Multiple Observer Siting on Terrain with Intervisibility or Lo-Res Data

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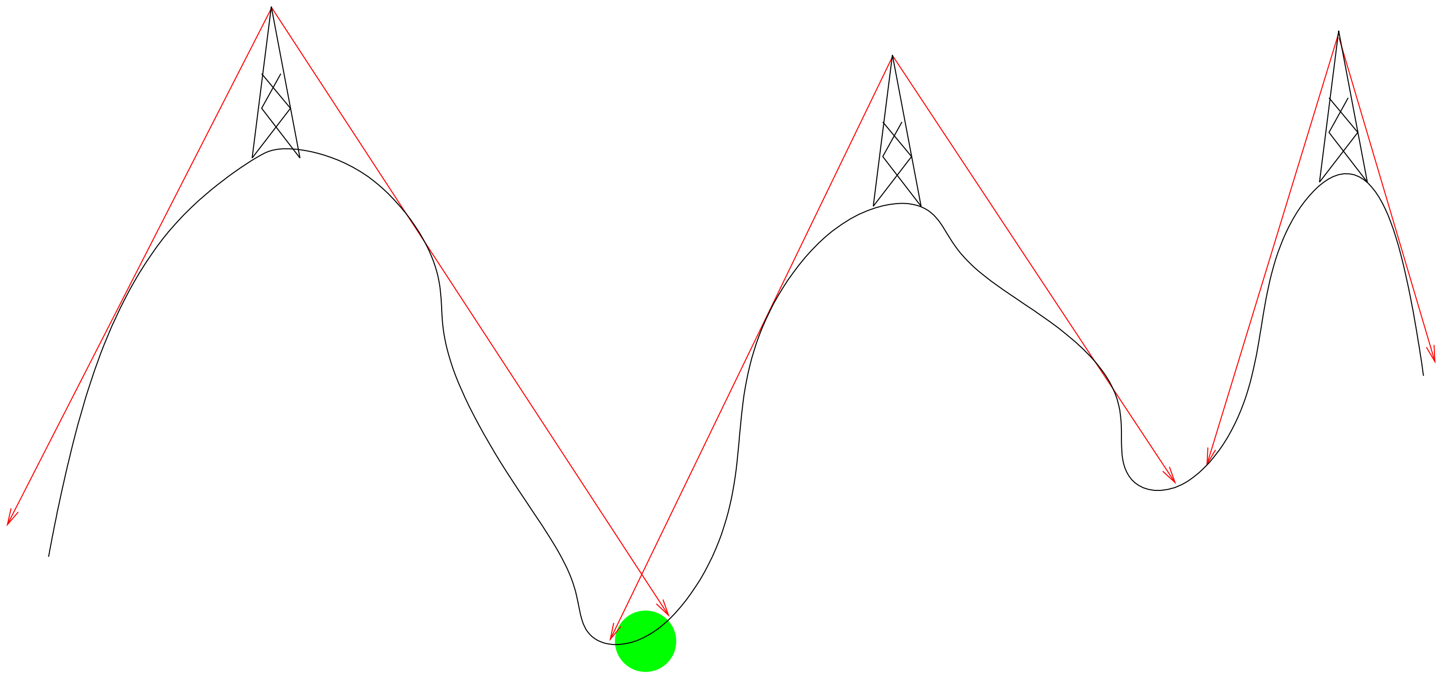
—What?—

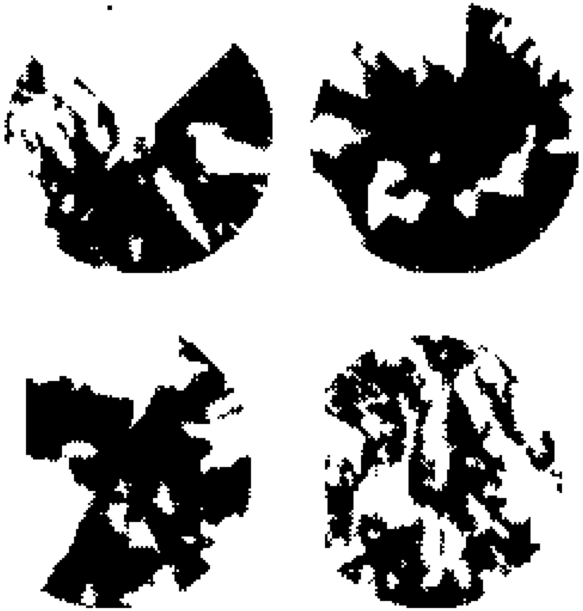
- Consider some terrain.
- We want to “see” (observe, surveil, transmit to) it.
- Where do we place observers, so that between them, they can see most everything?
- Maybe the observers want to see each other.
- Do it fast on large datasets. $\geq 1201 \times 1201$ ***posts*** with ***16 bit elevations.***
- **Optimize, investigate effects of: intervisibility, lower data resolution.**

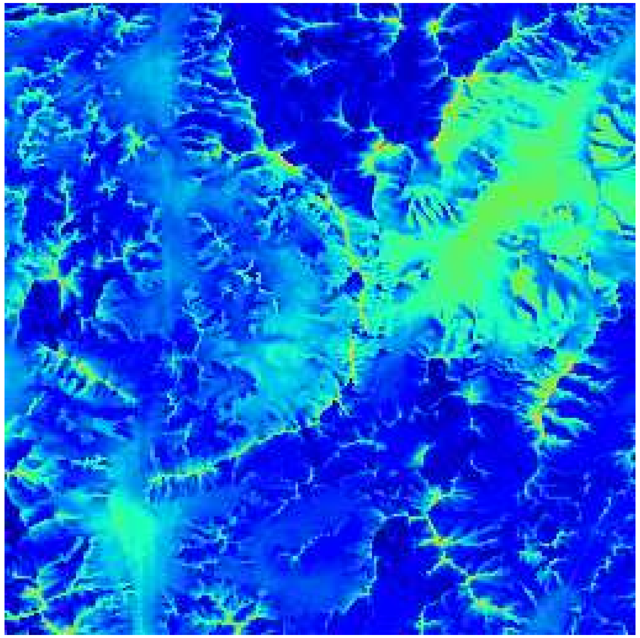
—Applications—

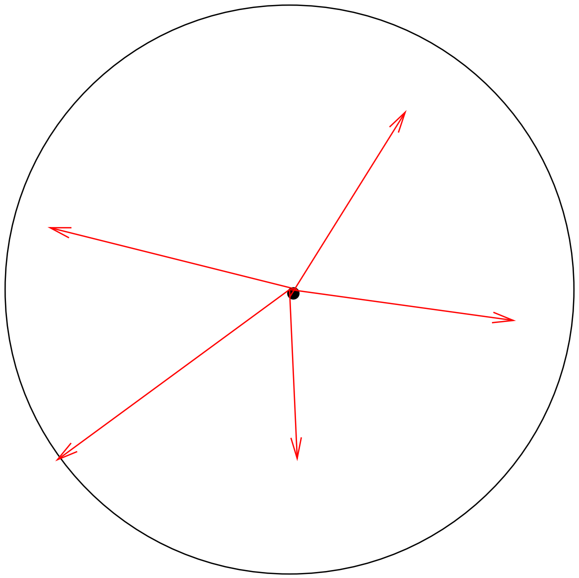
- Radio transmitters
- Observation
- Visual nuisance mitigation



