KNOWMESH — Meshless geometry with knowledge representation

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Organization

- We've enjoyed success with two quite different data structures, and would be happy for others to adopt them, but that's not DARPA-hard, so ...
- here's a more ambitious proposal.
- My talk's organization:
  - Our two recent data structure projects:
    - Geo* with ODETLAP,
    - Segmented height field with tetrahedral mesh.
  - KNOWMESH definition.
  - Two proposed KNOWMESH applications:
    - GIS,
    - architecture.

1st recent data structure: Geo*/ODETLAP

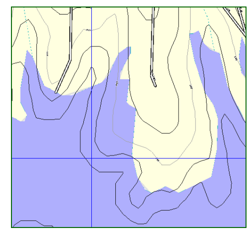
Franklin and Cutler, DARPA award, *Geospatial representation and analysis (Geo*): Geologically correct terrain data structures & radar siting*, March 24, 2005 – Jan 31, 2009.

Terrain representation

- Inspired by, but mathematically quite different than, Laplacian PDE.
- Lossy compression of terrain and slope
- Conflates inconsistent datasets

Terrain operators

- Siting/intervisibility toolkit
- Trajectory (aka path, motion) planning
- Drainage analysis



Commercial product's inconsistent layer representation

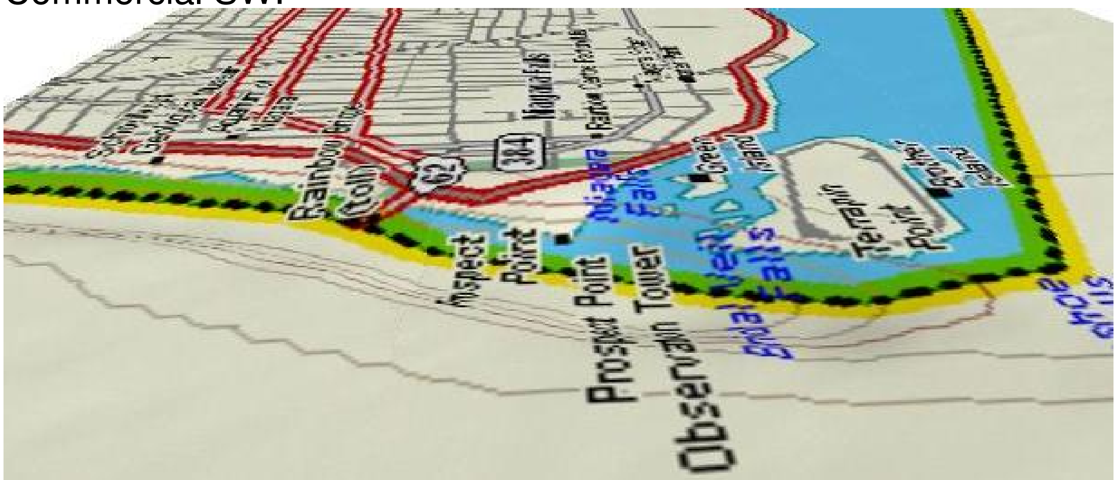
Slope Accuracy on Compressed Terrain — Why consider slope?

Slope is important for:

- mobility.
- erosion.
- aircraft.
- visibility.
- recognition.

Bad commercial slope representation

Commercial SW:



Bad commercial slope representation

Commercial SW: 

Photo:

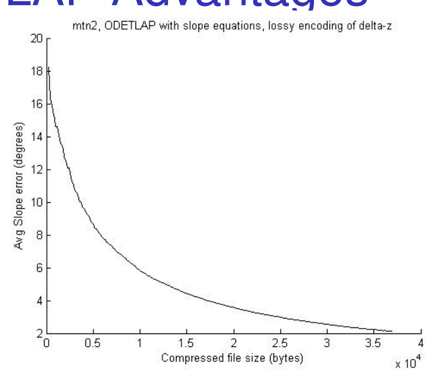
ODETLAP Method

- Small set of posts $\Rightarrow$ complete matrix of posts
- Solve this overdetermined linear system:
  - $z_{ij} = h_{ij}$ for known points,
  - $4z_{ij} = z_{i-1,j} + z_{i+1,j} + z_{i,j-1} + z_{i,j+1}$ for all nonborder points.
- Add more equations to pin down slopes.
- Emphasize accuracy vs smoothness by weighting the two types of equations differently.
- Competing methods' problems:
  - No information flow across contours,
  - Hardwired distance.

