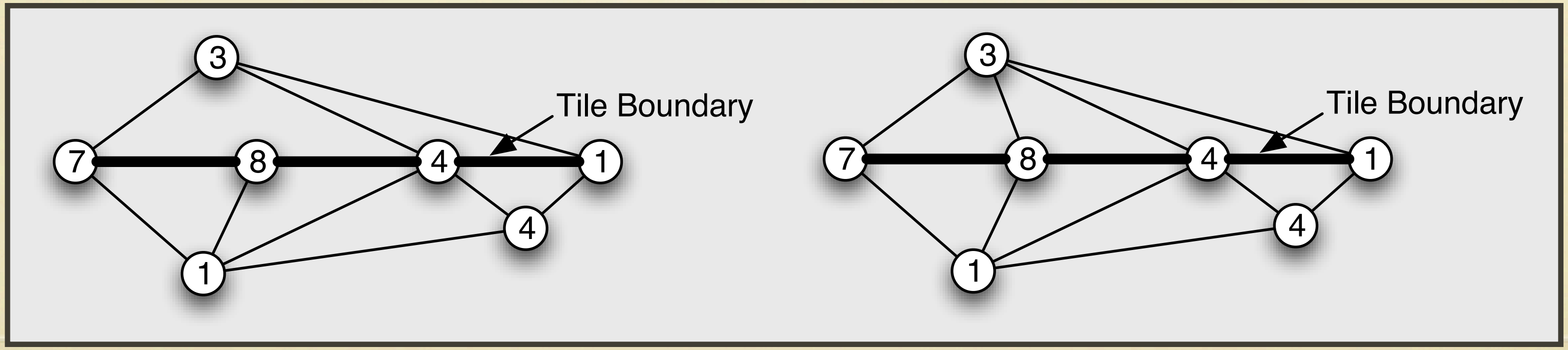
- Two structures:
  - Triangles
  - Vertices



- Triangles store:
  - Pointer to adjacent triangles
  - Pointer to vertices
  - List of points inside
- Points store:
  - Location (x,y,z)
- TIN is accessed through lower left vertex V

Combining Tiles

- Need to combine tiles such that boundary points are consistent
- We refine one tile at a time starting with the upper left tile. We maintain consistency by adding points to right and bottom neighbors.
- There is no known way to maintain Delaunay globally and I/O-efficiently



Using r.refine

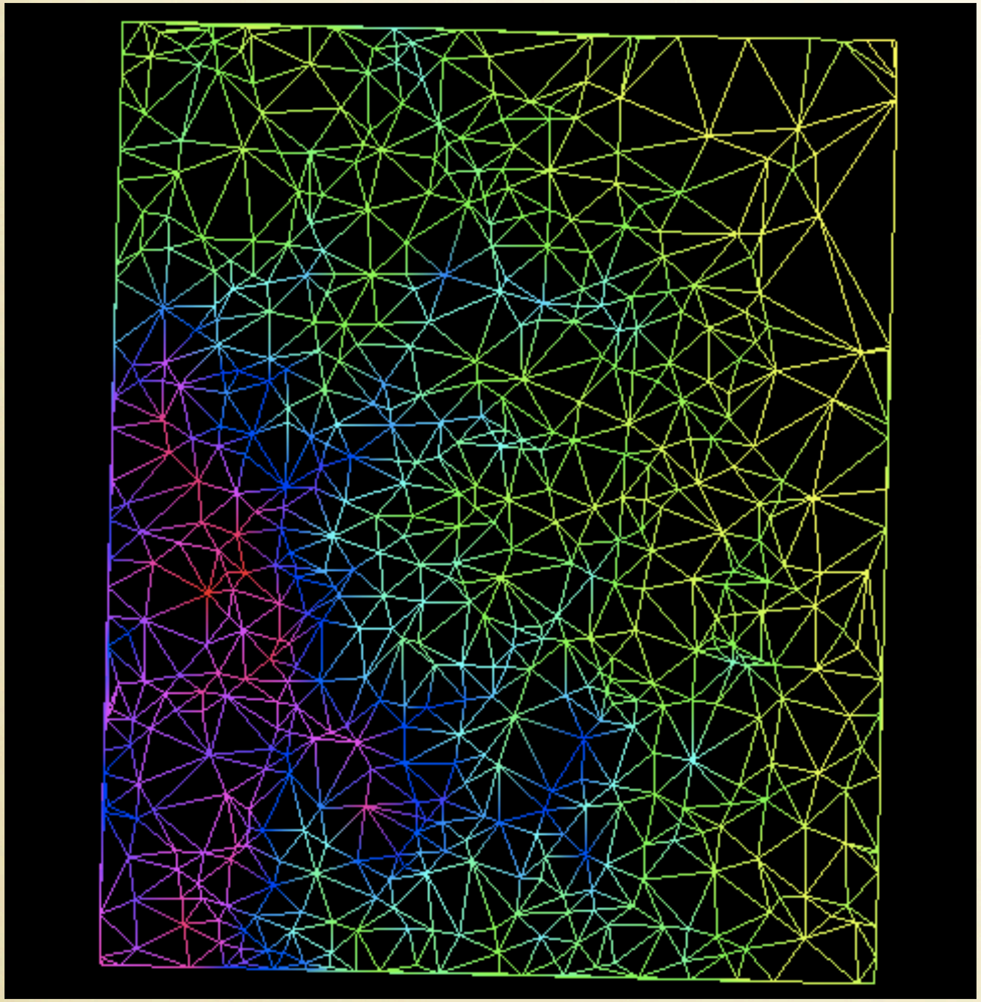
Running r.refine

- Flags
  - –d Don’t use Delaunay
  - –n Include nodata points
  - –r Render
- Parameters
  - Input grid
  - Epsilon (% of Max Elevation)
  - Output TIN
  - Output sites
  - Output vector
  - Memory (Default 500 MB)