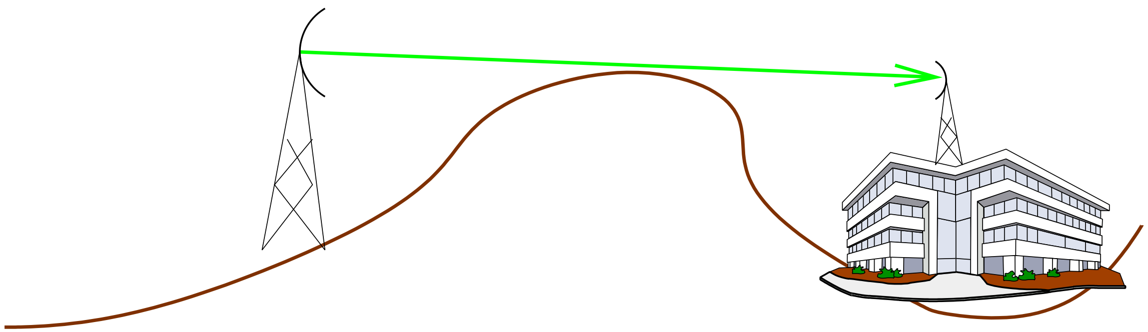
—Preliminaries—







- **viewshed,**
- **visibility index (vix),**
- $\mathcal{R}$**: radius of interest**
- $\mathcal{H}$**: observer and target height.**



—Elimination of Superfluous Details—
—Simplifications—

Goal: to make progress

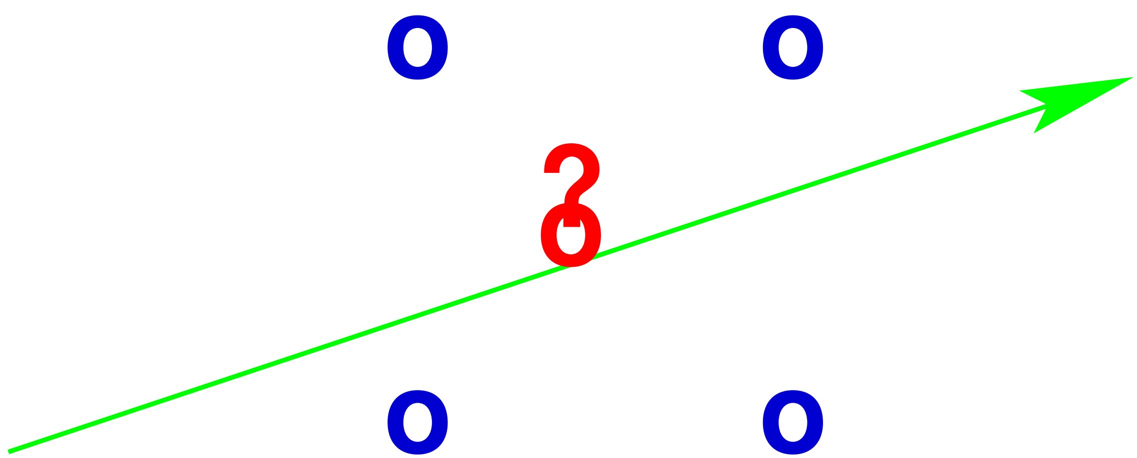
- **No vegetation,** ***altho important in the real world.***
- **No curvature correction, since that's easy.** ***For each target at a distance D from the observer, subtract $\frac{D^2}{2E}$ from its elevation, where E is the earth's radius. Relative error: $\left(\frac{D}{2E}\right)^2$.***
- **Data format: matrix of elevation posts.** ***Comparative advantages/disadvantages of TINs well known.***

—Why are Efficiency and Large Test Cases Important?—

- Many algorithms demonstrated only on “toy” examples don’t scale up.
- E.g., time $T = N^3$ on an $N \times N$ grid, is too slow.
- “Quantity has a quality all its own.”

—Line of Sight Design Uncertainty—

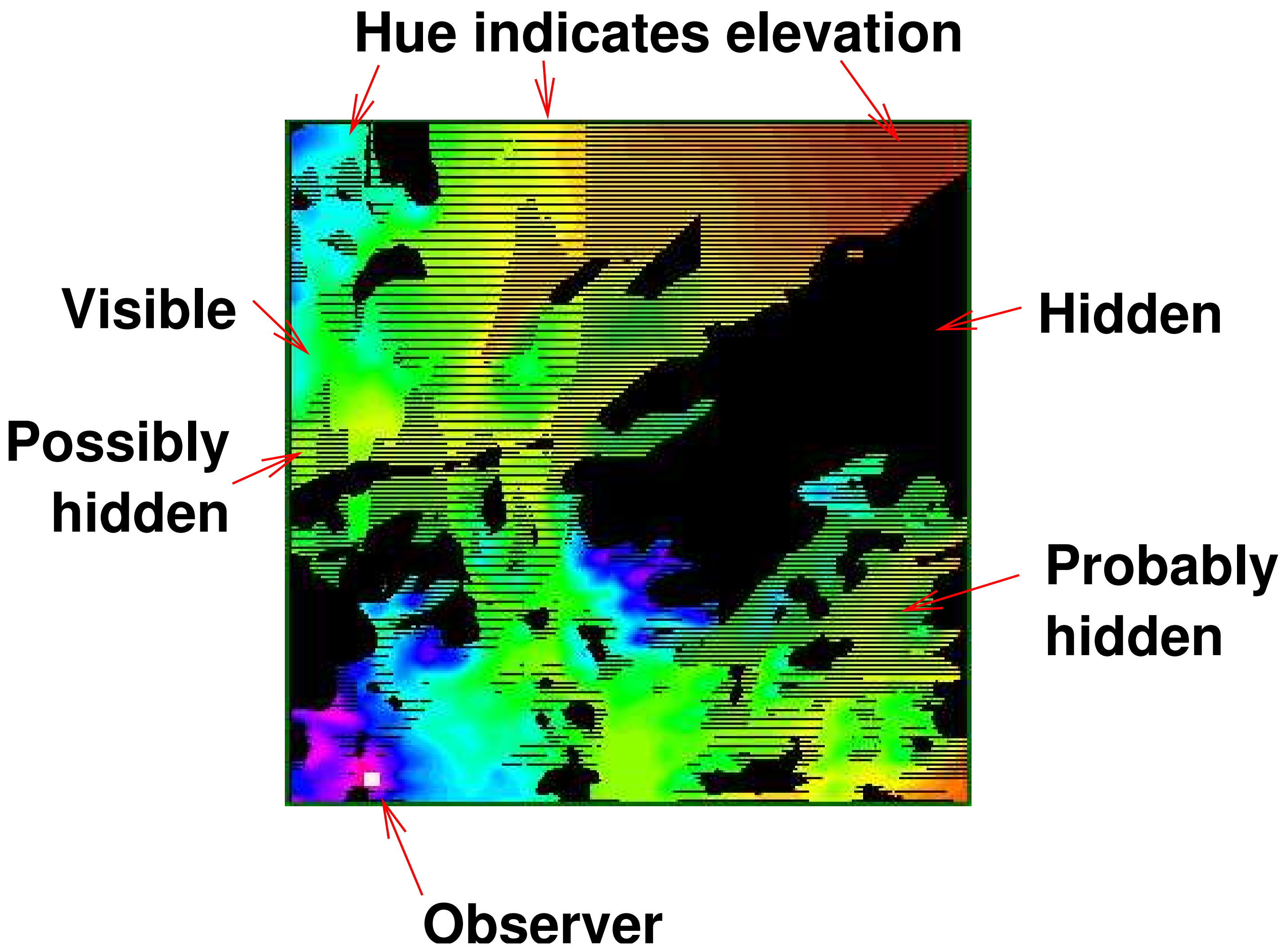
How to interpolate sight line elevations between adjacent posts.