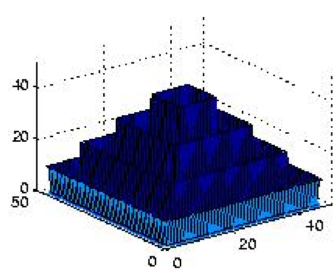
ODETLAP Advantages

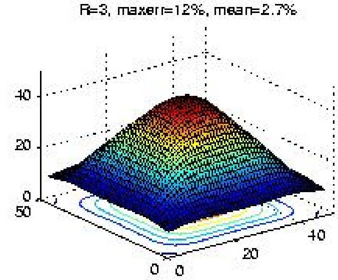
Handles

- missing–data holes.
- incomplete contours,
- complete contours,
- kidney–bean contours,
- isolated points,
- inconsistent data.



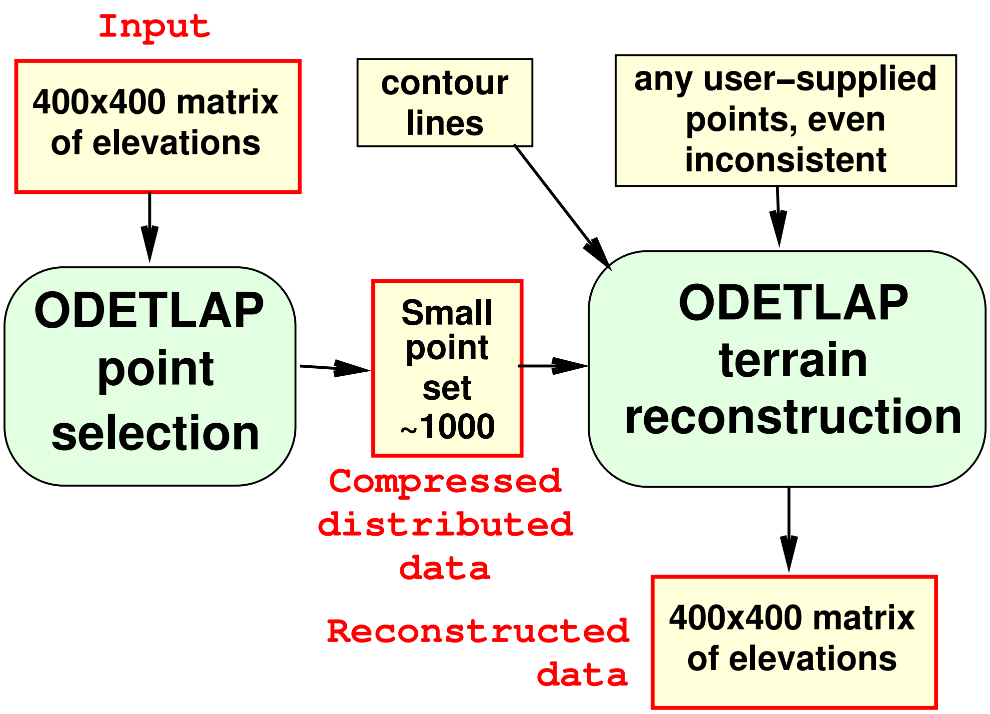
Slope error vs compressed file size *original: 320KB*



