Spatial Analysis and Modeling (GIST 4302/5302)

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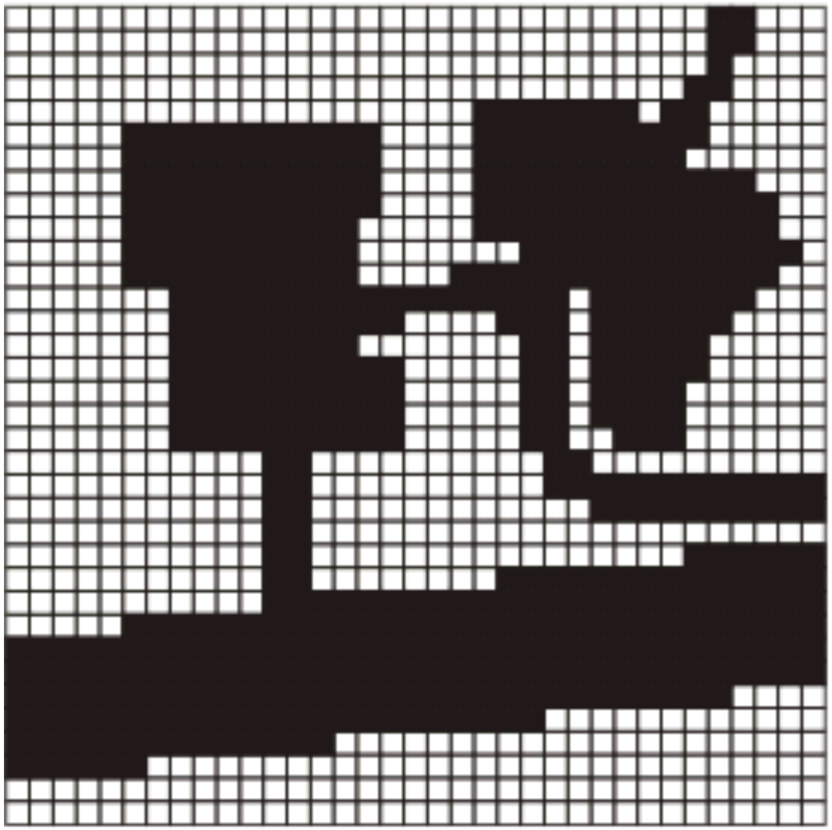
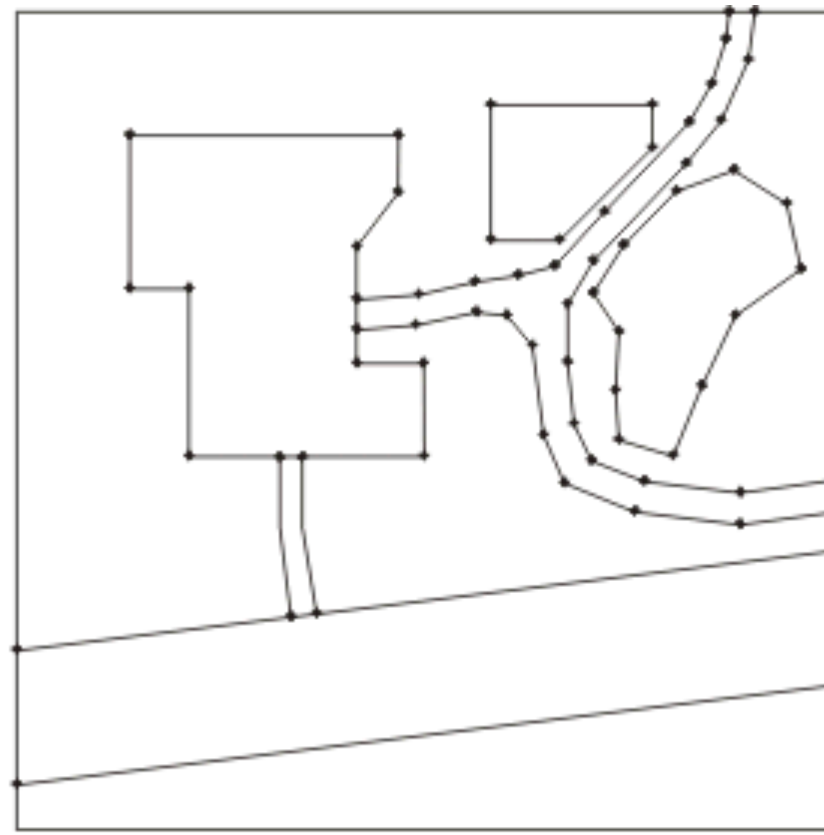
Representation of Spatial Data

Representation of Spatial Data Models

- ***Object-based model:*** treats the space as populated by discrete, identifiable entities each with a geospatial reference
  - Buildings or roads fit into this view
  - GIS Softwares: ArcGIS
- ***Field-based model:*** treats geographic information as collections of spatial distributions
  - Distribution may be formalized as a mathematical function from a spatial framework to an attribute domain
  - Patterns of topographic altitudes, rainfall, and temperature fit neatly into this view.
  - GIS Software: Grass



Raster



Vector

Field-based Approach

Spatial fields

- If the spatial framework is a Euclidean plane and the attribute domain is a subset of the set of real numbers;
  - The Euclidean plane plays the role of the horizontal xy-plane
  - The ***spatial field*** values give the z-coordinates, or “heights” above the plane

Regional Climate Variations

Imagine placing a square grid over a region and measuring aspects of the climate at each node of the grid. Different fields would then associate locations with values from each of the measured attribute domains.

Properties of the attribute domain

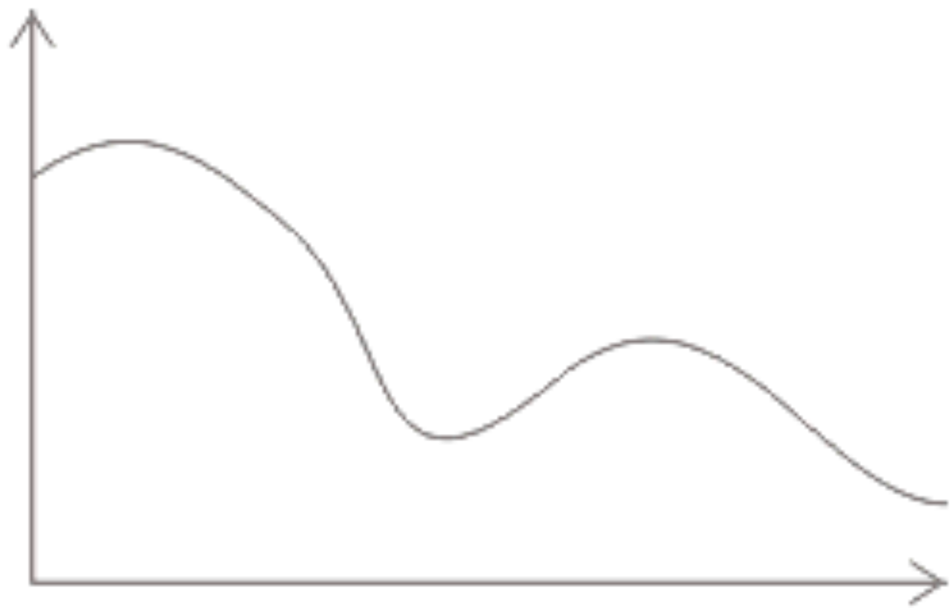
- The attribute domain may contain values which are commonly classified into four levels of measurement
  - ***Nominal attribute***: simple labels; qualitative; cannot be ordered; and arithmetic operators are not permissible
  - ***Ordinal attribute***: ordered labels; qualitative; and cannot be subjected to arithmetic operators, apart from ordering
  - ***Interval attributes***: quantities on a scale without any fixed point; can be compared for size, with the magnitude of the difference being meaningful; the ratio of two interval attributes values is not meaningful
  - ***Ratio attributes***: quantities on a scale with respect to a fixed point; can support a wide range of arithmetical operations, including addition, subtraction, multiplication, and division

Continuous and differentiable fields

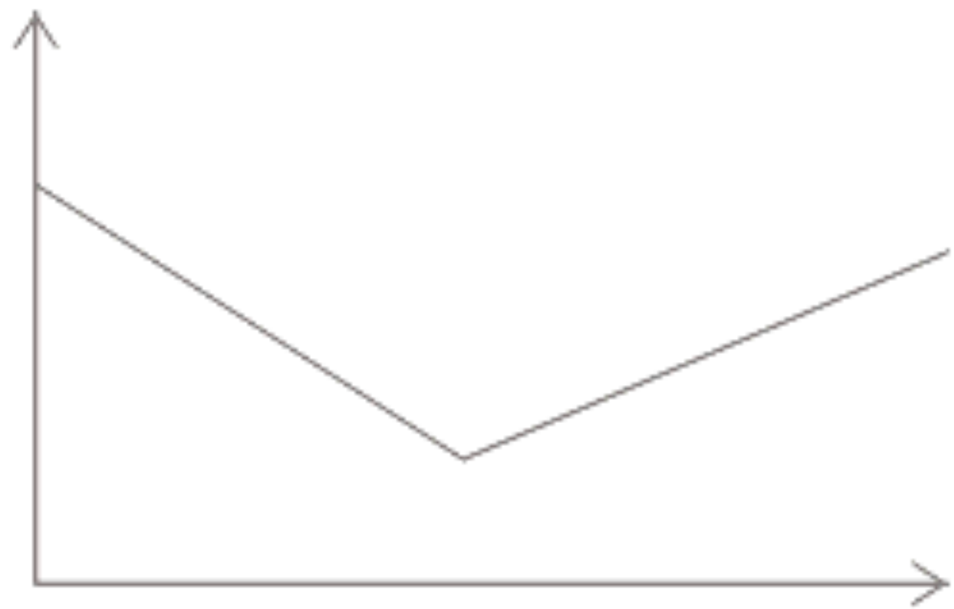
- ***Continuous*** field: small changes in location leads to small changes in the corresponding attribute value
- ***Differentiable*** field: rate of change (slope) is defined everywhere
- Spatial framework and attribute domain must be continuous for both these types of fields
- Every differentiable field must also be continuous, but not every continuous field is differentiable