The particular rule may greatly change the computed viewshed.

We must assume *something*, but bilinear interpolation is too rigid.

—Large Uncertainty—



—Summary Procedure—

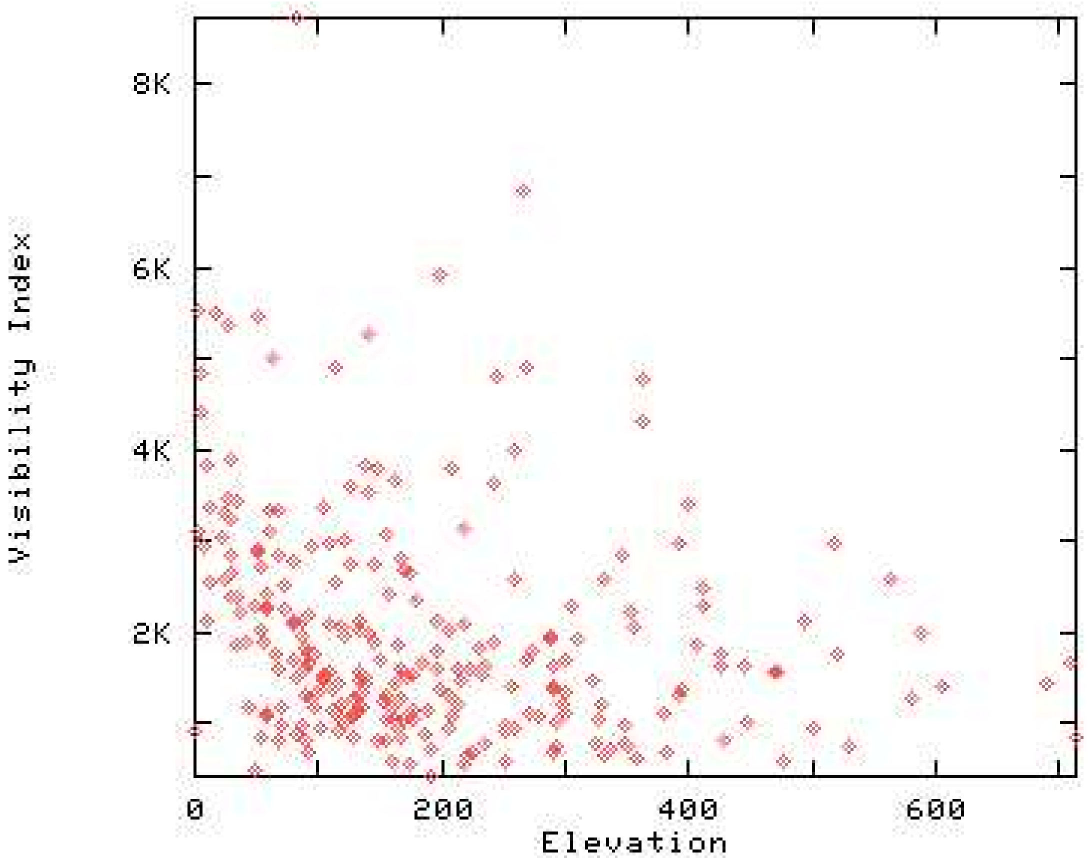
VIX: **Compute approximate visibility index of every point (possible observer).**

FINDMAX: **Select a manageable subject of the possible observers, the "top observers".**

VIEWSHED: **Compute the viewshed of each top observer.**

SITE: **Select actual observers from the top observers with a greedy algorithm.**

- Consider each point in the cell in turn as an observer.
- Pick $\mathcal{T}$ random targets uniformly and independently distributed within $\mathcal{R}$ of the point
  - Count visible fraction.
  - That is this observer's estimated visibility index.
  - Visibility index not strongly correlated to elevation.



- **Select a manageable subset of the most visible tentative observers from** VIX**'s output, to be called the *top observers*.**
- **Somewhat subtle since there may be a small region containing all points of very high visibility, such as the center of a lake surrounded by mountains.**
- **Since multiple close observers are redundant, force the tentative observers to be spread out as follows.**

—Spreading Out the Top Observers—

- **Choose an appropriate value for $\mathcal{L}$, the desired number of top observers, perhaps 1000.**
- **Partition the map cell into about $\mathcal{L}/\mathcal{K}$ equal-sized smaller blocks. Experimentally, $\mathcal{K} \approx 2$ is good.**
- **In each block, find the $\mathcal{K}$ points of highest approximate visibility index (as determined by** VIX**).**

—VIX, FINDMAX, VIEWSHED , SITE—

For each top observer, find viewshed at height $\mathcal{H}$ out to radius, $\mathcal{R}$:

- **Run lines of sight out to perimeter points at $\mathcal{R}$.**
- **Compute visibility of each point along line.**
- **(Messy details omitted.)**
- **Time is linear in number of points.**

—Vix, Findmax, Viewshed, Site—

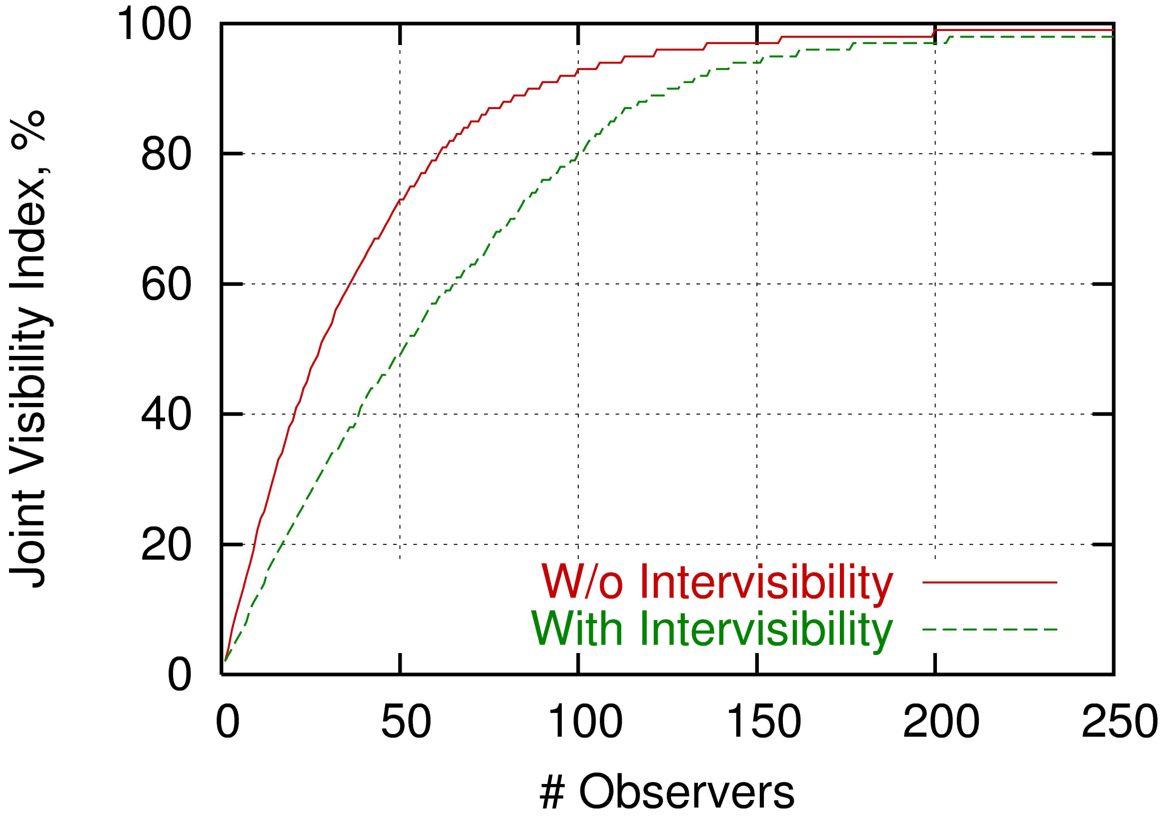
- **Find quasi-minimal subset of top observers to cover the terrain cell as thoroughly as possible.**
- **A simple greedy algorithm. (It works for *us!*)**
- **At each step, include the observer whose viewshed will increase the joint viewshed by the largest area is included.**
- **Do bit operations on precomputed viewsheds.**
- **(Many details omitted.)**
- **Don't try to add an observer that was earlier tried and not added.**