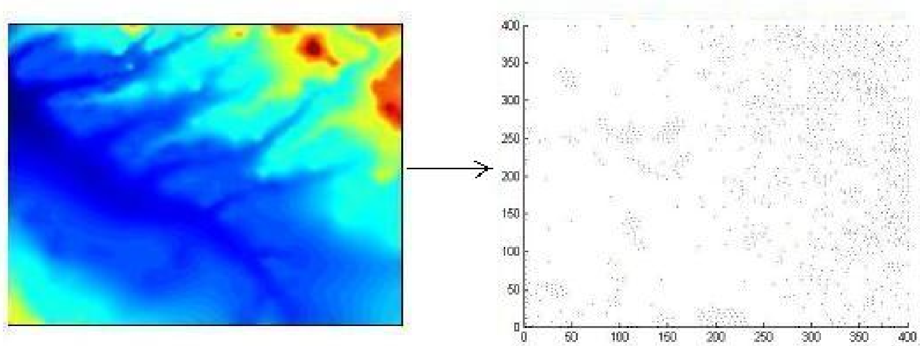


Smooth surface fitted to square contours

ODETLAP compression process



ODETLAP summary

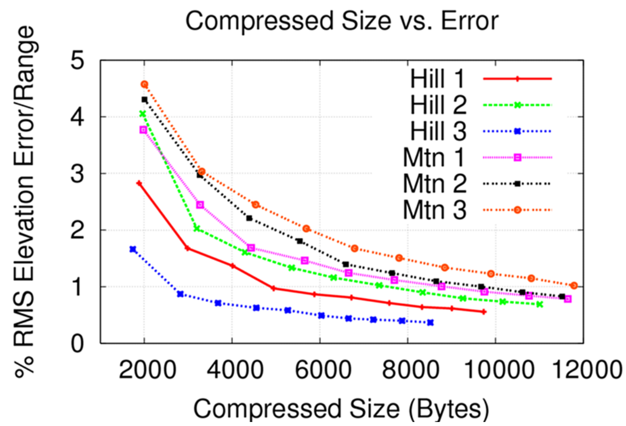


Original Surface (320 KB)

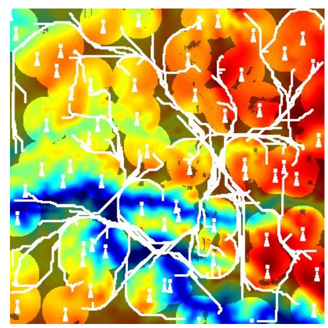
Compressed Surface (4071 Bytes)

Average Absolute Error = 2.451
Maximum Absolute Error = 25.822

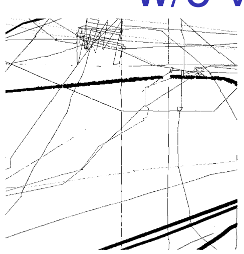
More ODETLAP results



Paths avoiding observers:

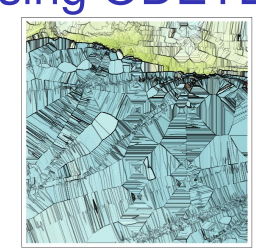


Sea floor bathymetry trackline fitting w/o visible artifacts using ODETLAP

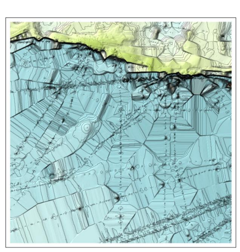


Bathymetry Dataset

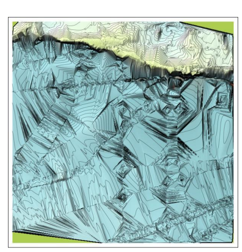
Kriging w. ArcGIS



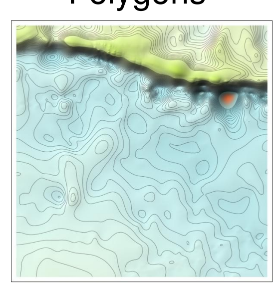
Voronoi Polygons



Inverse Distance



2nd-order Spline Interp



ODETLAP, $R = 100 \to 10$

2nd recent data structure: CDI Segmented height field with tetrahedral mesh

- Cutler, Franklin, and Tom Zimmie, NSF award CMMI-0835762, *CDI Type I: Fundamental Terrain Representations and Operations*, Sept 5, 2008 – Aug 31, 2011,
- Unifying computational geometry, computer graphics, and civil engineering hydrology,
- To predict erosion, specifically overtopping levee failure.
- *($50,000,000,000 US flood damage in 1990s).*
- ex post facto, to reverse-simulate failures.