One dimensional examples

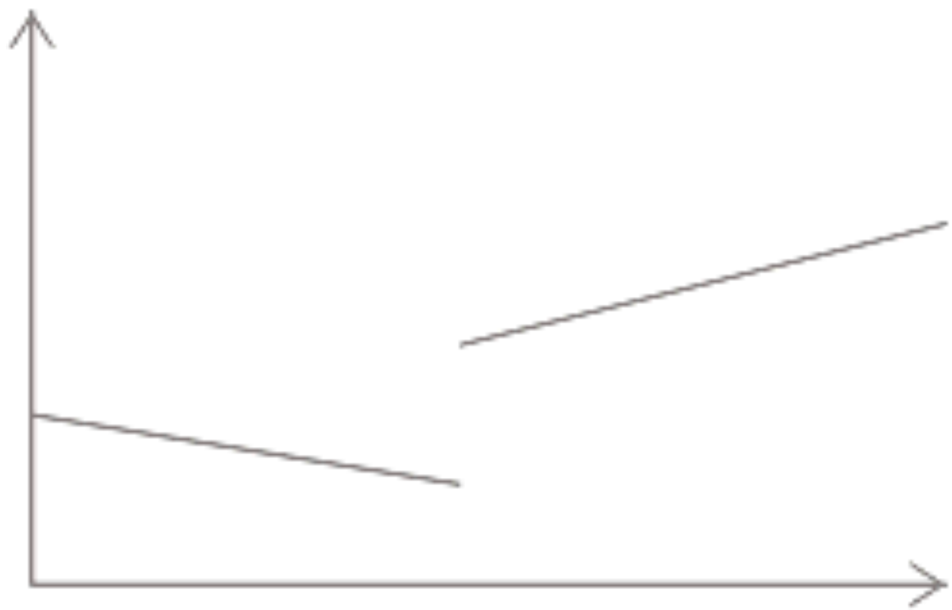
- Fields may be plotted as a graph of attribute value against spatial framework



One dimensional examples

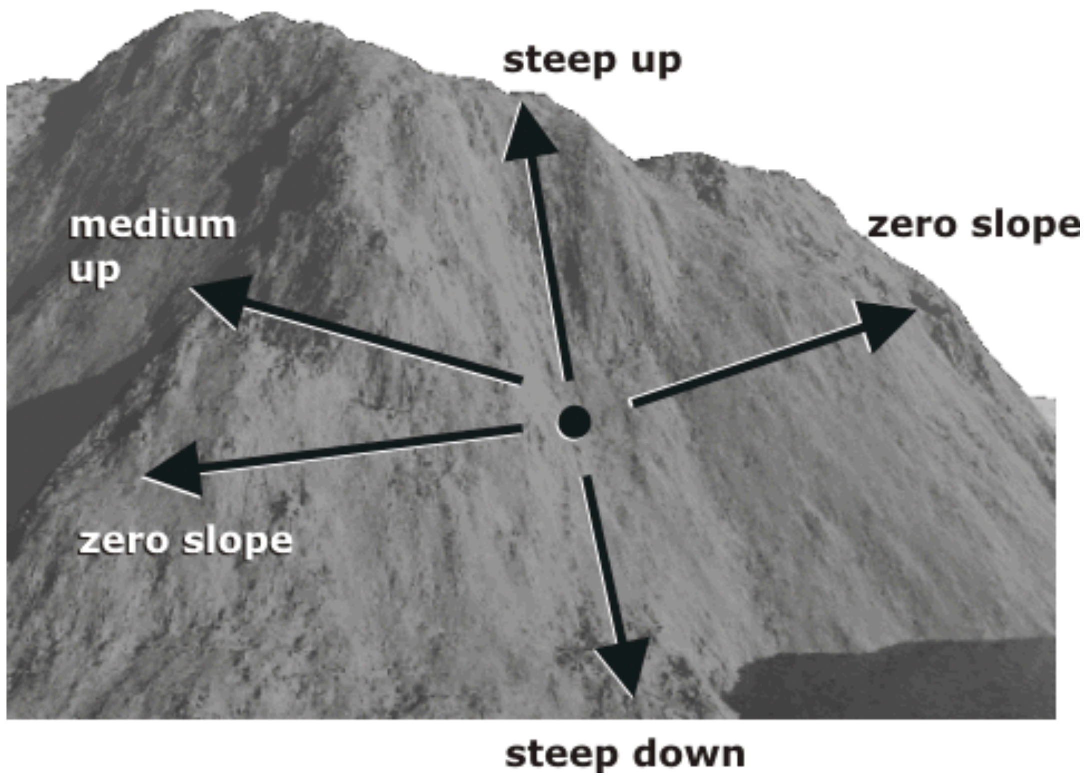


One dimensional examples



Two dimensional examples

- The slope is dependent on the particular location and on the bearing at that location

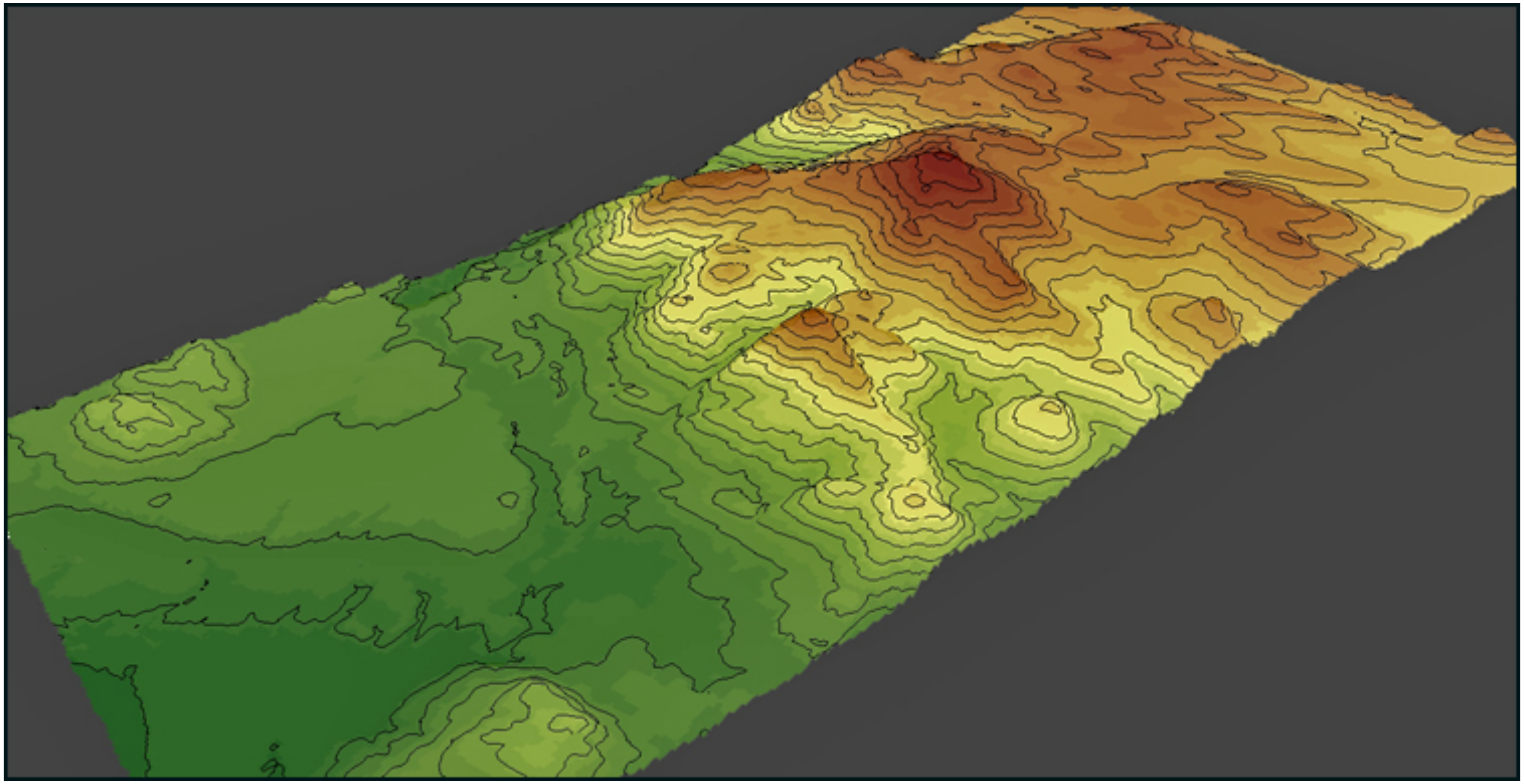


Representations of Spatial Fields

- Points
- Contours
- Raster/Lattice
- Triangulation (Delaunay Trangulation)