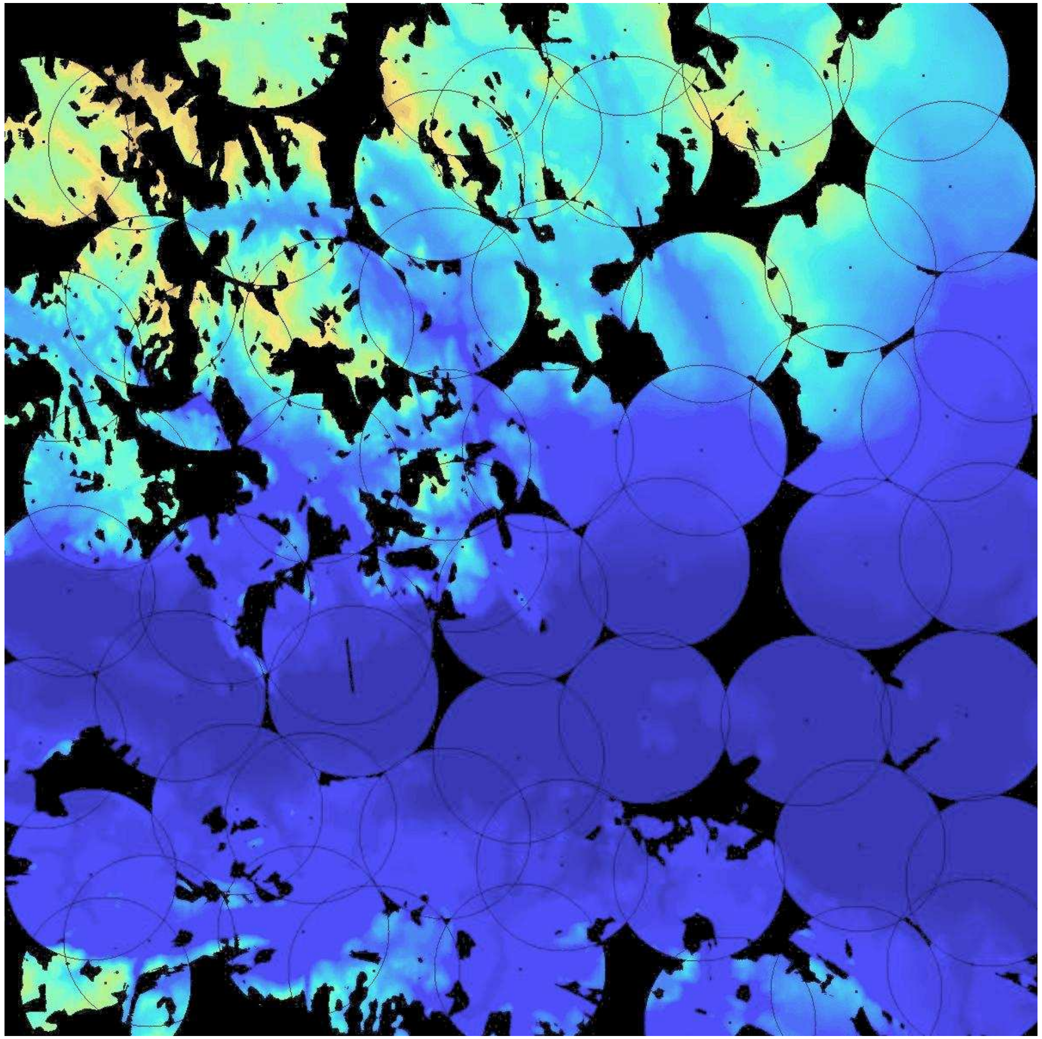
—Study & Improve—

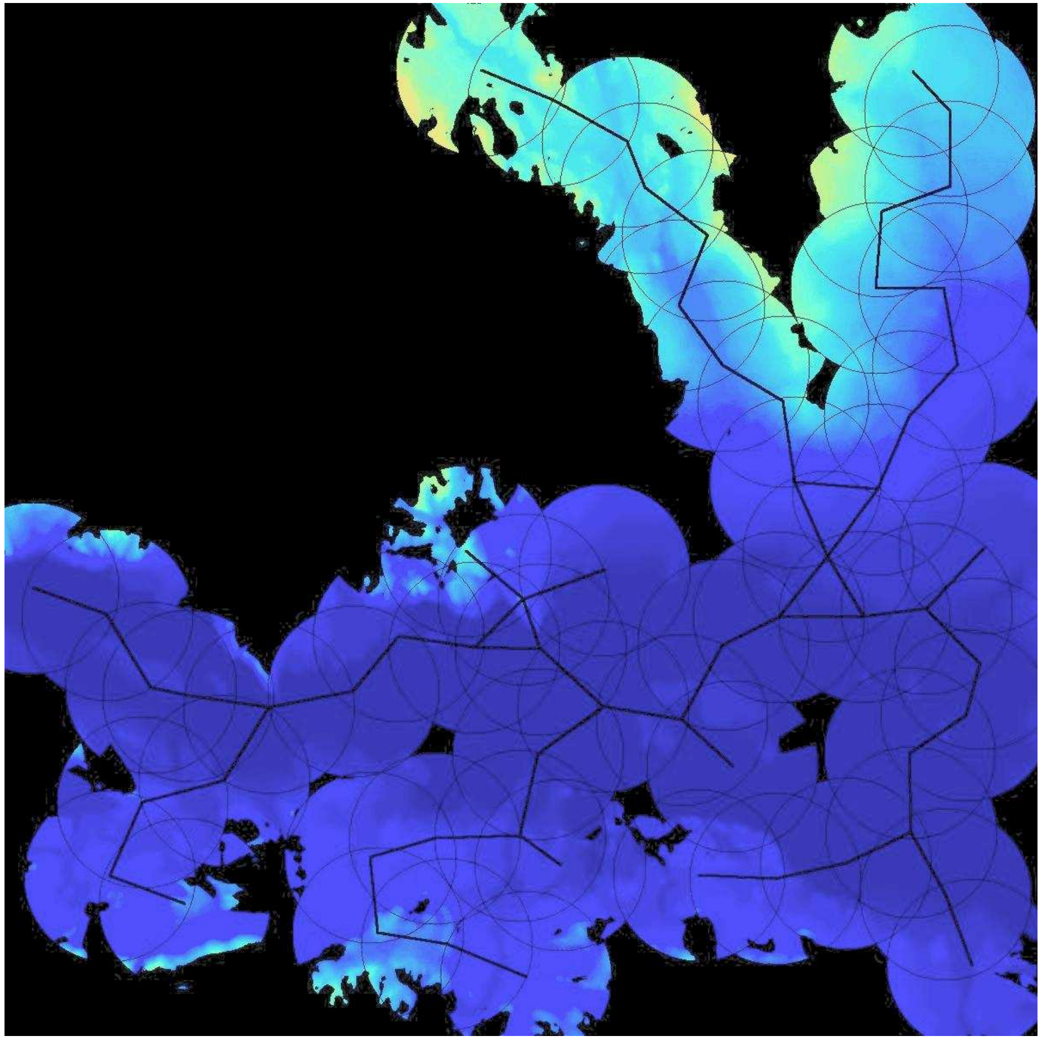
- **Intervisibility**
- **Reduce vertical resolution**
- **Reduce horizontal resolution**
- **Optimize** FINDMAX
- **Optimize** VIX