CDI Problem and goals

Validation of Erosion Models for Levee Overtopping

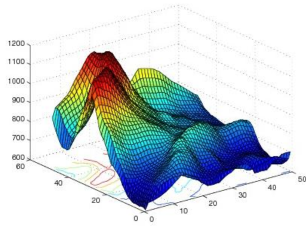
Levee overtopped for several hours during Katrini

Dramatic gouging/scooping

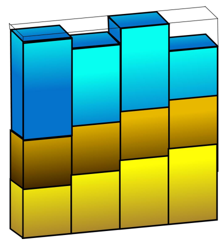
- new representation for volumetric terrain, a.k.a. *soil*,
- better modeling of local erosion in terrain and earthen structures such as levees,
- experimental validation in the RPI geotechnical centrifuge,
- predictive reverse simulation of earthen levee erosion,
- visualization of non-homogeneous terrain erosion,
- out-of-core parallel simulation on large terrain datasets,
- collaboration in Brazil.

CDI Data structures

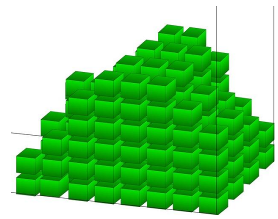
Previous:



Height field

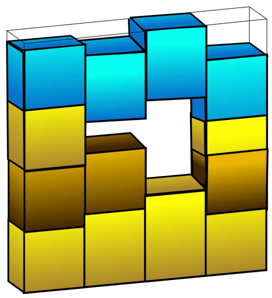


Layered height field

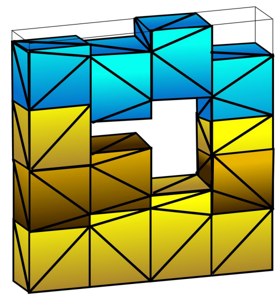


Voxel grid

Us:

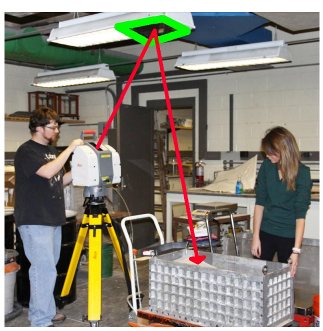


Segmented height field



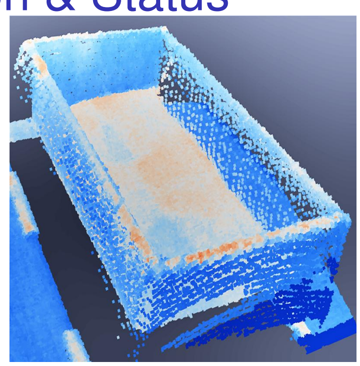
Segmented height field with tetrahedral mesh

CDI Data collection & Status



Scanner setup

Closeup of tank



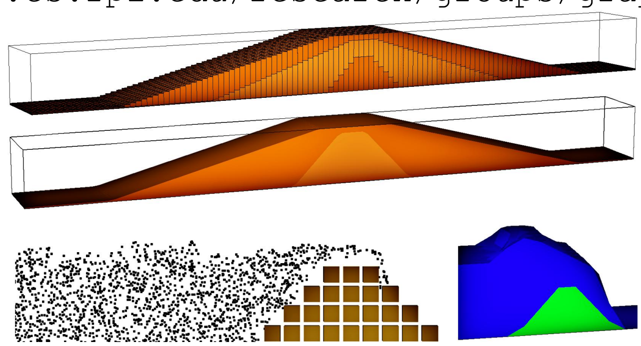
Dense grid of scanner points

- model with homogeneous lifts of sand — 1-g tests
- laser scanning
- data structure design and implementation
- importation of scan results into data structure
- initial visualization, SPH model and simulations
- visit to Brazil