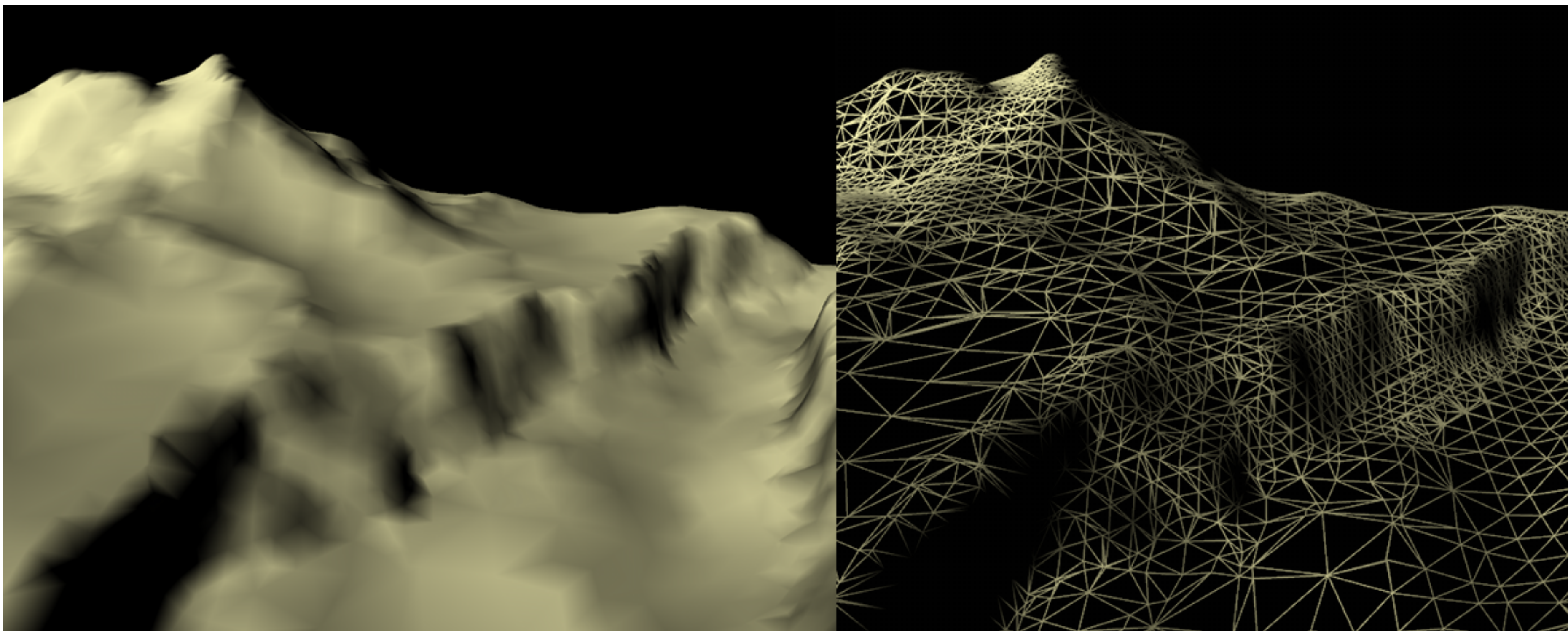
Example

- Contour lines and raster



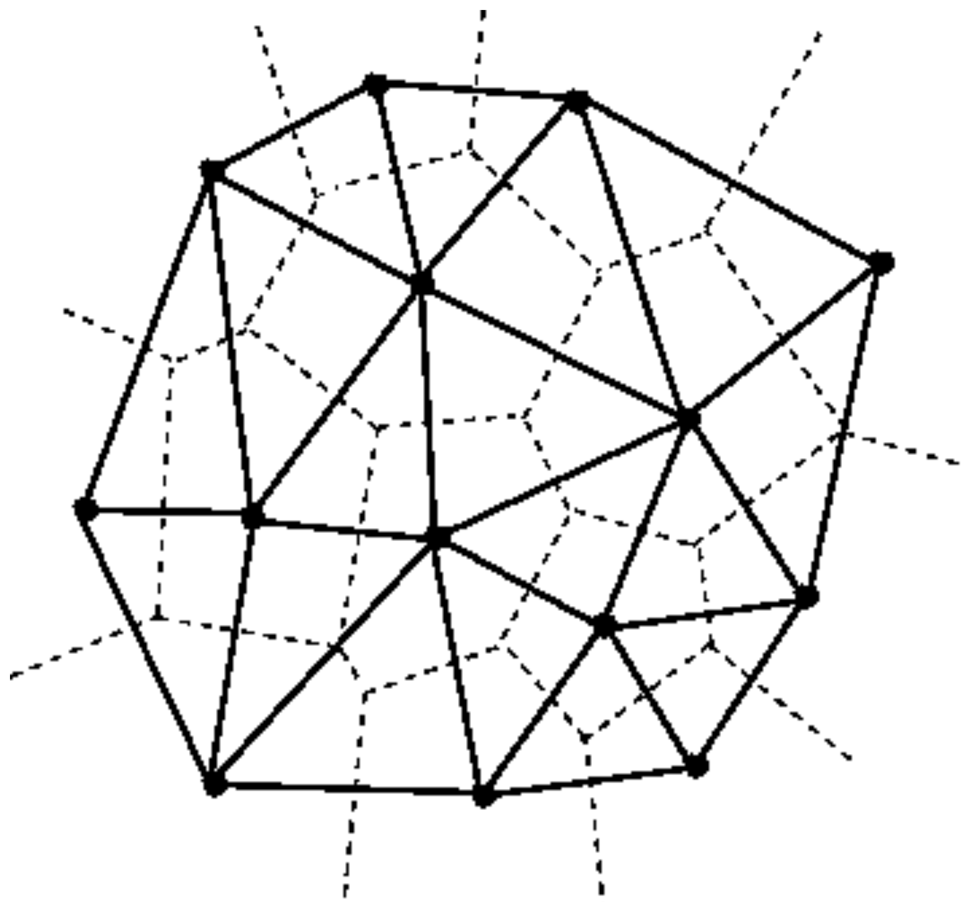
Example

- Trangulations



Side Note: Delaunay Triangulation and Voronoi Diagram

- Dual Graph

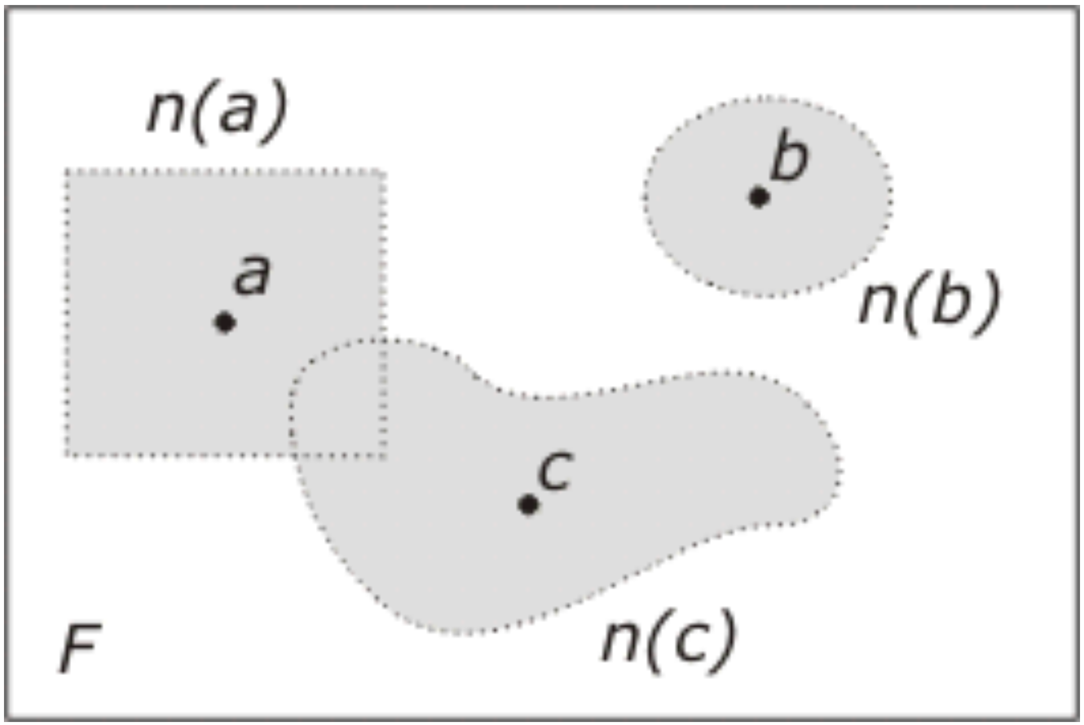


Operations on fields

- A field operation takes as input one or more fields and returns a resultant field
- The system of possible operations on fields in a field-based model is referred to as ***map algebra***
- Three main classes of operations
  - Local
  - Focal
  - Zonal