—Intervisibility—

- **Assume an edge between any pair of mutually visible observers.**
- **Require this graph to be connected.**
- ***Intervisibility requires more observers.***



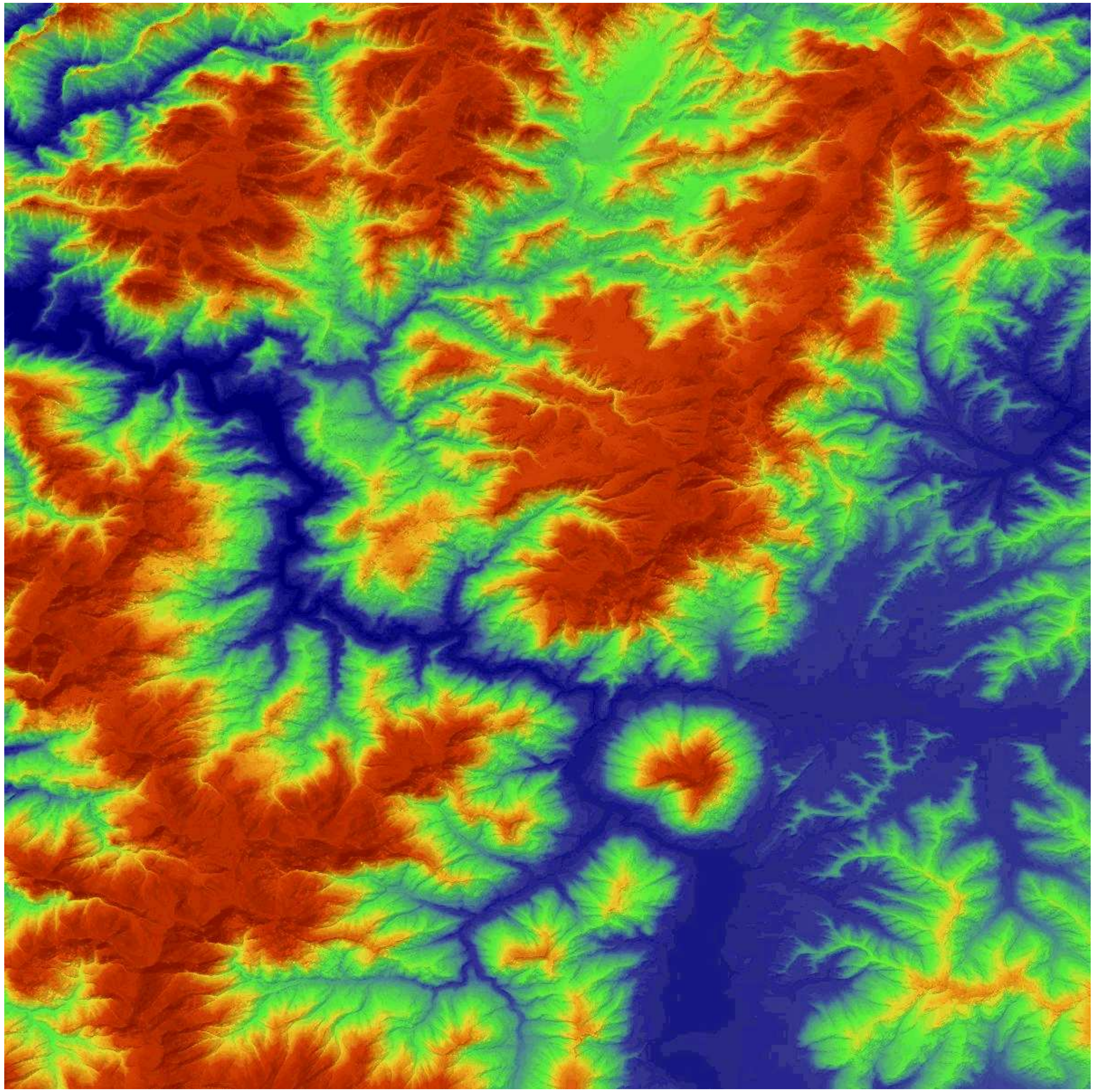




W/o intervisibility

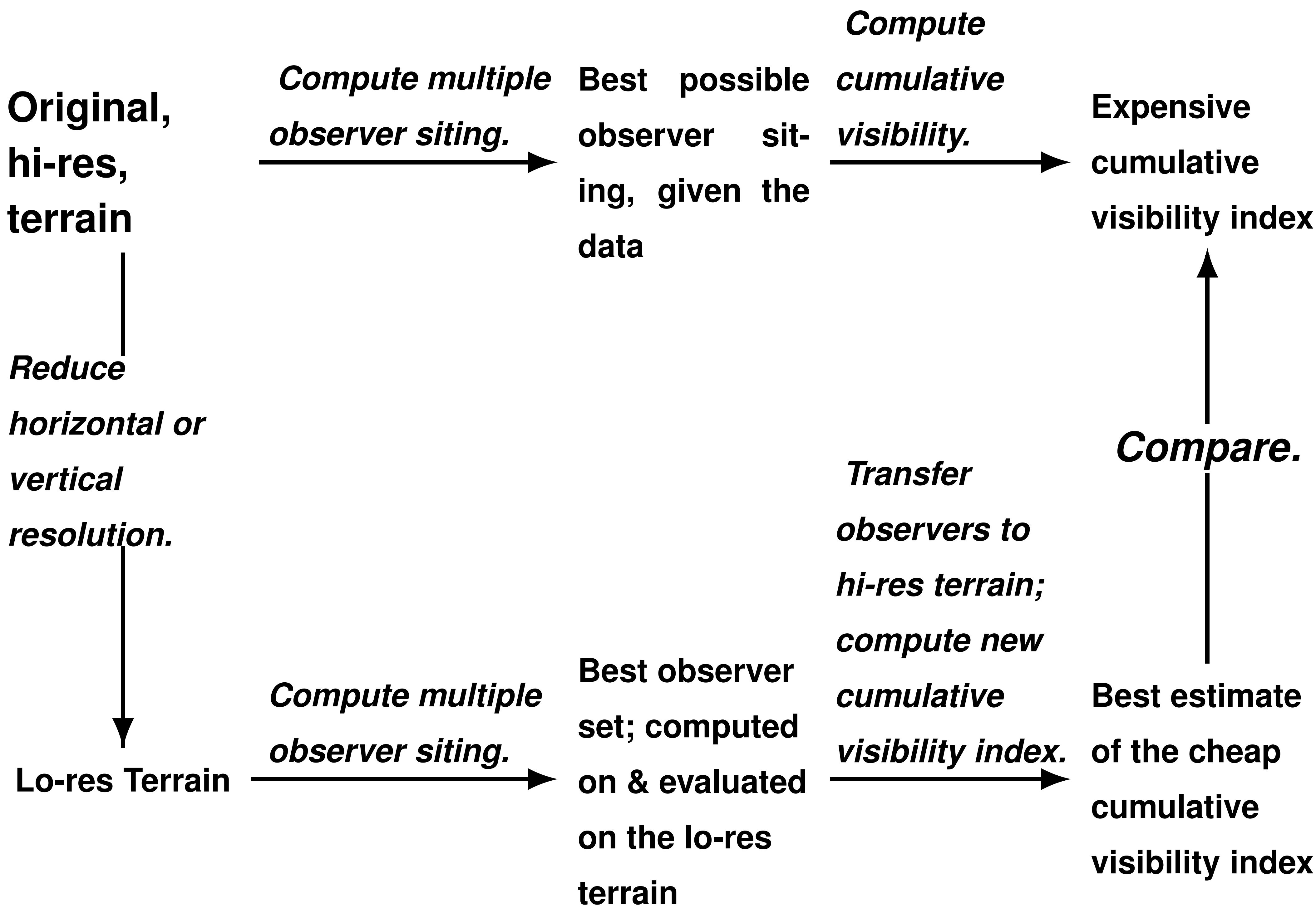
With intervisibility

—Reduced Resolution Test Case—



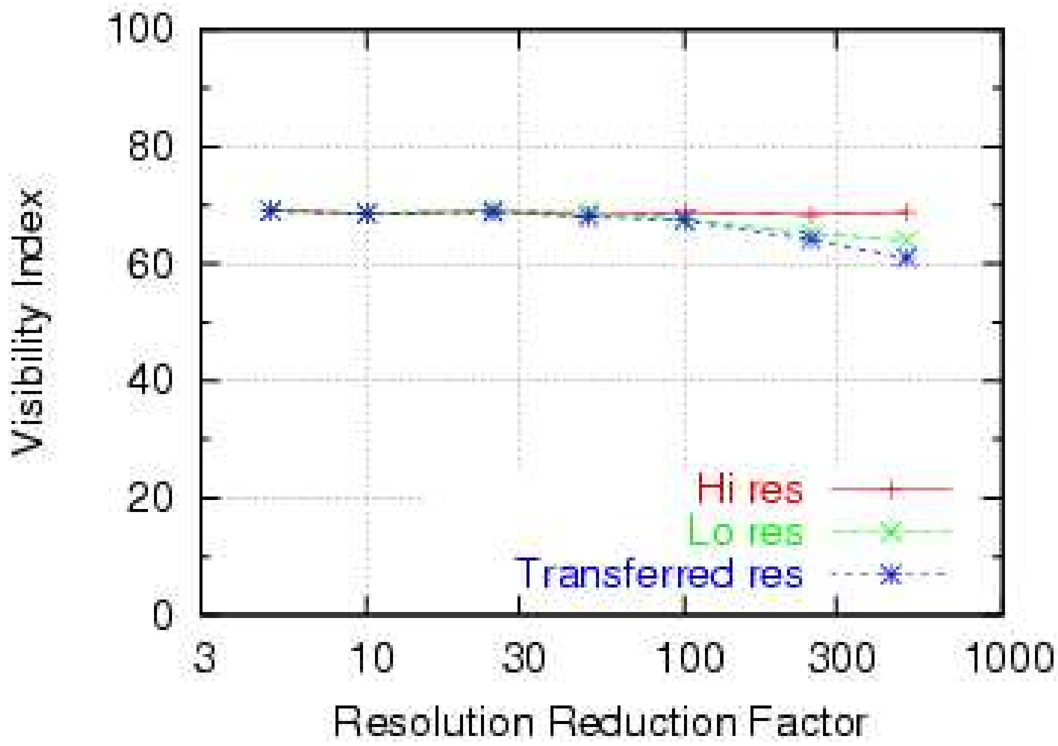
—Reduced Resolution Evaluation Procedure—

- This took careful thought.
- OK if new set of observers is different, if they're just as good.
- Must evaluate goodness on the best, the original, data.


Original, hi-res, terrain
Compute multiple observer siting.
Best possible observer siting, given the data