CDI Future

- multiple layers of soil.
- sand-clay mixtures, silts, layered materials.
- complete SPH model.
- geotechnical centrifuge.
- automated change detection.
- More info:

`http://www.cs.rpi.edu/research/groups/graphics/erosion/`



Preliminary simulation

Recap

- ODETLAP has been successful.
- Segmented height field with tetrahedral mesh is being successful. (Tetrahedra allow slope accuracy required for fluid simulation.)
- However for future, we propose embedding more knowledge and inferencing in the data structure.
- Reduce the problem of keeping the structure consistent.

What is KNOWMESH?

$$\text{Unstructured set of } \mathcal{S} = \{S\} \text{ of rich objects}$$
$$+$$
$$\text{expression rule } \mathcal{S} \to \mathfrak{D}$$
$$\to$$
$$\text{KNOWMESH domain } \mathfrak{D}$$

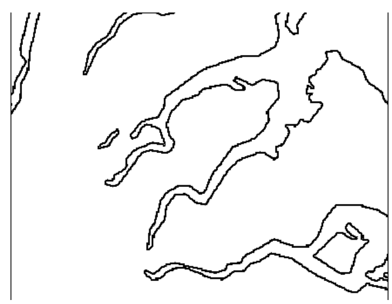
- No explicit global topology. Ideally any $\mathcal{S}$ represents a legal $\mathfrak{D}$.
- Rich expression rules, encompassing deep domain knowledge.
- Mechanization of descriptive geometry: intelligent viewer describes salient aspects to intelligent listener, who fills in details.
- Draws on current practices in *Knowledge representation*.
- Easier conflating of inconsistent input (see ODETLAP below).

KNOWMESH will allow a compact and flexible geometry representation at all scales.

KNOWMESH in GIS

Construct terrain looking like terrain.

- Often discontinuous (C^{-1}).
- Many sharp local maxima.
- But very few local minima.
- Lateral symmetry breaking — major river systems.



Peninsulas or fjords?

- Different formation processes in different regions.
- Features do not superimpose linearly; two canyons cannot cross and add their elevations.
- C^∞ linear systems, e.g,. Fourier series, are wrong.
- Terrain also has structure that people can recognize even though it is hard to formalize; see Figure.

Terrain formation operators

- Problem: Determine the appropriate operators, somewhere inside the range from conceptually shallow (ignoring all the geology) to deep (simulating every molecule).
- One solution: **Scooping.** Carve terrain from a block using a scoop that starts at some point, and following some trajectory, digs ever deeper until falling off the edge of the earth.
- Properties: Creates natural river systems w cliffs w/o local minima.
- Every sequence of scoops forms a legal terrain.
- Progressive transmission is easy.

Hydrography from terrain

- Problem: Hydrography (river lines) might be erroneous, incomplete, violate global rules.
- E.g., in Brazil slope of river too low to determine completely by differencing elevation, and trees hide rivers.
- How to fix?
- Solution: Observed partial hydrography $\rightarrow$ Synthetic terrain $\rightarrow$ corrected hydrography
- Result is guaranteed legal.