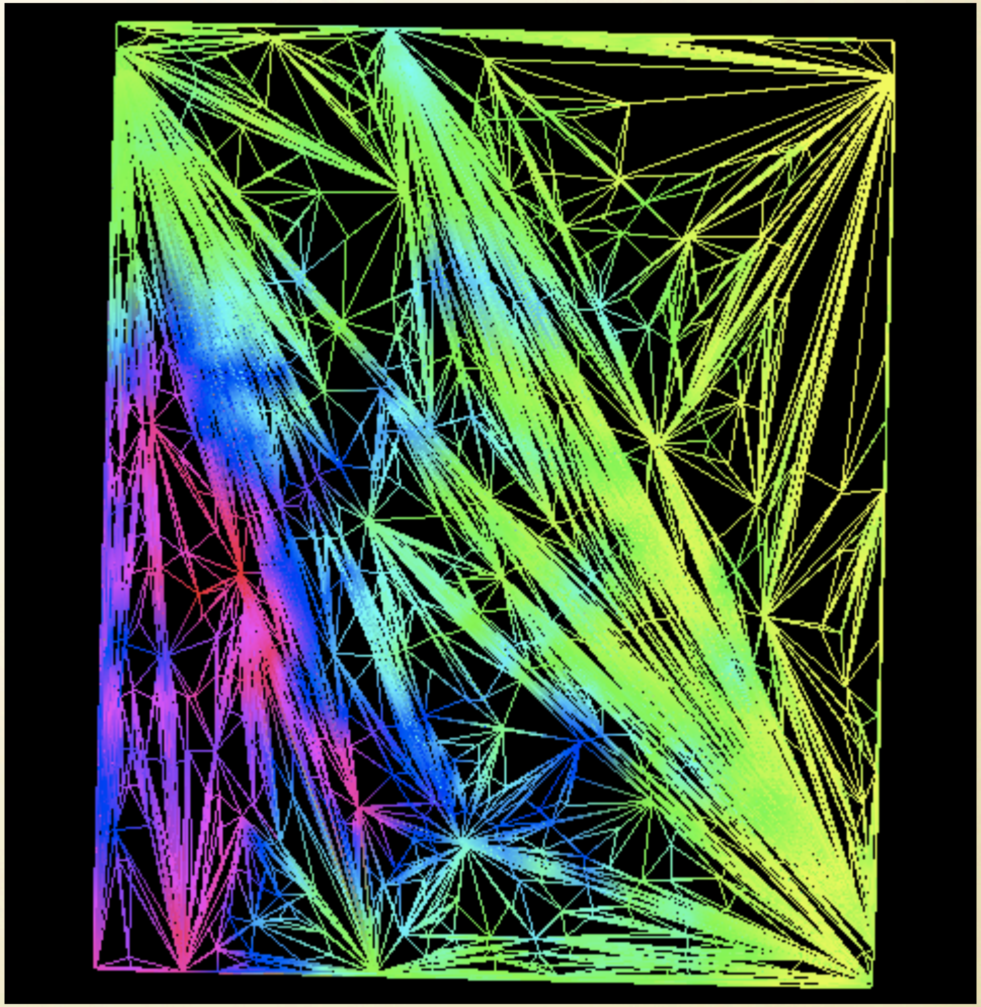
```
Description:
 r.refine: scalable raster-to-TIN simplification.

Usage:
 r.refine [-dnr] grid=name [epsilon=value] [tin=name]
   [output_sites=name] [output_vect=name] [memory=value]

Flags:
  -d   Do NOT use Delaunay triangulation
  -n   Include nodata points (more points, better boundaries)
  -r   Render TIN in OpenGL

Parameters:
          grid   Input raster
       epsilon   Error threshold, in percentage of max elevation
                 default: 1.0
           tin   Output TIN file
                 default: output.tin
  output_sites   Name of output sites file.
                 default: NULL
   output_vect   Name of output vector file.
                 default: NULL
        memory   Main memory size (in MB)
                 default: 500
```

r.refine Output

```
GRASS:~/nfs-gis/> r.refine grid=elev eps=3 output_sites=eleve3 output_vect=eleve3
region size is 472 x 391
r.refine grid=elev output=output.tin output-sites=eleve3 outputVect=eleve3
error=3.00 mem=500.00 delaunay=1 no_data=0 render=0
raster2grid: reading raster elev....done
refining
write TIN tile to sites file eleve3
 100%
write TIN tile to vect file eleve3
done refining
.......DONE........
err=3.00% absErr=27.48 mem=500.00MB numTiles=1
raster: 184552 points
TIN: triangles=2350 points=1183
total time: 1.70        99.9%
```