Compute cumulative visibility.
Expensive cumulative visibility index
Reduce horizontal or vertical resolution.
Compare.
Transfer observers to hi-res terrain; compute new cumulative visibility index.
Lo-res Terrain
Compute multiple observer siting.
Best observer set; computed on & evaluated on the lo-res terrain
Best estimate of the cheap cumulative visibility index

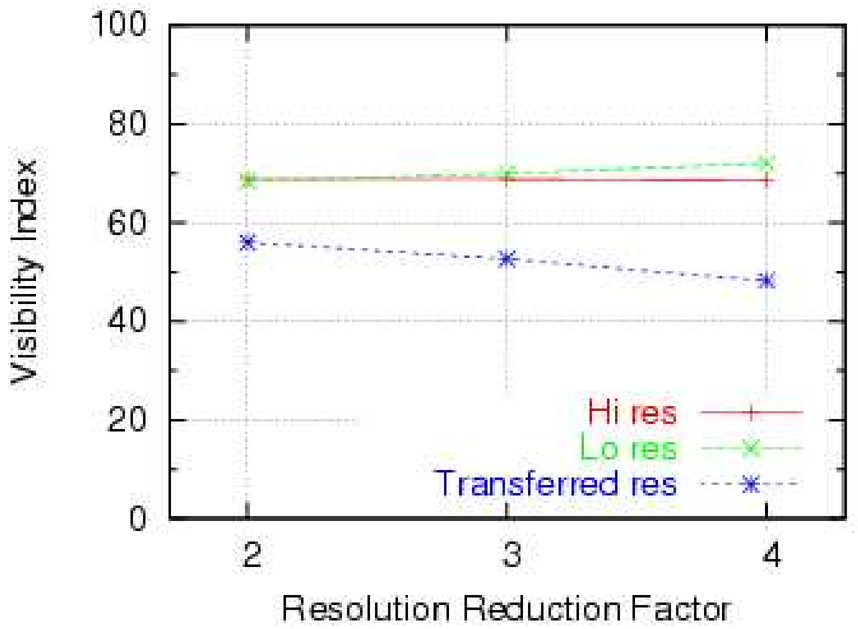
—Reducing Vertical Resolution—

- Do we need hi vertical resolution?
- Vertical resolutions: 0.1m. .5, 1.0, 2.5, 5., 10., 25., and 50.m.
- $(\mathcal{R}, \mathcal{H})$: (80,10), (100,5), (100,10), (100,30), (100,50), (300,10), (500,50).
- *Conclusion:* little effect.