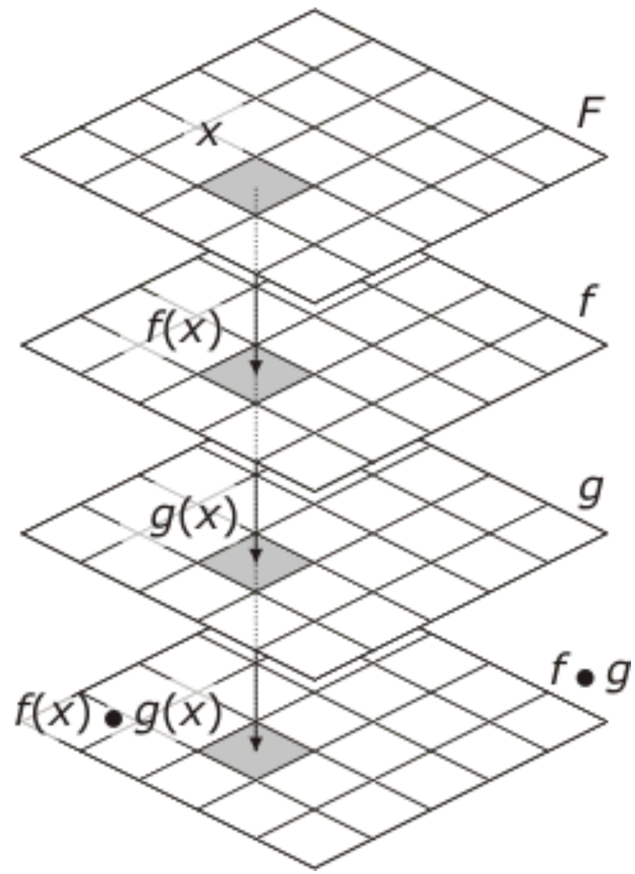
Neighborhood function

- Given a spatial framework *F*, a ***neighborhood function*** *n* is a function that associates with each location *x* a set of locations that are "near" to *x*



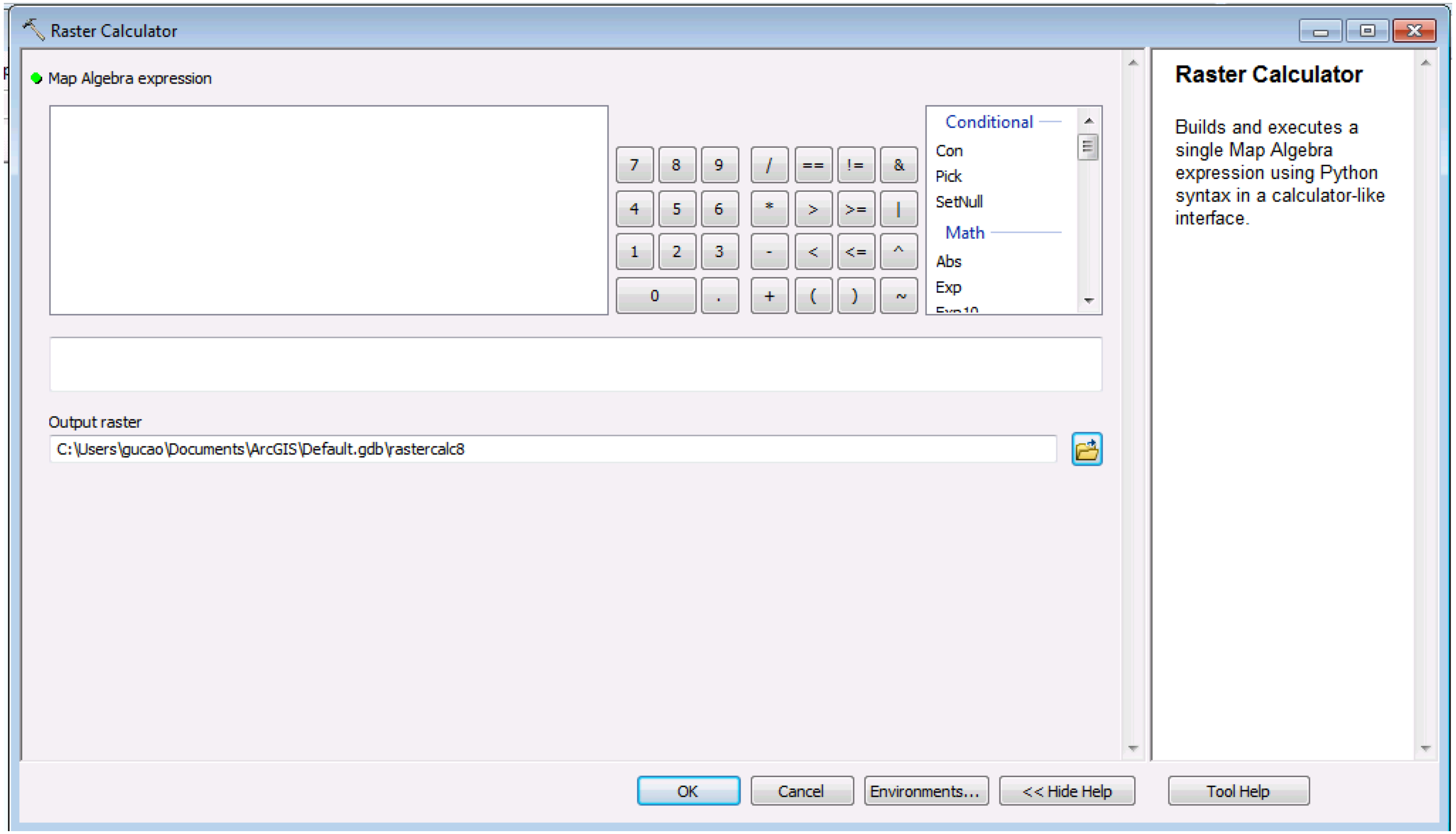
Local operations

- ***Local operation:*** acts upon one or more spatial fields to produce a new field
- The value of the new field at any location is dependent on the values of the input field function at that location
  - $\bullet$ is any binary operation



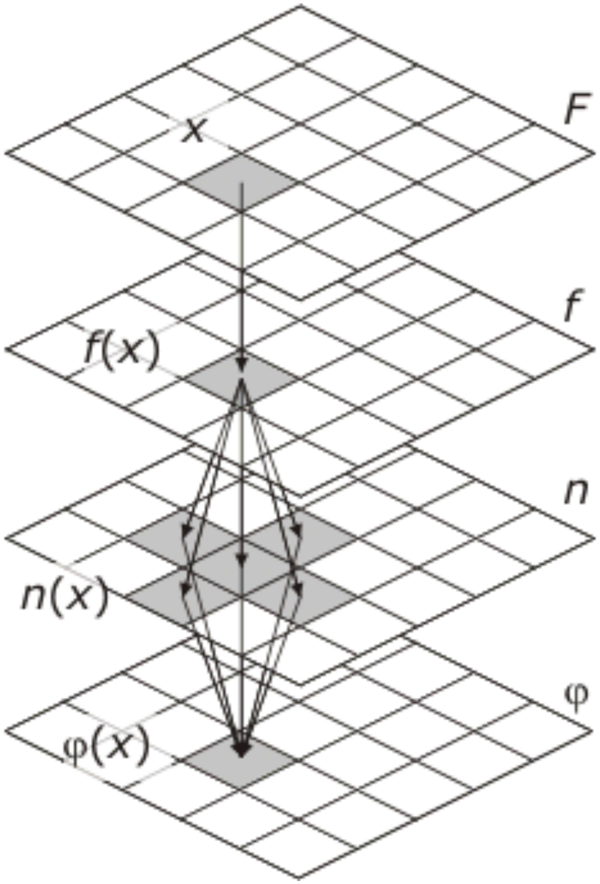
Local operations

- Typical operations:
  - Raster calculator



Focal operations

- ***Focal operation***: the attribute value derived at a location *x* may depend on the attributes of the input spatial field functions at *x* and the attributes of these functions in the neighborhood *n*(*x*) of *x*

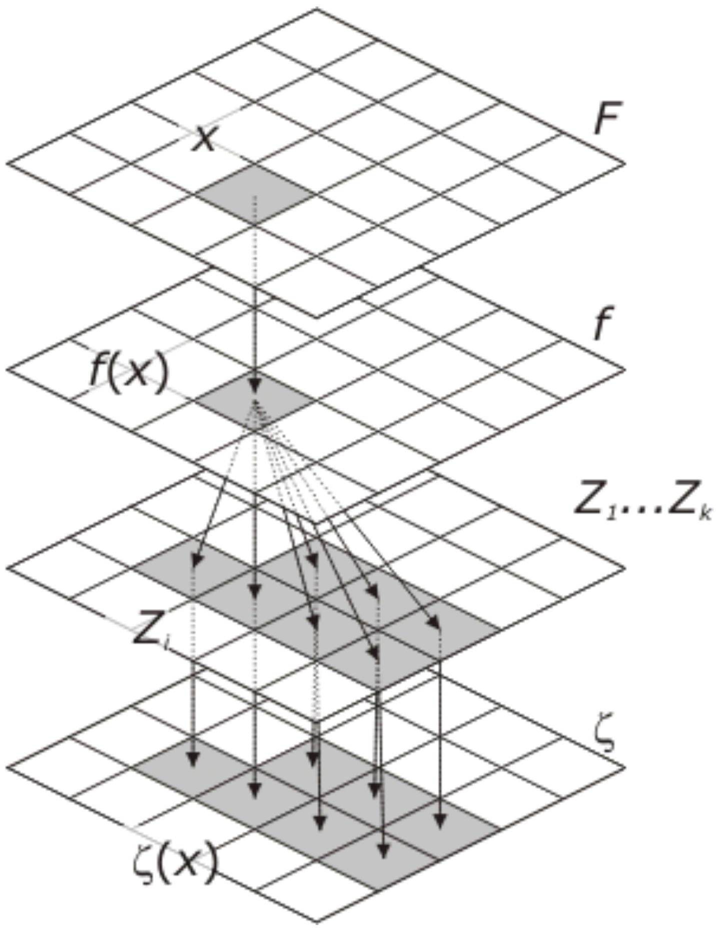


Focal operations

- Typical operations:
  - Slope
  - Aspect
  - Hill shade
- Focal statistics

Zonal operations

- ***Zonal operation***: aggregates values of a field over a set of zones (arising in general from another field function) in the spatial framework
- For each location *x*:
  1. Find the Zone Z_i in which *x* is contained
  2. Compute the values of the field function *f* applied to each point in Z_i
  3. Derive a single value $\zeta(x)$ of the new field from the values computed in step 2