KNOWMESH in architecture

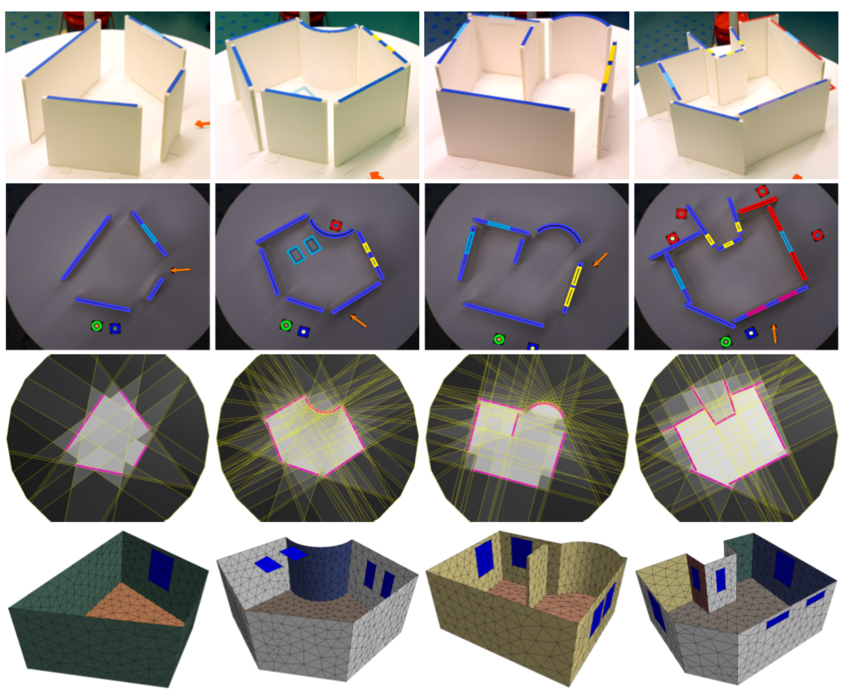
Goal: represent a real campus of buildings, not a synthetic hodge podge.

- Encoding: abbreviated description as an architect would give it.
- E.g., "a 1970s brutalist-style university library designed for 1M books", see Figure.
- Lacks precise geometry, but is well suited to viewer recognition.

RPI's Folsom Library

Next level of detail: sketch the approximate walls, renderer completes to form closed rooms. Already implemented.
Use Gestalt Psychology, describing how humans can interpret incomplete shapes as closed forms.

Modeling deep architectural knowledge



From physical sketch to consistent CAD model

Sketch recognition details

Current algorithm

- infers a consistent labeling of inside/outside
- completes holes in exterior/interior wall geometry
- snaps nearly parallel & nearly planar walls to a common plane or common grid (with a specified tolerance)
- trims off small pieces (probable noise or errors)

Next:

- extend the 2D system to work with scan data input (rather than just physical architectural sketching interface)
- extend to full 3D, defining volumes of interior vs.exterior
- merge with larger mixed urban & natural topography

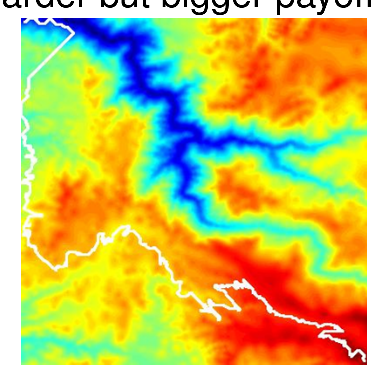
Interesting Challenges:

- Using sidedness constraints when available (scanner observed a planar wall from one side, we can assume which side is the exterior, etc)
- Efficiently process large, mixed datasets.
- Robustness

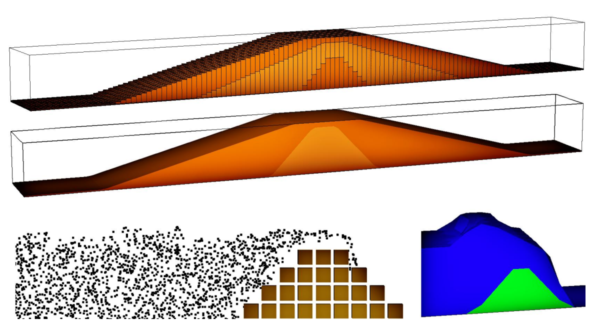
Summary: be ambitious

- ODETLAP, Segmented height field with tetrahedral mesh work very well.
- However
- Include deeper knowledge with reasoning.

Harder but bigger payoff.



Path planning up a mountain



Preliminary simulation