Delaunay



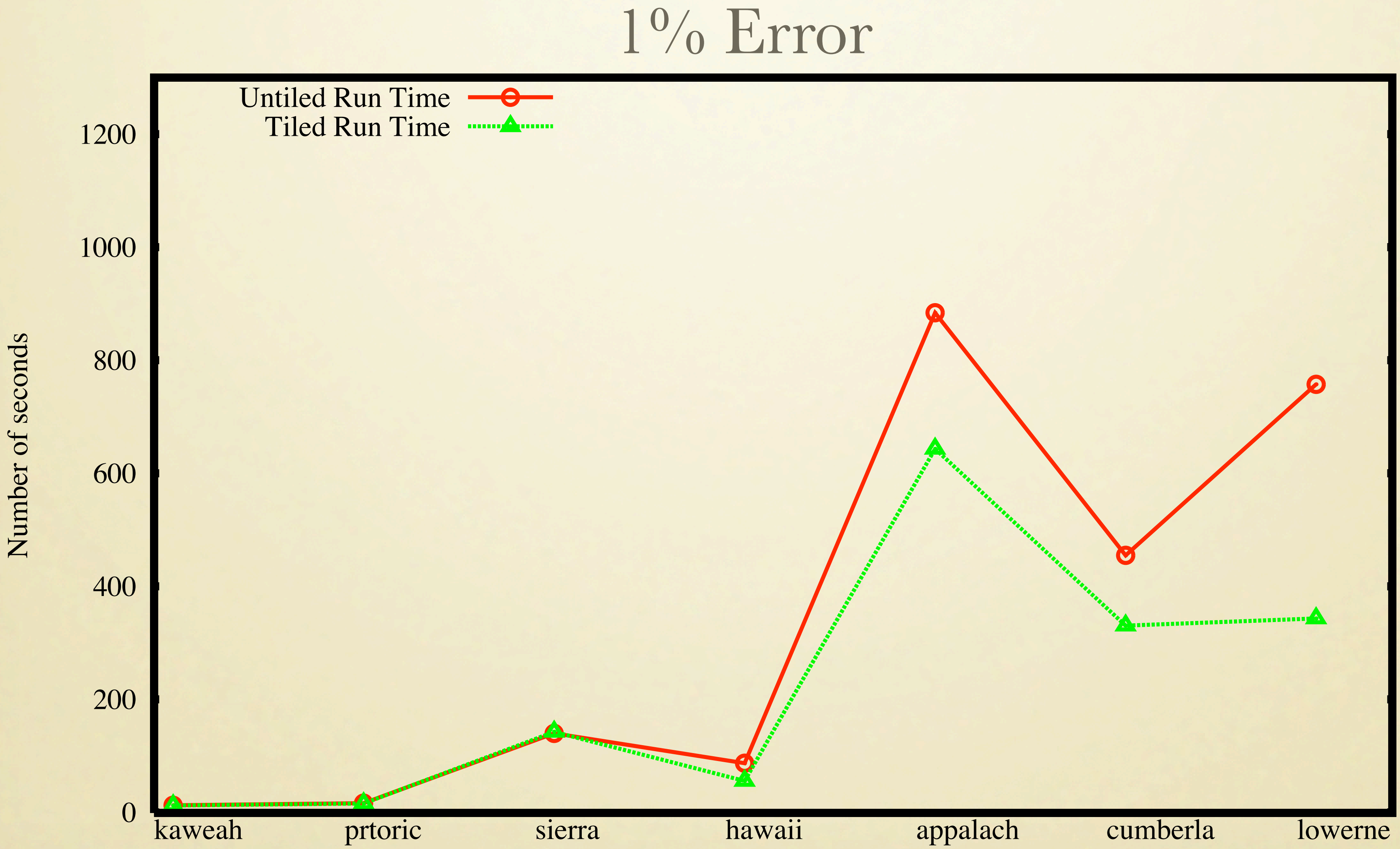
Non-Delaunay

Results

Test Platform

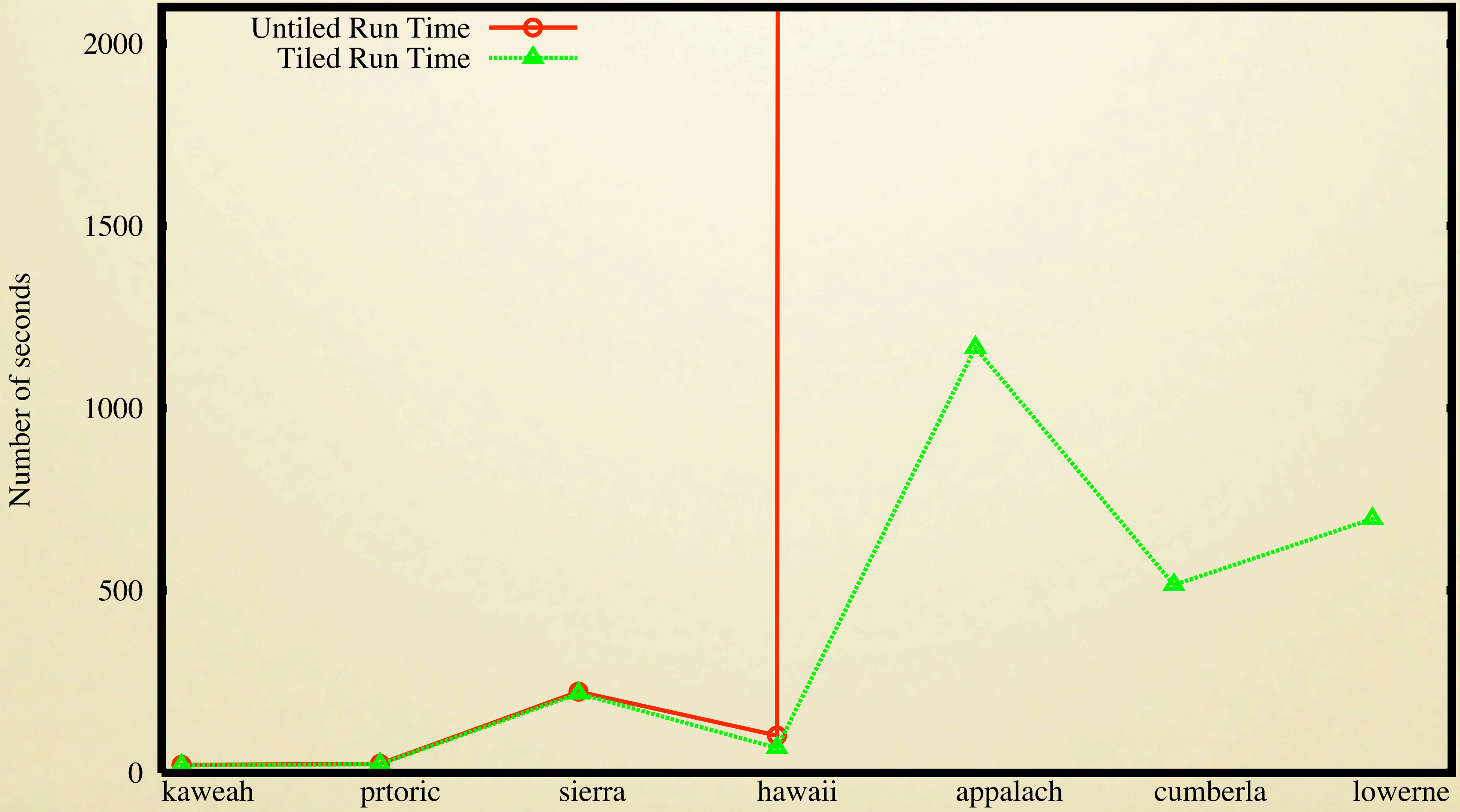
- Apple Dual Processor G5
- 2.5 GHZ CPU
- 1 GB RAM
- Data Sets from 1.6 million to 122 million points