Zonal operations

- Typical operations:
  - Zonal
  - Viewshed
  - Watershed

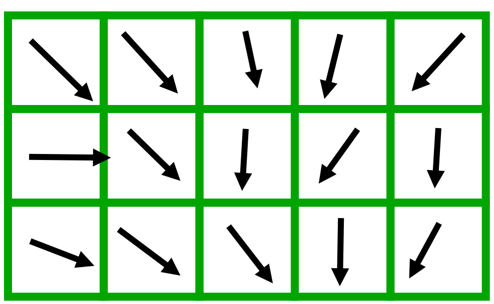
More on Watershed Analysis

The terrain flow information model for deriving channels, watersheds, and flow related terrain information.

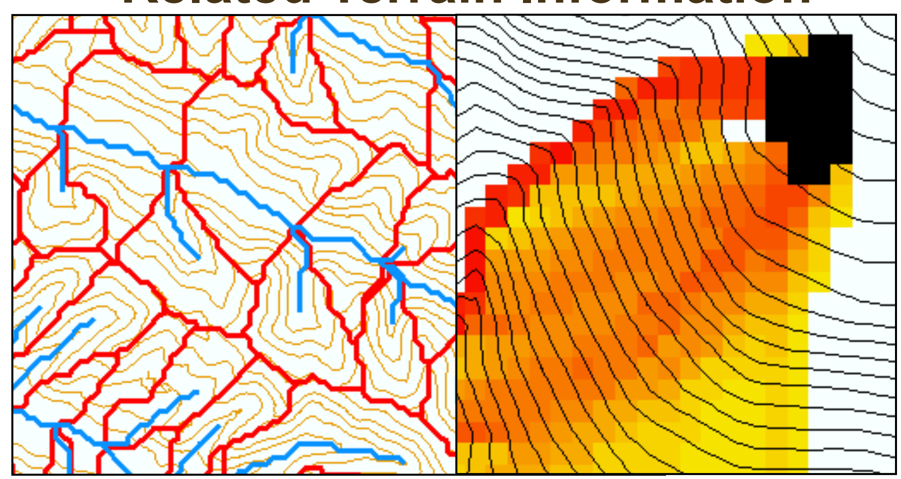
Raw DEM

Pit Removal (Filling)

Flow Field



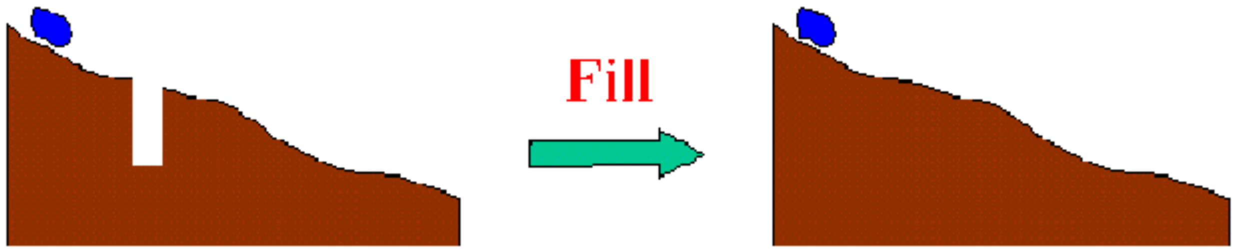
Channels, Watersheds, Flow Related Terrain Information



Watersheds are the most basic hydrologic landscape elements

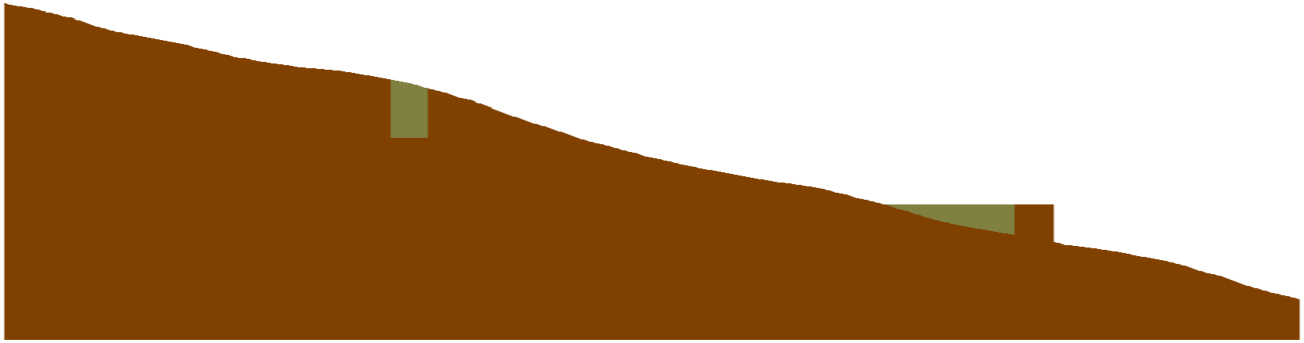
Courtesy of Dr. David G. Tarboton

The Pit Removal Problem



- DEM creation results in artificial pits in the landscape
- A pit is a set of one or more cells which has no downstream cells around it
- Unless these pits are removed they become sinks and isolate portions of the watershed
- Pit removal is first thing done with a DEM

Pit Filling



Increase elevation to the pour point elevation until the pit drains to a neighbor

Pit Filling

Original DEM

7	7	6	7	7	7	7	5	7	7
9	9	8	9	9	9	9	7	9	9
11	11	10	11	11	11	11	9	11	11
12	12	8	12	12	12	12	10	12	12
13	12	7	12	13	13	13	11	13	13
14	7	6	11	14	14	14	12	14	14
15	7	7	8	9	15	15	13	15	15
15	8	8	8	7	16	16	14	16	16
15	11	11	11	11	17	17	6	17	17
15	15	15	15	15	18	18	15	18	18