—Reducing Horizontal Resolution—

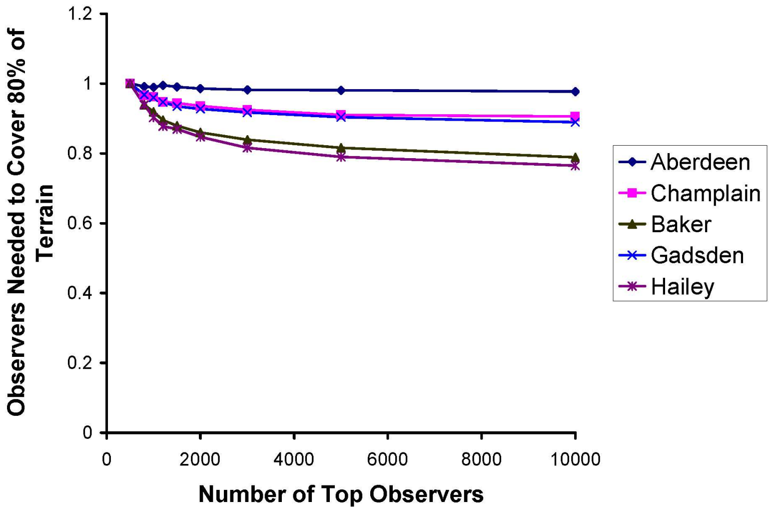
- **Reduce from 1201×1201 to 600, 400, 300.**
- **Test ($\mathcal{R}$,$\mathcal{H}$): (80,10), (100,5), (100,10), (100,30), (100,50), (300,10), (500,50).**
- ***Conclusion:* Even a factor of 2 reduction impacts the siting.**
- **This is important since so many viewshed programs are lo-res.**

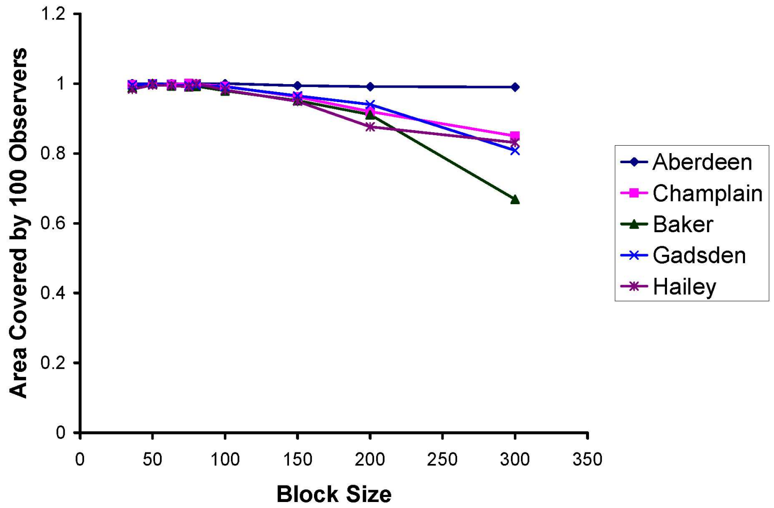


—Optimizing FINDMAX—

- About 1000 top observers is reasonable.
- Force the top observers to be spread out.
- Partition cell into blocks; select a few top observers per block.

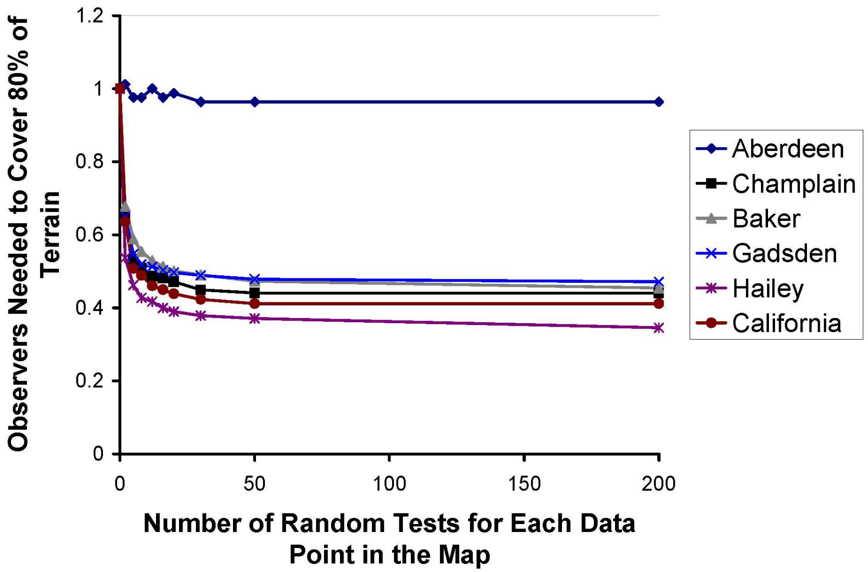
Many small blocks with 1–3 top observers per block is good.

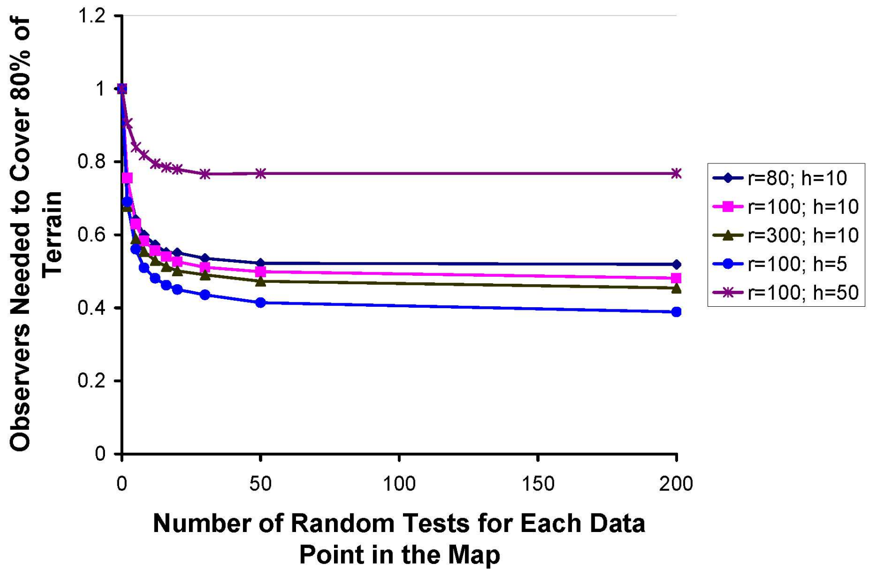




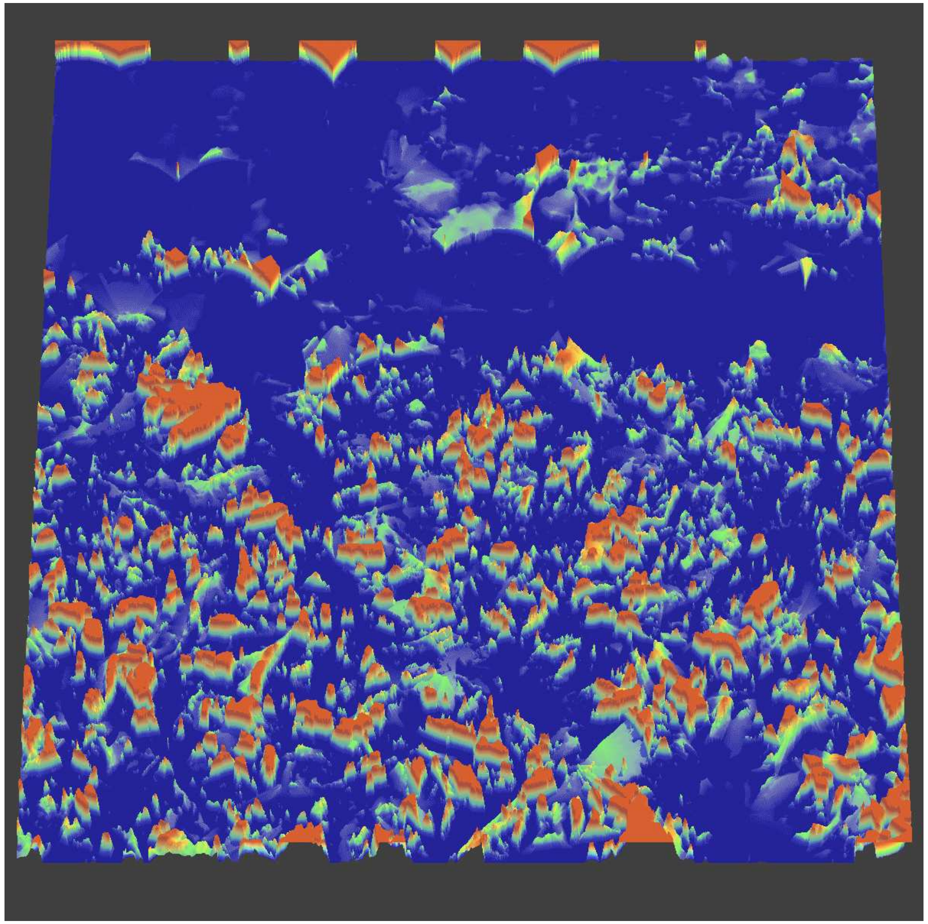
—Optimizing VIX—

- # random targets needed to estimate a visibility index?
- 20-30 is fine.
- Effect of varying the number of tests per observer on the number of observers needed to cover 80% of various cells, for $R = 300$:





—Effect of Higher Observers—



Height of each point represents the observer ht at which that point becomes visible (up to some max ht).

—Acknowledgements—

- Linux, Matlab, Povray, LaTeX, g++, icc, xv
- National Science Foundation grants CCF 03-06502 and CNS 03-23324.
- http://www.geocities.com/s-mullen/natparks/black_canyon.jpg

—PhDs Graduated—

- **Clark K. Ray, *Representing Visibility for Siting Problems*, 1994. (*now at* US Military Academy, West Point)**
- **Michael B Gousie, *Contours to Digital Elevation Models: Grid-based Surface Reconstruction Methods*, 1998. (Wheaton College)**
- **Helio Pedrini, *An Adaptive Method for Terrain Surface Approximation Based on Triangular Meshes*, 2000. (Universidade Federale do Paraná)**

—Masters Graduates—

- **Steve Lord, *Upgrading of the U.S.M.A. Wargame*, 1979.**
- **Steve Wong, *A Tactical Model Simulation for 3-Dimensional Look-Alike Sonar Trainers*, 1981.**
- **Colin Verrilli, *One Source Voronoi Diagrams with Barriers — A Computer Implementation*, 1984.**
- **David Sun, *Implementation of a Fast Map Overlay Program in C*, 1989.**

- **Venkateshkumar Sivaswami, *Point Inclusion Testing in Polygons and Point Location in Planar Graphs Using the Uniform Grid Technique* 1990.**

- **James TenBrink, *The Maintenance of Voronoi Diagrams Imposed Upon Moving Point Sets*, 1991.**

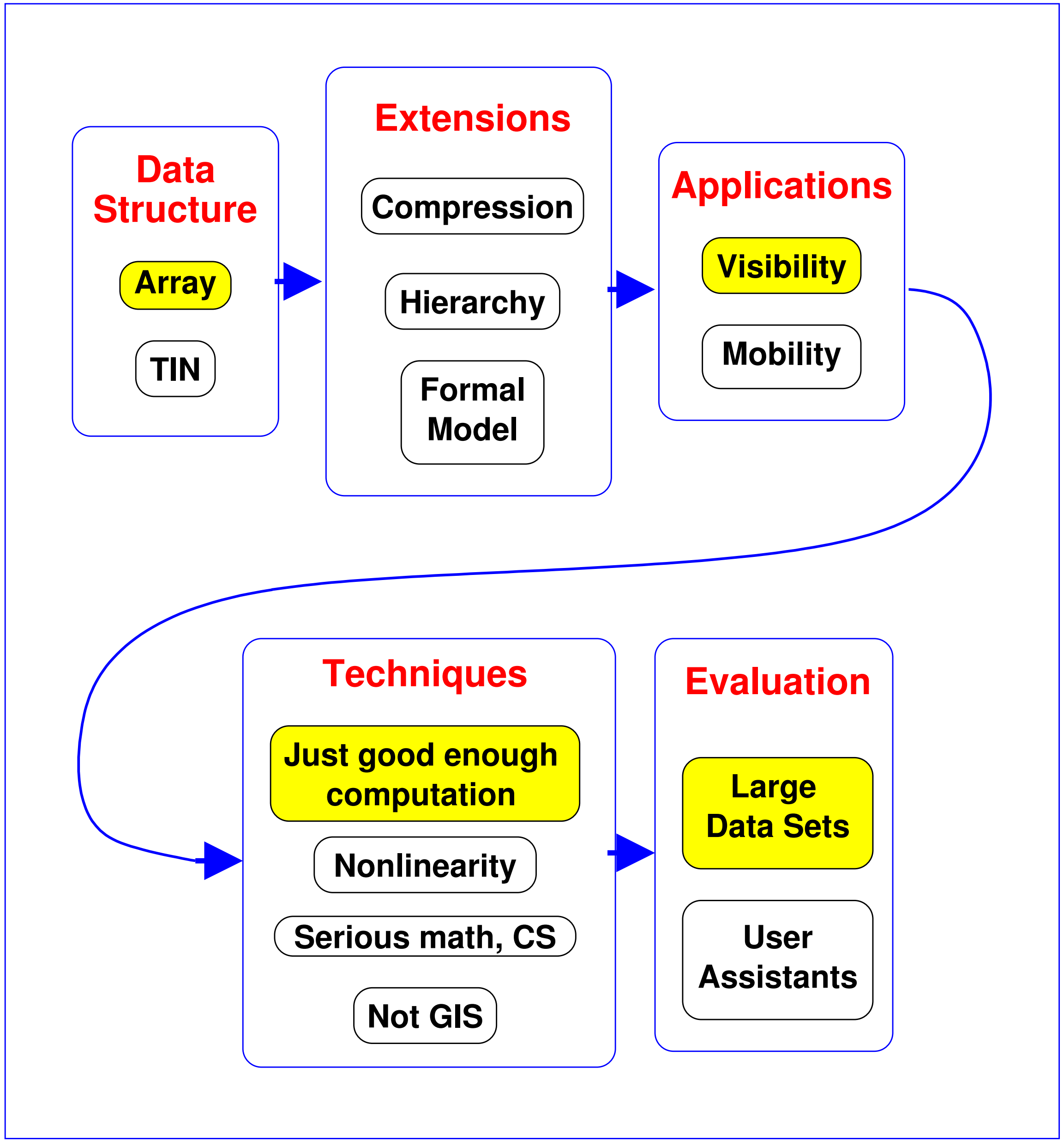
- **Cheok Hee, *The Cross Area Problem in Cartography*, 1992.**

- **John Childs, *Interpolating Contour Lines Using an Overdetermined Laplacian PDE*, 2003.**

- **Christian Vogt, 2004 (expected).**

—Summary—

- Very fast
- Handles 2000×2000 cells.
- Systematically studied and optimized
- Nevertheless, more is possible.



Data Structure
Array
TIN
Extensions
Compression
Hierarchy
Formal Model
Applications
Visibility
Mobility
Techniques
Just good enough computation
Nonlinearity
Serious math, CS
Not GIS
Evaluation
Large Data Sets
User Assistants