Tiled vs Untiled Runtime Comparison

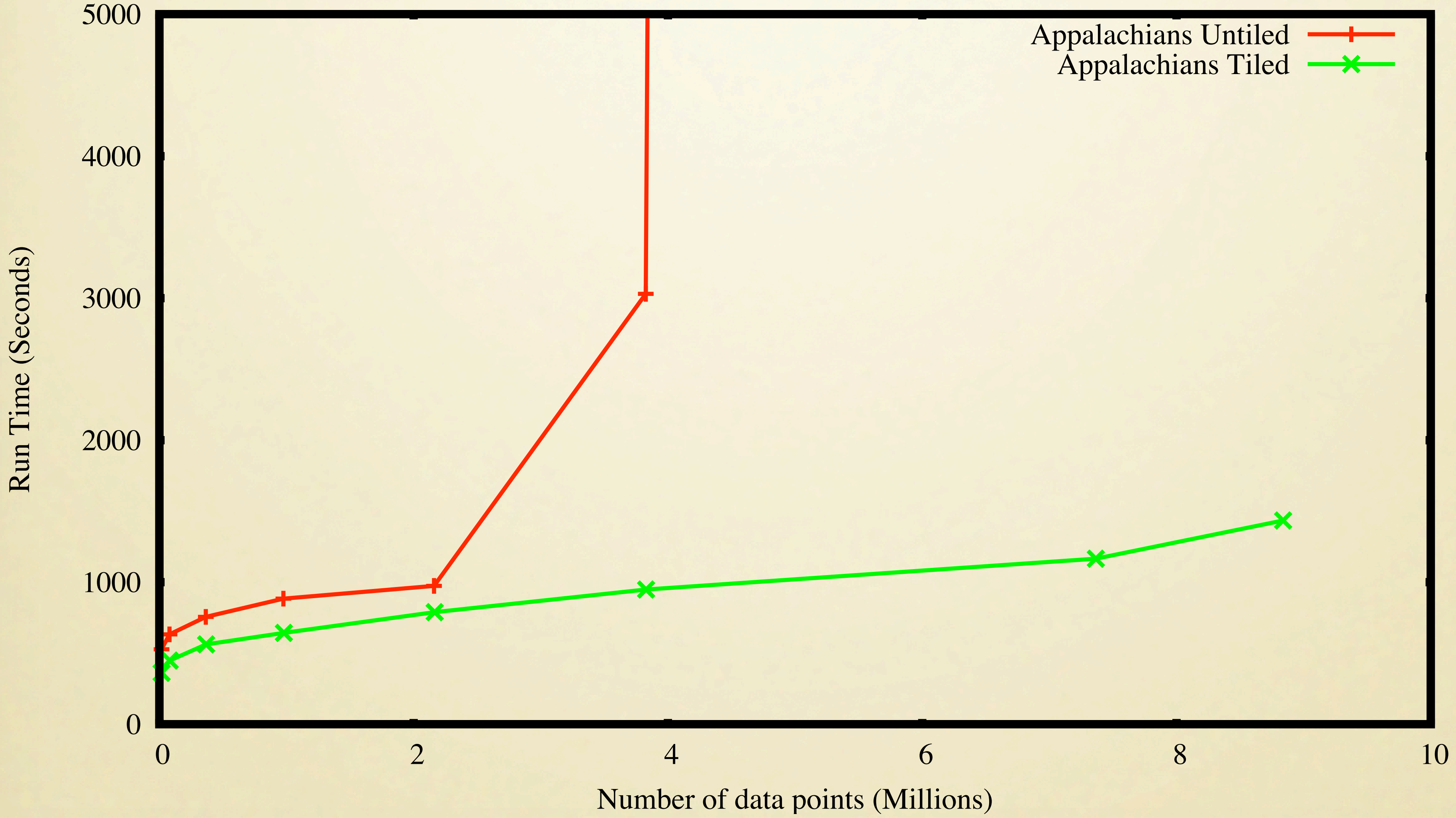


Titled vs Untiled Runtime Comparison

0.1% Error

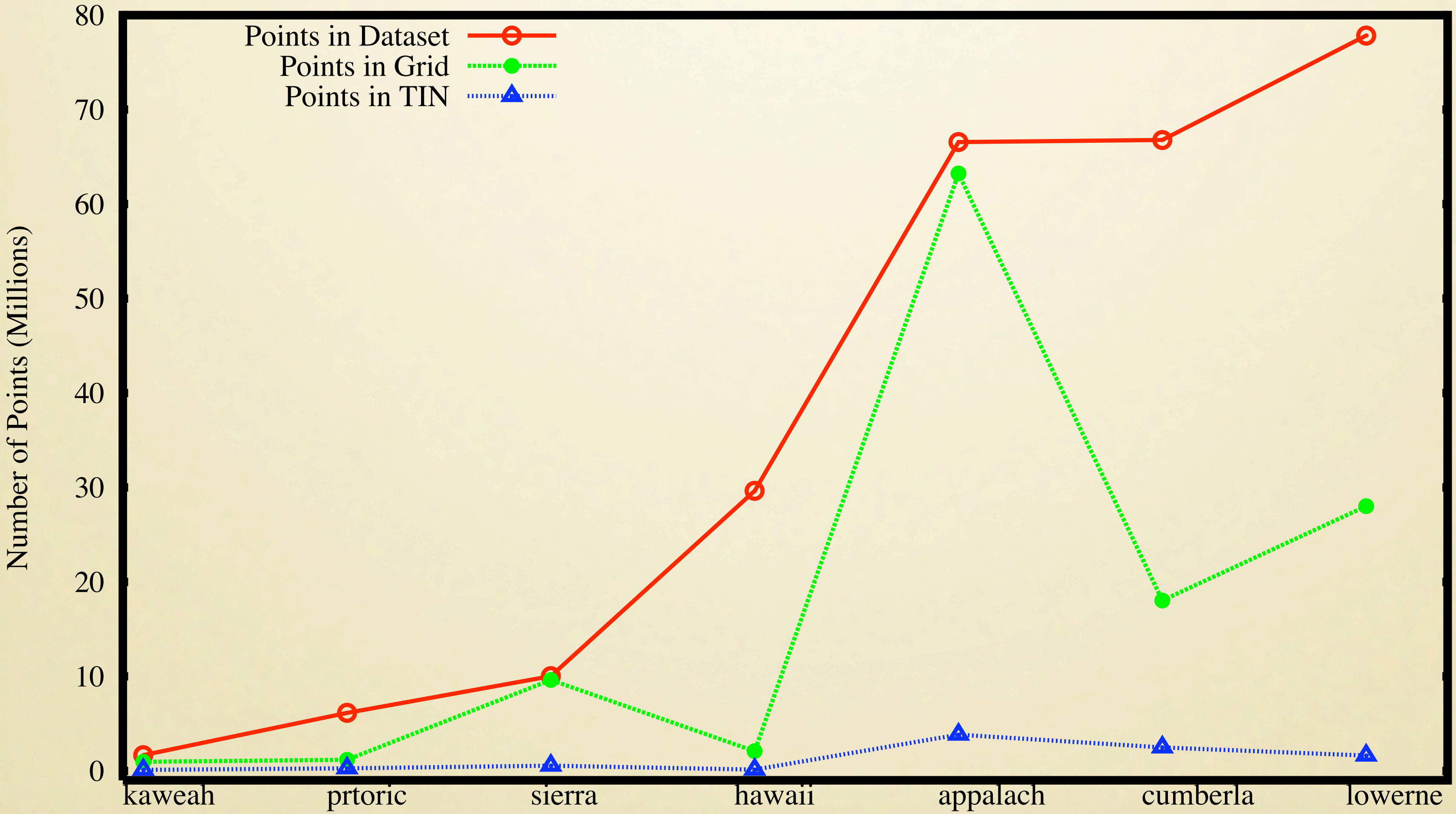


Tiled vs Comparison On Appalachians