Pits

Grid cells or zones completely surrounded by higher terrain

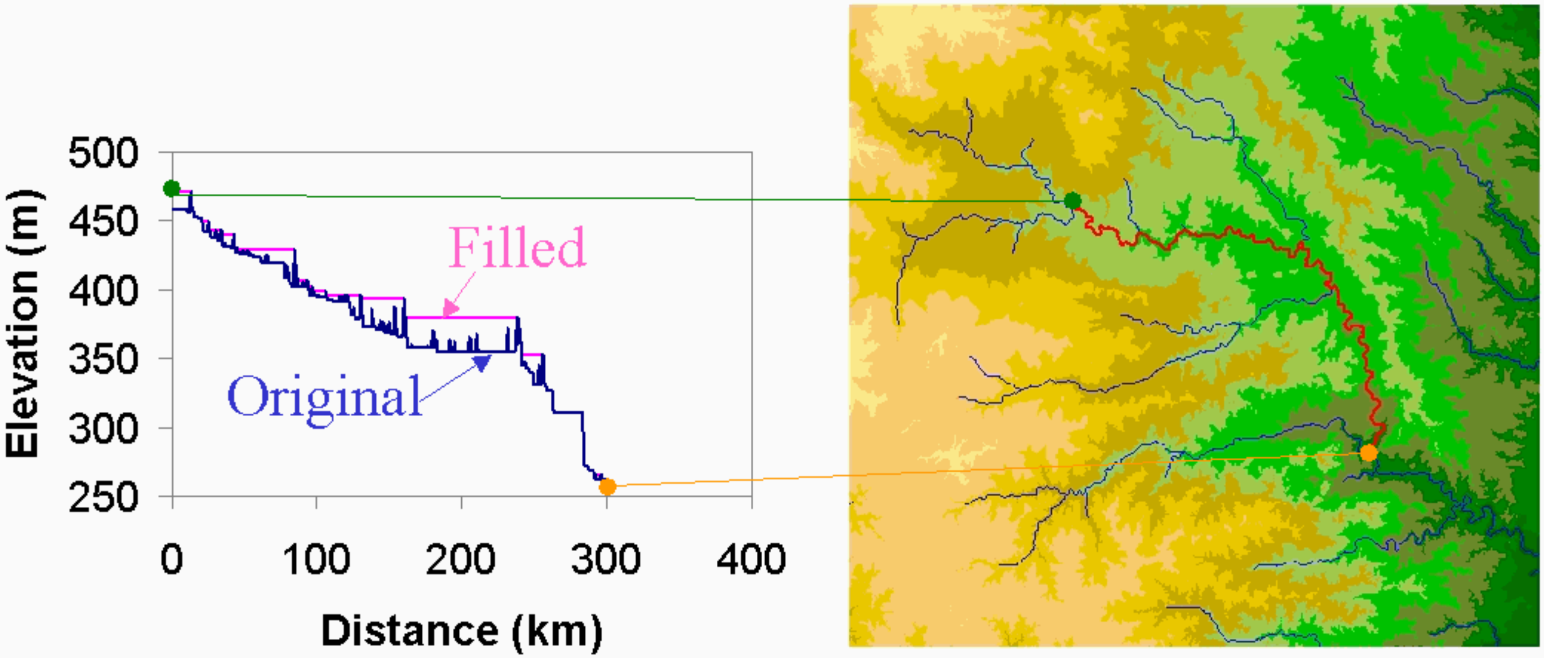
Pits Filled

7	7	6	7	7	7	7	5	7	7
9	9	8	9	9	9	9	7	9	9
11	11	10	11	11	11	11	9	11	11
12	12	10	12	12	12	12	10	12	12
13	12	10	12	13	13	13	11	13	13
14	10	10	11	14	14	14	12	14	14
15	10	10	10	10	15	15	13	15	15
15	10	10	10	10	16	16	14	16	16
15	11	11	11	11	17	17	14	17	17
15	15	15	15	15	18	18	15	18	18

