Terrain Volume Estimation
How much material is in that hill?
How much sediment has been eroded?
In Engineering, Cut & Fill

Finding Area Below a Curve
Require surface data (profile)
Require base height
maybe also a profile (here, a single value)
Require region of interest
How to deal with negative area?

Raster Volume Estimation
Requirements
DEM
Demarcated area of interest
Base Height / surface
Stored as a field in the polygons

Raster Processing
Convert polys to raster 'BASE'
  Cell value = base height
DIFF = DEM - BASE
In this case, remove negative areas
  POSDIFF = if(DIFF > 0, DIFF, null())
  POSDIFF = CON(DIFF > 0, DIFF)
Convert to Volume
  VOL = POSDIFF * <cell area>
Aggregate Volume by 'Polygon'
  r.statistics base=BASE, cover=VOL method=sum output=VOLPATCH
VOLPATCH = ZONALSUM(VOL, BASE)

Example: Dune Estimation

Critical Dune Areas

Buffer Areas
Ensures that all dunes are included
Risk of including non-dunes

Clip / Mask Elevations
Get volume estimate by dune field
Could also do a zonal estimate

Profile View

Establish Base Elevation

Mask Areas Below Base
This “clips” out areas that are not dunes
  Eliminates excess area in buffer region
Calculate Differential Height
Height Above Base Elevation
\[ D_{\text{height}} = \text{DEM} - <\text{Bheight}> \]

Height Differences to Volume
Convert height to volume for each cell
\[ \text{Height (meters)} \times \text{cell area (meters}^2) \]
Sum the volume across the field
This is a zonal operation
Negative values will lower the total sum

Results
1.65 km\(^3\) on Lake Michigan Shoreline

Why Simulate Terrain?
Create artificial surfaces w/ known properties
Testing GIS terrain algorithms
Fill in detail of generalized DEMs
Generate realistic mock-ups
Architecture / CAD backdrops
Computer games
Art

Not Just Heightfield!
May include other features
But we focus on elevation

General Approaches
Statistical
Simulate properties of terrain surfaces
Attempt to replicate appearance through measures
Physical
Simulate processes that shape terrain
Erosion, deposition, mass movement...
Begin with a form, then mold it

Statistical
Main property of interest is autocorrelation
Terrain data strongly sp. autocorrelated

Fractals
Mathematics of self-similarity
Developed in 60's – 70's
Functions that produce similar patterns
Across many different scales
Applications in many domains
Art, Design
Life sciences
Physical sciences

Fractal Examples
Odd Properties
Koch Snowflake
Area < circle inscribing original level 1 triangle
Length infinite
Fractals and Terrain
Terrain somewhat self-similar
Especially in arid regions
A 1-D Implementation
Begin with a line
Randomly perturb midpoint
Reduce perturbation range
Repeat

Diamond-Square Algorithm
Common Fractal terrain generator
Begin with 8 nodes
  Generate corners
  Calc. Avg for midpoints
  Randomly deviate midpoints
  Reduce perturbation range
  Repeat

Recursion
Can be implemented recursively

Worked Example
Let the corners = 100
  Displacement std dev be 20
Get average for the midpoints
  Displace it by a random amt.
  Reduce std dev to 10
Then do a smaller square

Fractal Dimension / Roughness
Rough: f = 3 (GRASS r.surf.fractal); Smooth: f = 2

Issues
Basic form determined by initial values
Local variability constant
Artifacts
  Creases & pokey bits
  No correlation across quadrants

Raster Example
Generated via Diamond-Square
Subsequently modified in Grid
Lakes are large pits

Land Cover
Land cover can also be simulated
Use if/then statements on simulated surfaces!
  Here, two different surfaces were simulated

Example
Three simulated surfaces
Ht surface smoothed
LC1 surface reclassed
  Forest/non forest
LC2 surface reclassed
  Ag/urban
Non-forest reclassed to Ag/Urban
Heights < 0 set to water in final land cover
Other Fractal-like Methods
Perlin Noise
   Add random signals together
   Increasingly small frequencies
   Persistence / Amplitude
Random Faulting / Uplift

Physical Models
Simulate actual terrain shaping processes
Some very complex
   May use many inputs
   Environmental modeling
Others not so complex

Example
Process Model Examples
A glacier tool to widen / deepen valleys
Simple erosion / deposition model
   Calculate profile curvature
   Reduce height at locations with high p.c.
   Increase height at locations with low p.c.

Combination Models
Blob Drop Model
   Begin with flat surface
   Drip blobs onto surface
   If blobs stack too high, part will roll down
   Drip more blobs
Elements of reality – e.g. gravity, mass movement
   But implemented in a very simple fashion

Drawbacks & Issues
Terrain not truly fractal
   Not self-similar across all scales
Terrain variability not stationary
   Large flat areas, large rugged areas
Good physical models are complex
   Take a long time on fast computers

Summary
Volume Estimation
   Application and Approach
   Demonstration on Dune Volume
Simulation Rationale
Statistical Models
   Fractals, Perlin noise, geostatistics
Physical Models
   Erosion/Deposition models
Combinations / Other
   TIN / Skeleton Modifications
Issues