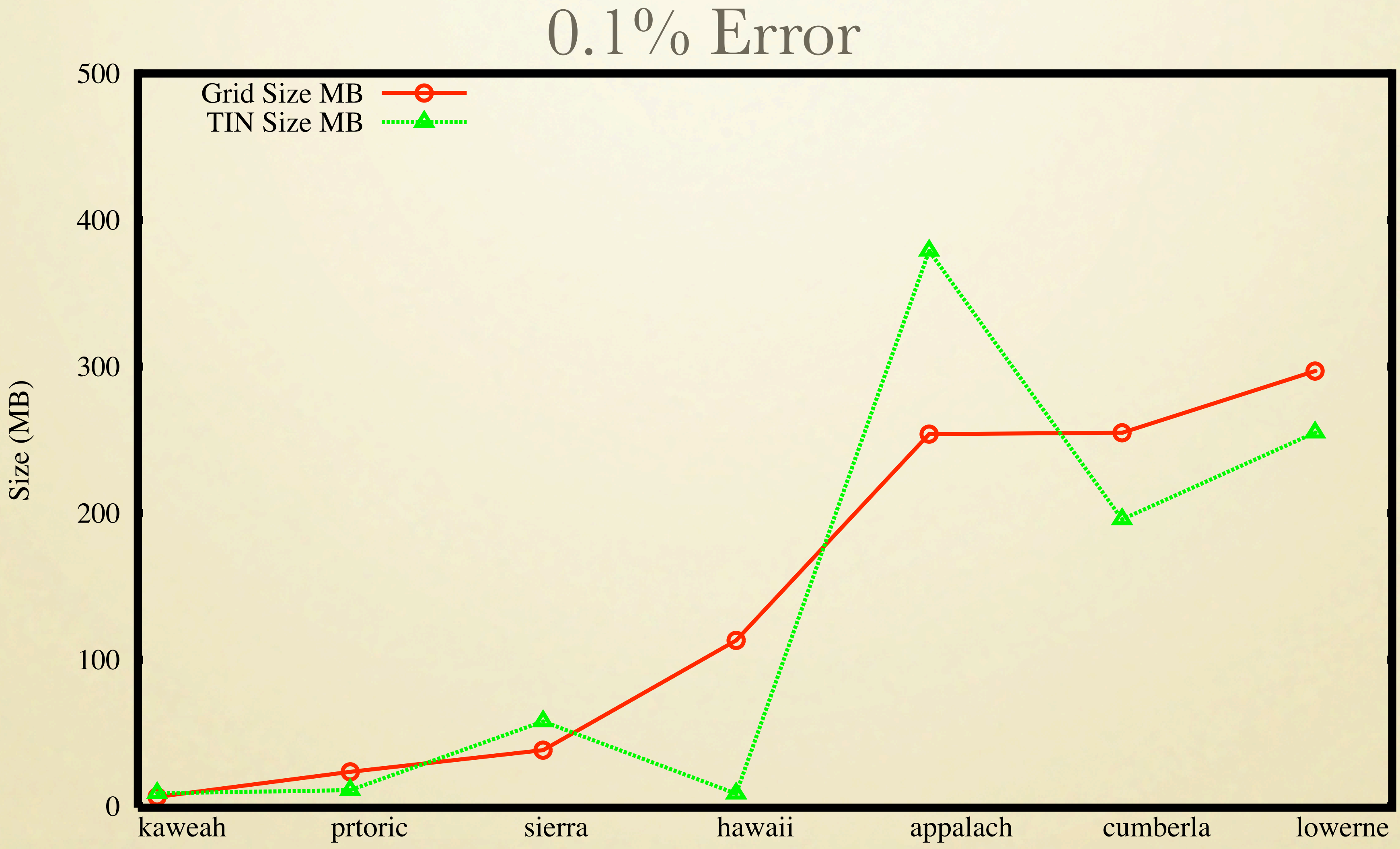


Grid vs TIN Point Comparison

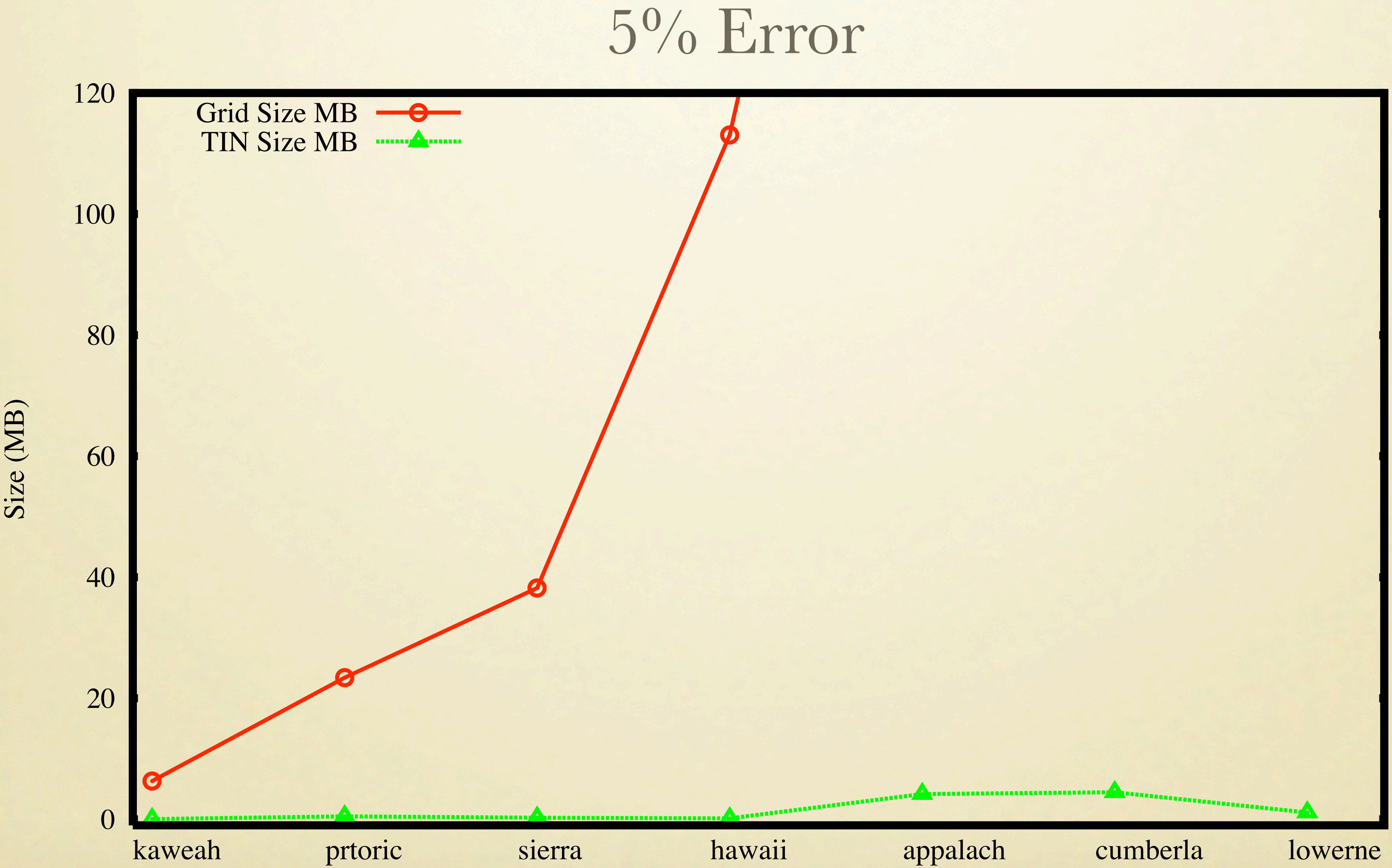
0.1% Error



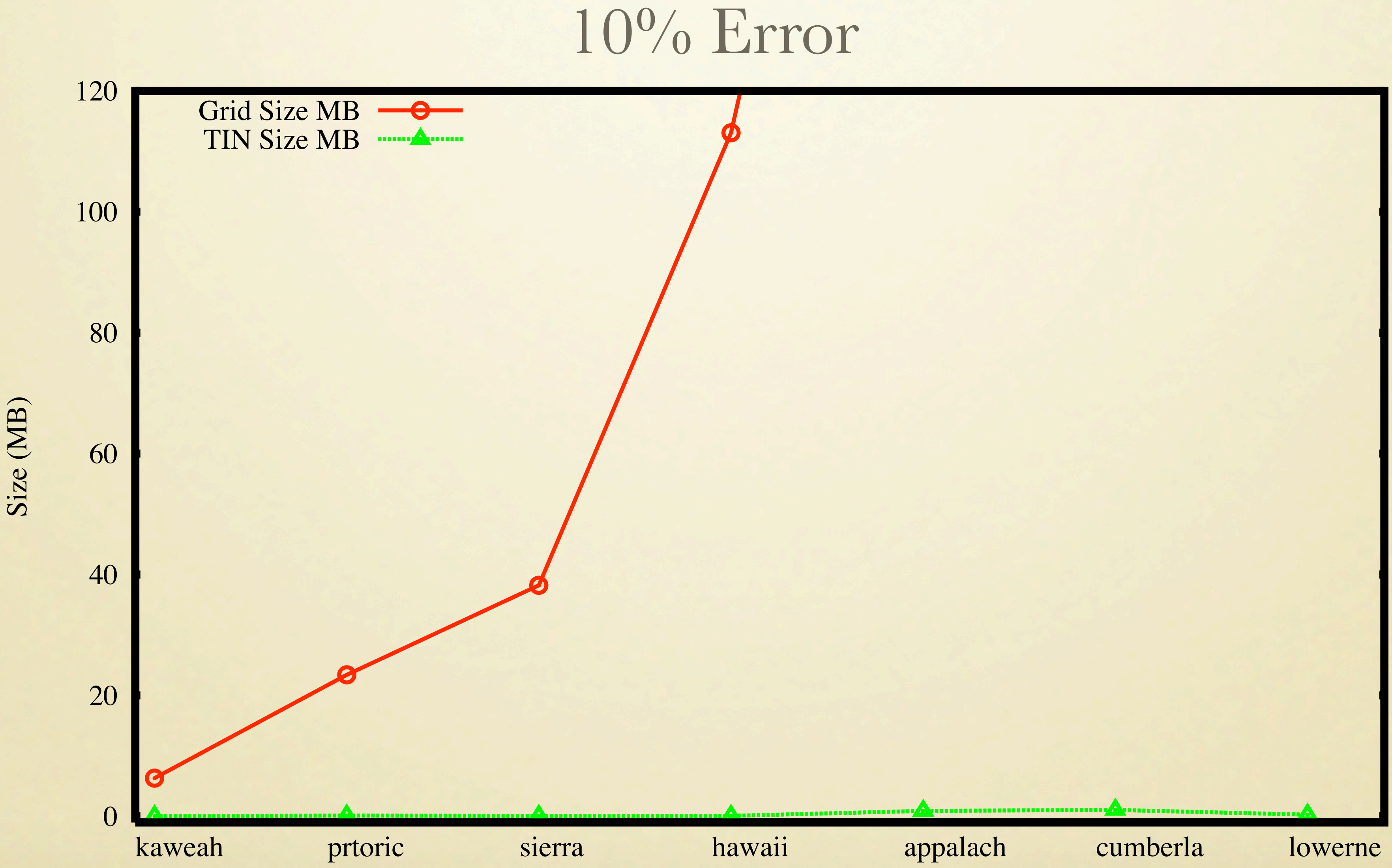
Grid vs TIN Size Comparison



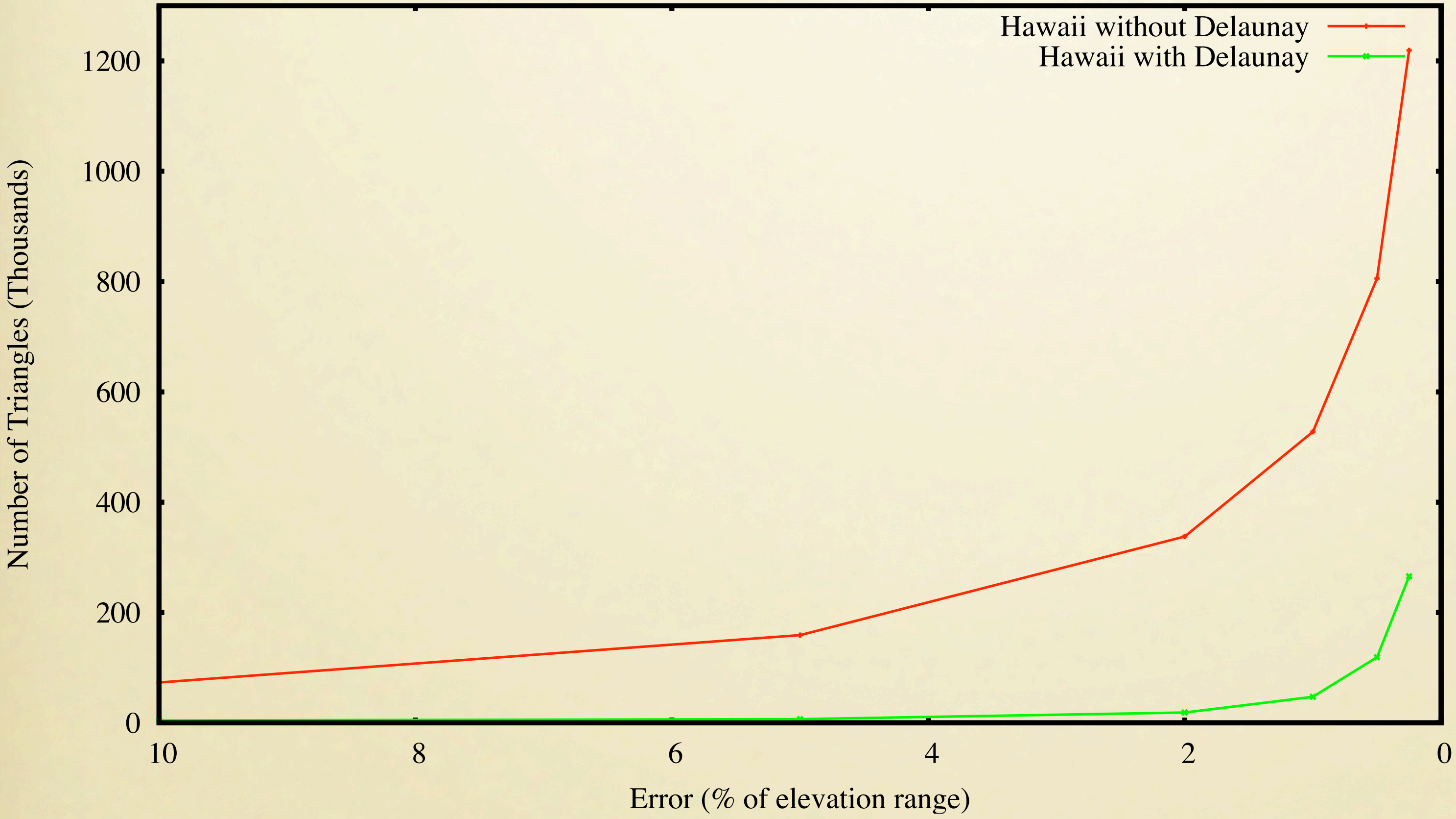
Grid vs TIN Size Comparison

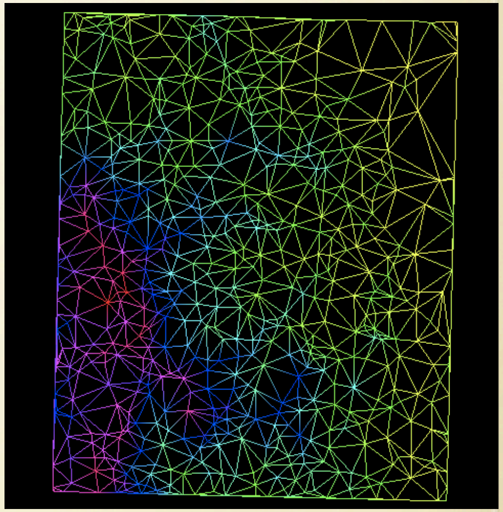


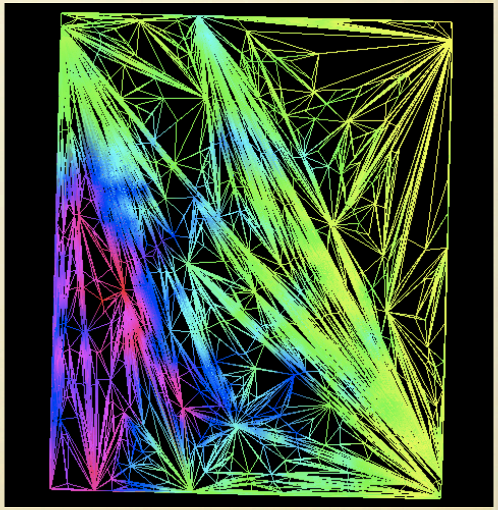
Grid vs TIN Size Comparison



Effects of Delaunay On Number of Triangles







Conclusions & Future Work

Future Work

- Assure quality of data. (No artificial dams or ridges)
- Apply flow modeling to TINs
- Parallelize code
- Take sample points (LIDAR) as input

Conclusions

- r.refine provides a starting point for work on TINs
- We introduce a scalable and practically efficient refinement application to GRASS