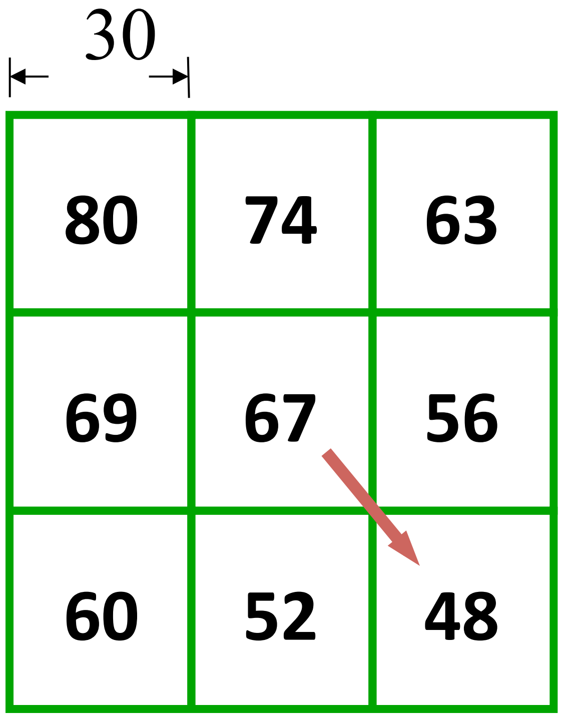
Pour Points

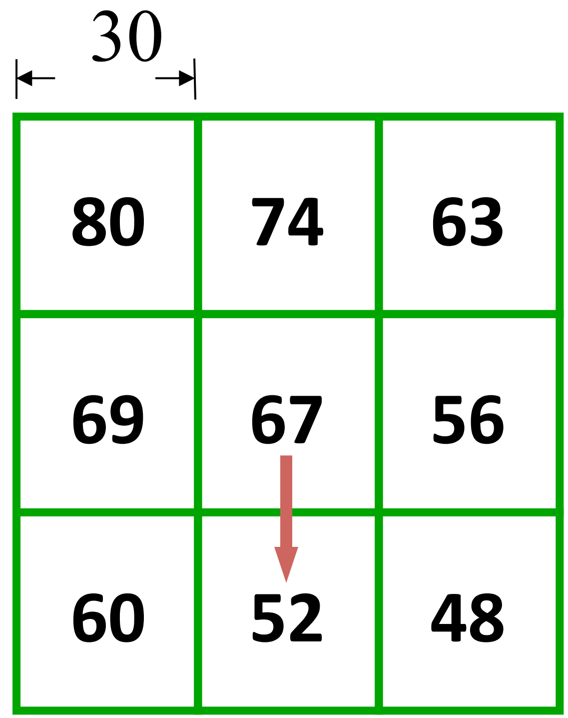
The lowest grid cell adjacent to a pit

Effect of Pit Filling on Elevation



Hydrologic Slope
- Direction of Steepest Descent

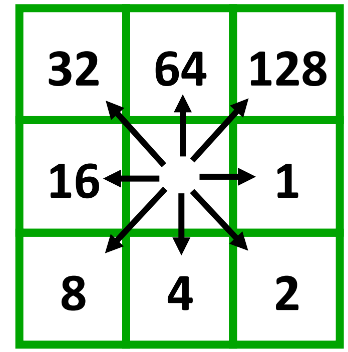


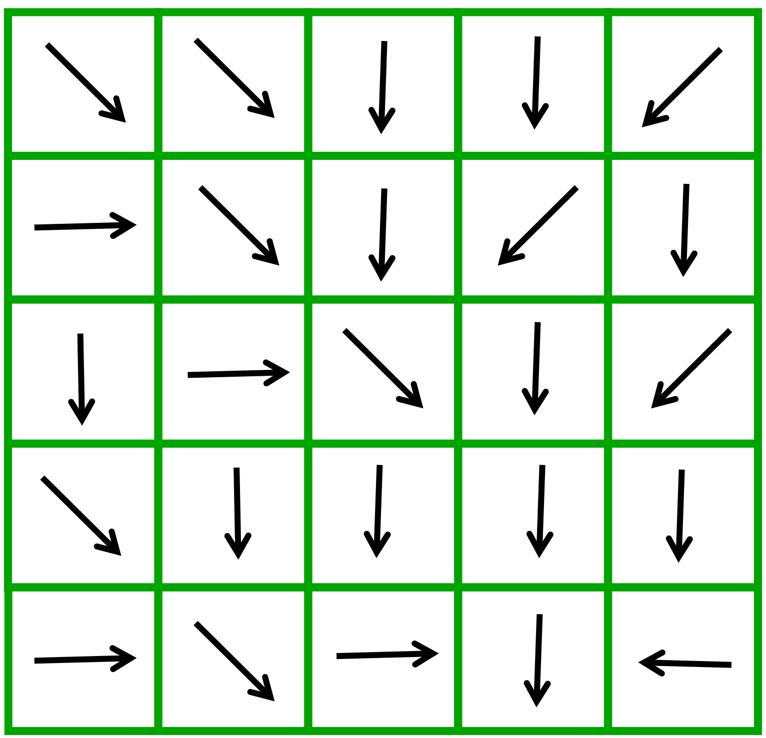


Slope: $\frac{67-48}{30\sqrt{2}} = 0.45$

$$\boxed{\frac{67-52}{30} = 0.50}$$

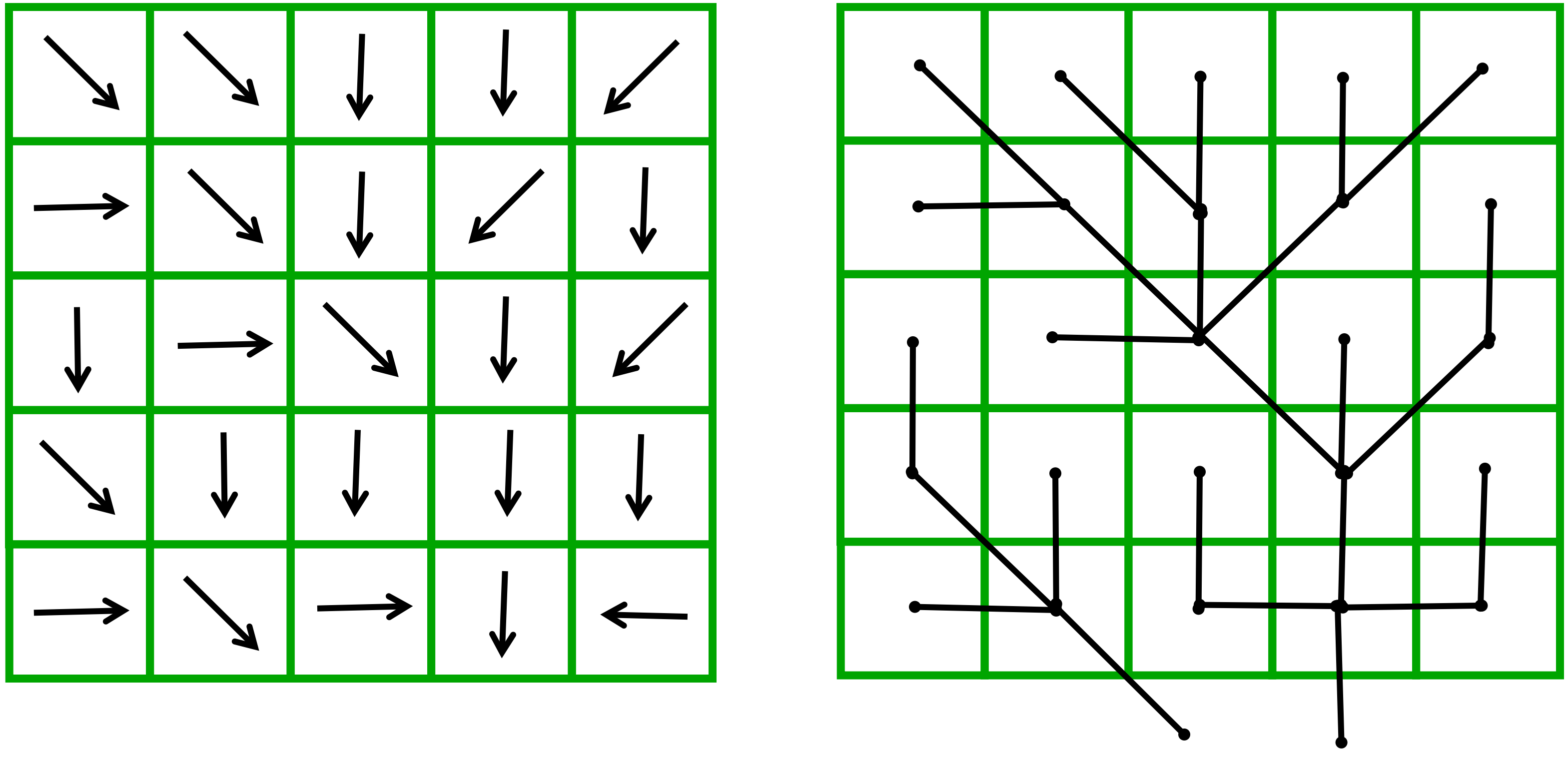
Eight Direction (D8) Flow Model





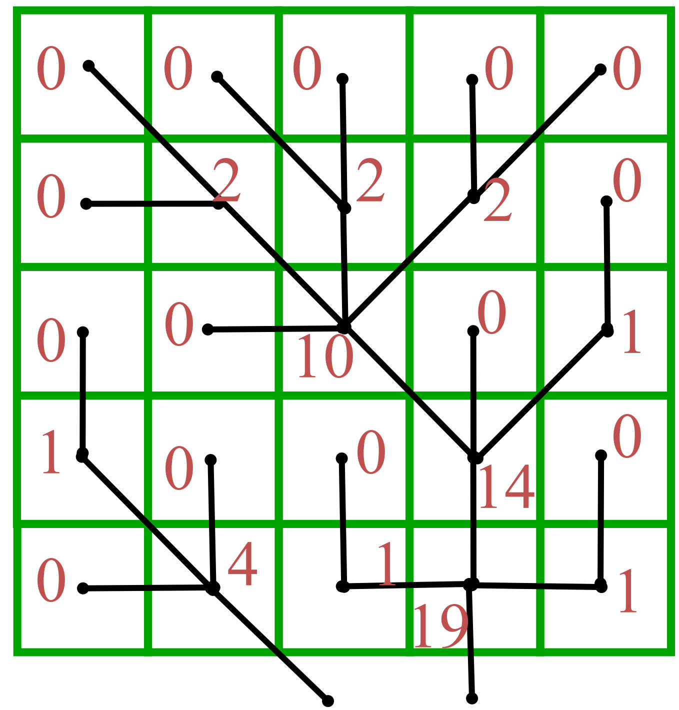
2	2	4	4	8
1	2	4	8	4
4	1	2	4	8
2	4	4	4	4
1	2	1	4	16

Grid Network



Flow Accumulation Grid.
Area draining **in** to a grid cell

0	0	0	0	0
0	2	2	2	0
0	0	10	0	1
1	0	0	14	0
0	4	1	19	1

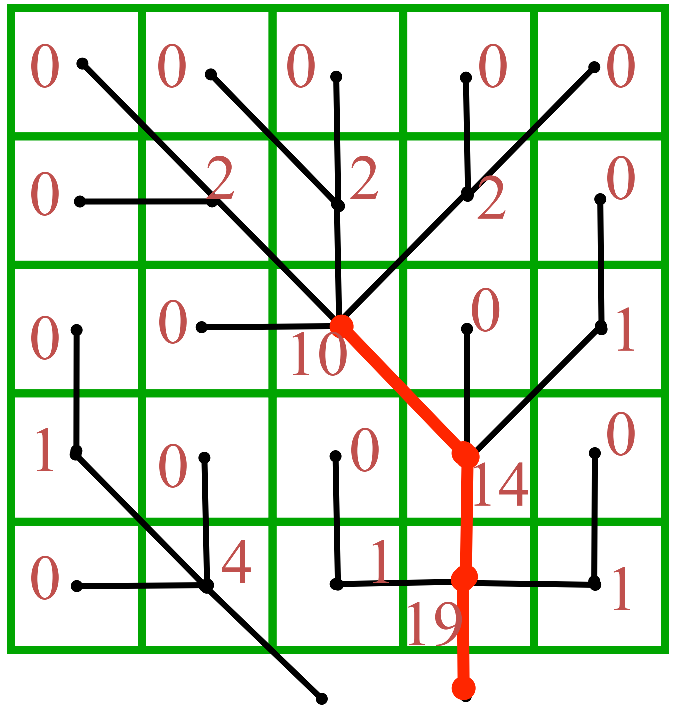


Link to Grid calculator

Flow Accumulation > 10 Cell Threshold

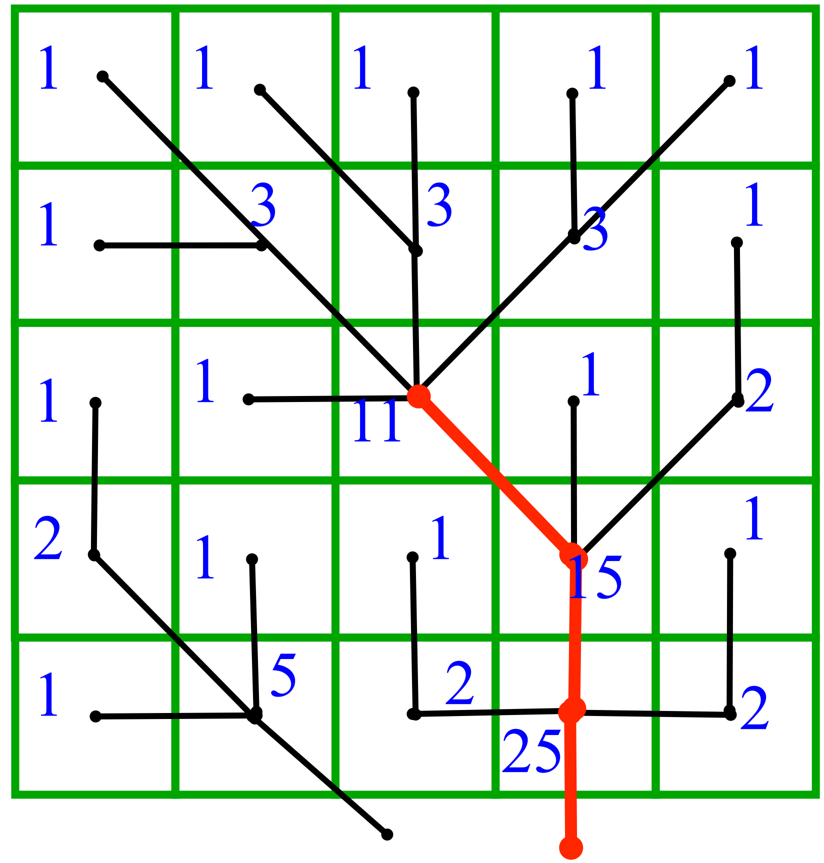
0	0	0	0	0
0	2	2	2	0
0	0	10	0	1
1	0	0	14	0
0	4	1	19	1

Stream Network for 10 cell Threshold Drainage Area



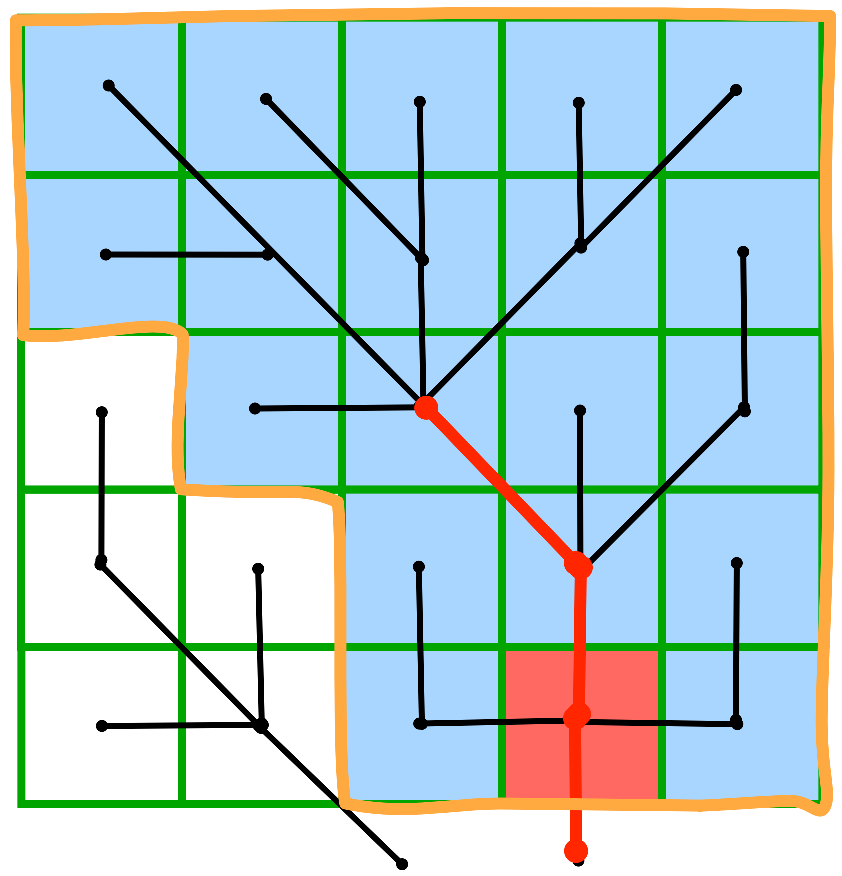
TauDEM contributing area convention.

1	1	1	1	1
1	3	3	3	1
1	1	11	1	2
2	1	1	15	1
1	5	2	20	2



The area draining each grid cell includes the grid cell itself.

Watershed Draining to Outlet



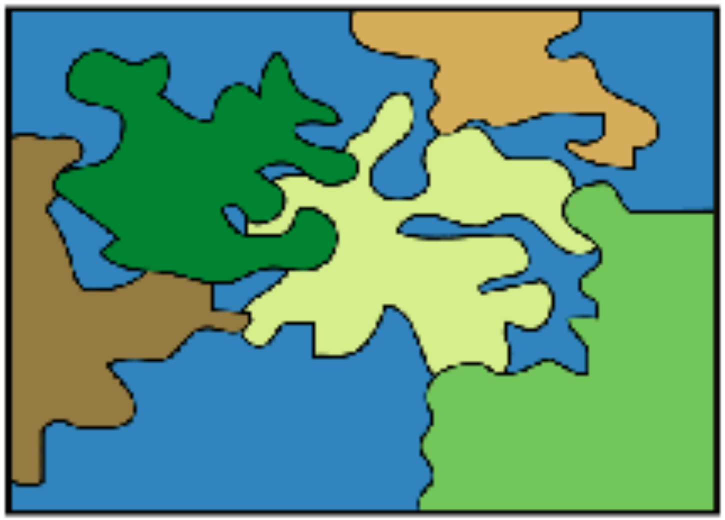
Summary of Key Processing Steps

- [DEM Reconditioning]
- Pit Removal (Fill Sinks)
- Flow Direction
- Flow Accumulation
- Stream Definition
- Stream Segmentation
- Catchment Grid Delineation
- Raster to Vector Conversion (Catchment Polygon, Drainage Line, Catchment Outlet Points)

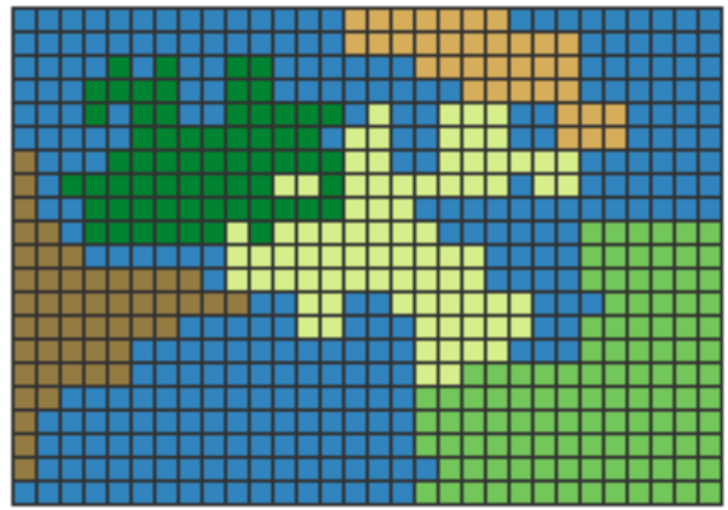
Summary Concepts

- The eight direction pour point model approximates the surface flow using eight discrete grid directions
- The elevation surface represented by a grid digital elevation model is used to derive surfaces representing other hydrologic variables of interest such as
  - Slope
  - Flow direction
  - Drainage area
  - Catchments, watersheds and channel networks

Summary: Object-based vs Field-based models



Polygon features



Raster polygon features

From:
http://resources.arcgis.com/en/help/main/10.2/index.html#/How_features_are_represented_in_a_raster/009t00000006000000/

Summary: Object-based vs Field-based models

- Object-based models:
  - Greater precision
  - Less redundant information (smaller storage footprints)
  - Complex data structures
- Field-based models:
  - Simpler data structures
  - More redundant information (larger storage footprints)
  - Less precision
- *Raster is faster, but vector is corrector*

Raster <-> Vector

- Vector-> Raster
  - Interpolation
    - Inverse distance weighted, Kriging, Spline
  - Density surface
    - Kernel density
  - Rasterization
- Raster->Vector
  - Watershed
  - Vectorization (raster to polygon)
  - …

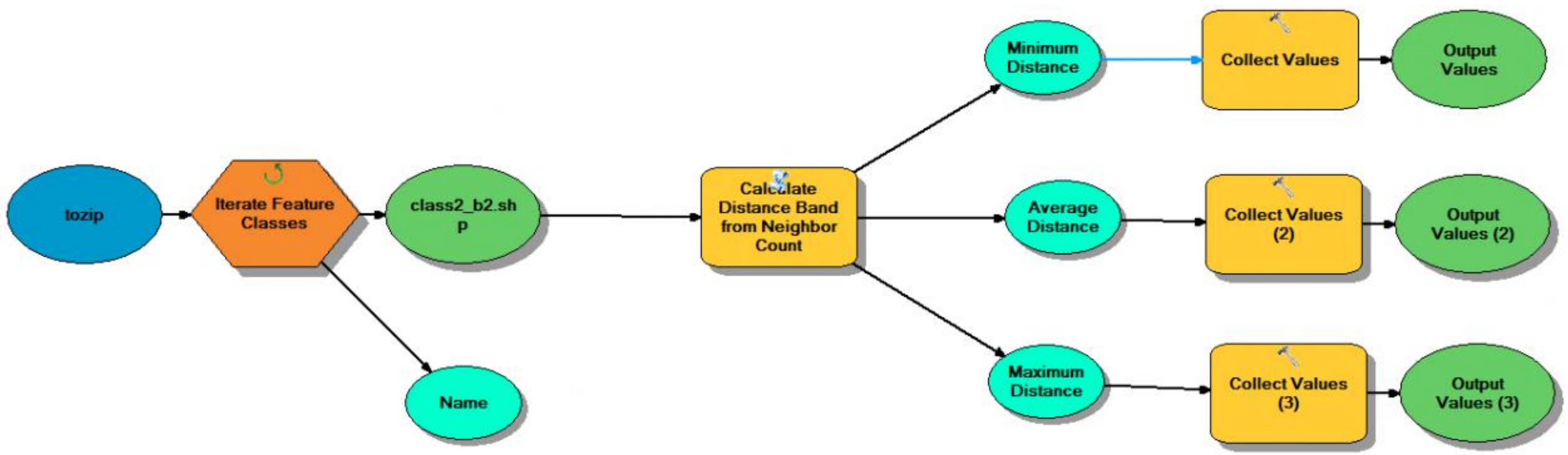
Model Builder

Model Builder

- Model Builder is a drag-and-drop interface to ArcToolbox called ModelBuilder allowing you to develop a flow chart of your GIS workflow
  - This flowchart is then run step by step to perform your analysis
- ArcGIS allows for custom scripting that can be added to ArcToolbox, introducing greater functionality
  - Custom export scripts, specialized versions of existing tools, develop tools not available in ArcToolbox

Model Builder

- Graphic Programming



Why Model Builder?

- Developing a model for a GIS analysis allows for repeat testing of a hypothesis using different data.
- The model can be coded into a GIS application, so that the steps are performed automatically.
- Easier reproduction of results.
- Simplification of workflow.
- Informs the computer how to conduct a series of steps that would be impractical for you to do manually.

Reproducibility

- In performing an analysis, you must have your workflow clearly defined.
- This ensures that you are performing the steps in the correct order using the appropriate tools.
- Missteps are easy, especially when there can be hours of computer processing between steps.
- The GIS model can be exported as a graphic flowchart or a modeling data structure.

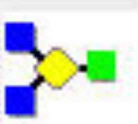
Workflow Efficiency

- There are many repetitive steps you will take in your daily workflow.
- Streamlining the process saves you time.
- If you always start working in a File Geodatabase with specific resolution and projection information, a model for generating your specialized GDB can be created.

Human Inefficiency

- You physically cannot perform the steps as fast as GIS can produce the results.
- Certain steps, such as iteration through a feature set would be prohibitively time consuming.
- Minimize the amount of time spent "babysitting" GIS to perform complex analyses.

Inside ArcToolbox

Icon	Name	Description
	Toolset	A container for organizing the contents of a toolbox.
	Tool	Runs an underlying function in the geoprocessing framework.
	Script	Can be written in any Common Object Model (COM)-compliant scripting language, such as Python, JScript, or VBScript. An ArcInfo Workstation ARC Macro Language (AML) can also be added to a toolbox as a script.
	Model	You can view and edit these in the new integrated ModelBuilder window.

Demo

- Demo
- Lab: Buffalo commons using Model Builder: