Session 7: Rasters and Terrain Analysis

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UC San Diego | EXTENSION

Class Schedule

Monday	Tuesday	Wednesday	Thursday	Friday
08/05/19 **Introduction to Geographical Information Systems** 10:45 am–12:15 am	08/06/19 **Cartography and Spatial Data Display** 8:30am – 11:00pm	08/07/19 **Querying Data for Spatial & Attribute Selections** 8:30am – 11:00pm	08/08/19 **Data Formats and Open-Source GIS** 8:30am – 11:00pm	08/09/19 **Map Projections and Coordinate Systems** 8:30am – 11:00pm
08/12/19 **Spatial Analysis Tools** 8:30am – 11:00pm	08/13/19 **Raster and Terrain Analysis** 8:30 am – 10:00 am **Scripps Institution of Oceanography** 1:00pm – 4:00pm	08/14/19 **Image Analysis** 8:30am – 11:00pm	08/15/19 **Editing Spatial Data and Geocoding** 8:30am – 11:00pm	08/16/19 **Web Mapping/ Wrap up** 8:30am – 11:30am

Outline: Rasters and Terrain Analysis

- Introduction
- Map Algebra
- Local Functions
- Neighborhood, Zonal, and Global Functions
- Terrain Analysis
- Demonstration

Rasters, or grids, are based on two dimensional arrays, which are data structures supported by many of the earliest programming languages. The raster row and column format is among the easiest to specify in computer code and is easily understood, thereby encouraging modification, experimentation, and the creation of new raster operations.

Today we will discuss popular grid formats used by GIS programs and the programs you will utilize to interact with these data structures.

Introduction: Raster Analysis

- Raster cells store data
  - Integer or floating point values
- Connected cells can form networks
  - Grouped into neighborhoods
- Examples:
  - Predict fate of pollutants
  - Model spread of disease

The flexibility of raster analyses has been amply demonstrated by the wide range of problems they have helped solve. Raster analyses are routinely used to predict the fate of pollutants in the atmosphere, the
spread of disease, animal migration, and crop yields. Time varying and wide area phenomena are often analyzed using raster data, particularly when remotely sensed inputs are available.

Raster Data Models

- Each cell represents some variable (e.g. temperature or elevation)
- Groups of cell share a value representing some sort of geographic characteristic

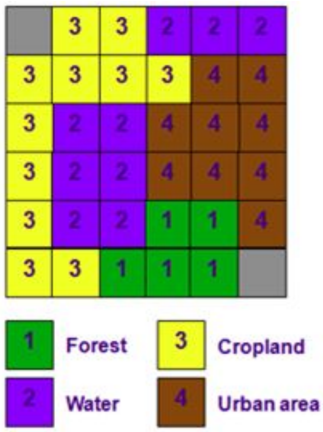
Source: ESRI - Displaying Raster Data

5

The raster data model represents the real world as an array of cells arranged in rows and columns.
Satellite images, aerial photographs, digital elevation models (DEMs), scanned maps, and pictures are examples of raster data.
Each cell has a value that is used to represent some characteristic of that location, such as temperature, elevation, or a spectral/light value. In this raster, groups of cells that share a value represent the same type of geographic characteristic or phenomenon such as land type.

Raster Cells

Example: Raster cells representing land use classes



Value Attribute Table (VAT)

OID	VALUE	COUNT	TYPE	AREA	CODE
0	1	5	Forest	2345	F010
1	2	9	Water	3256	W010
2	3	11	Cropland	3867	CL030
3	4	9	Urban area	3256	UA040

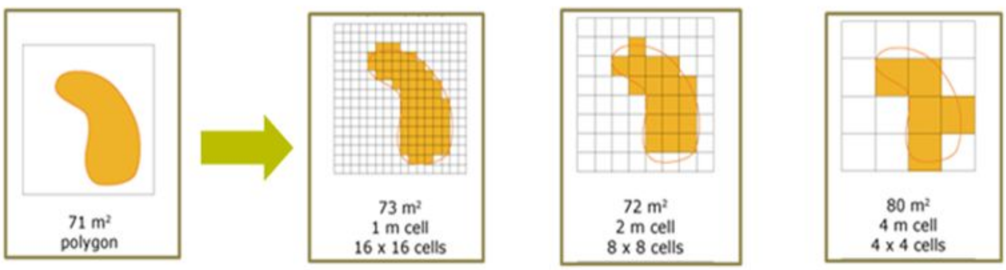
Source: ESRI - Displaying Raster Data

The raster cell is the smallest unit of information in raster data.
In a map or GIS dataset, each cell represents a portion of the earth, such as a square meter or square mile, and the cell usually has an attribute value associated with it.
The following graphic illustrates a classification analysis of a satellite image for defining land uses. The categories in this land-use classification are include: Water, Forest, Wetlands, etc.
In this classification analysis, the integers in the grid are the cell values that represent the assigned land-use classes.
Cells containing NoData can be important to subsequent analyses as well.

Raster Cell Size

- **Cell size** = Spatial resolution
- Determines how coarse or fine features are represented

Example: Lake polygon represented as rasters



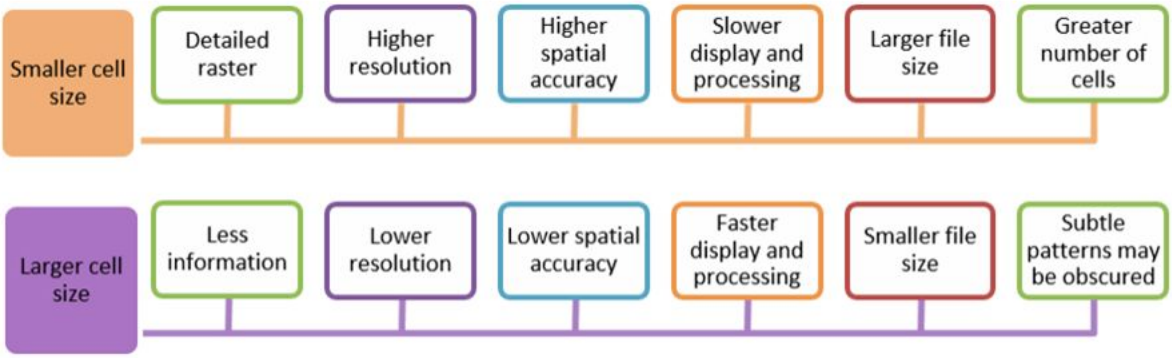
7

Source: ESRI - Displaying Raster Data

The cell size, or spatial resolution, of a raster becomes important when displaying or comparing raster data with other data types, such as vector. The cell size determines how coarse or fine the patterns or features in the raster will appear. Spatial resolution refers to the dimensions of the cell size representing the area covered on the ground. Therefore, if the area covered by a cell is 1 meter x 1 meter, the resolution is 1 meter. A lake (a simple polygon feature) is represented by a raster dataset at various cell sizes. The dimension of the cells (square meter values representing the area of the lake on the ground) can be as large or as small as needed to represent the surface. If a 4 x 4 grid depicts a lake where each cell represents 16 square meters on the ground, the total area of the cells representing the lake is 80 square meters.

Raster Cell Size

- **Choosing right cell size is important!**



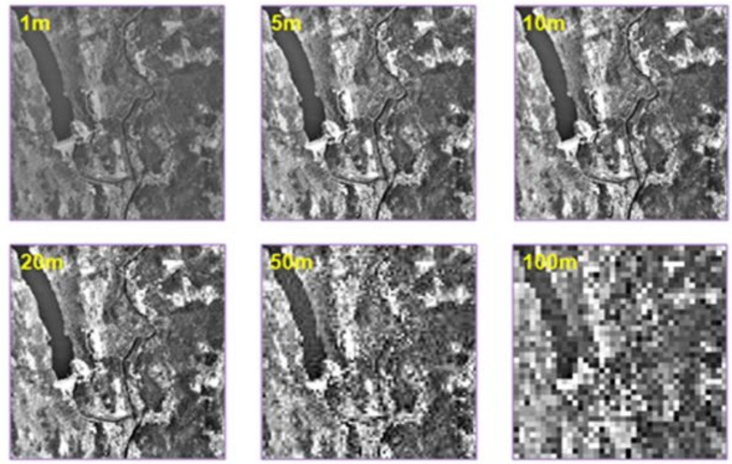
This comparison of large and small cell size in a raster shows how cell size affects the level detail represented by a raster.

Source: ESRI - Displaying Raster Data

Choosing right cell size is important. The cell size must be small enough to capture the required detail but large enough so that computer storage and analysis can be performed efficiently.
This comparison of large and small cell size in a raster shows how cell size affects the level of detail represented by a raster.

Choosing Cell Size

- Not simple choice
- Considerations:
  - Display time
  - Processing time
  - Storage
- Smaller cell size = greater spatial resolution



Source: ESRI - Displaying Raster Data

Choosing an appropriate cell size is not always simple. You must balance your application's need for spatial resolution with the practical requirements for quick display, processing time, and storage.
Aerial photo Raster data shown here is displayed at different cell sizes (the smaller the cell size, the higher the spatial resolution, and vice versa).
You sacrifice detail for processing speed and storage.

Choosing Cell Size

The following factors should be considered when specifying cell size:

- The spatial resolution of the input data and the storage size of the raster
- The application and analysis to be performed
- The level of detail you want for the analysis to be performed
- Accuracy and precision and the desired response time

Determining an adequate cell size is as important in your GIS application planning stages as determining which datasets to obtain. For example, if you are performing analysis at the parcel level, you would need a small cell. But if you are performing analysis at the county level or state level, your cell size can be larger.
The following factors should be considered when specifying cell size:

- The spatial resolution of the input data and the storage size of the raster
- The application and analysis to be performed
- The level of detail you want for the analysis to be performed
- Accuracy and precision and the desired response time

Raster and Images

- Raster and Image are often interchanged
  - Image: 2-D pictorial representation
  - Raster: Data model describing how image is stored
- All images are rasters
- Not all rasters are images

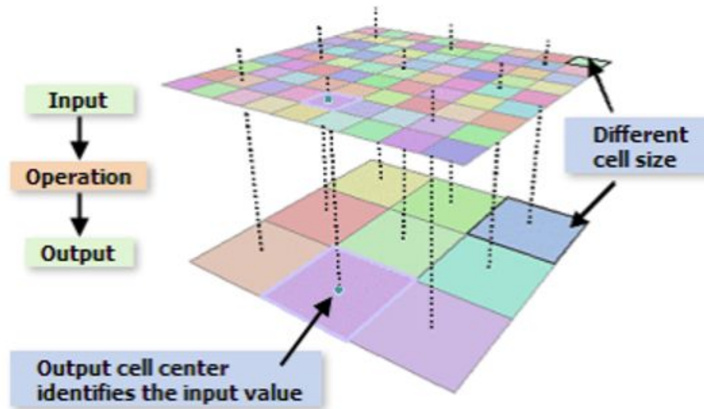
Raster and image are two terms that are often interchanged.

- An image is a generic two-dimensional pictorial representation.
  - It is not dependent on a wavelength nor a remote sensing device, such as a satellite, aerial camera, or terrain sensor.
  - An image is displayed on your screen or printed. You view images that represent rasters.
- A raster is the data model that describes how an image is stored.
  - A raster defines the pixels (cells) in rows and columns, the number of bands, and the bit depth that compose the image.

When you view a raster you are viewing an image of that raster data.
All images are rasters, but not all rasters are considered images. For example, a digital elevation model (DEM) is a cell-based raster dataset, but is typically not considered an image.
Other types of rasters that are not considered images are magnetic data, interferogram, bathymetric data, and other grid-based datasets.

Resampling Rasters

- Processing or displaying rasters requires resampling
- Datasets with different cell sizes are resampled to match coarsest cell size



12

Resampling Raster Data
Different raster datasets do not need to be stored using the same cell resolution. But when you are processing between multiple datasets, the cell resolution should ideally be the same. When multiple raster datasets are used and their resolutions are different, one or more of the input datasets will be automatically resampled to the coarsest resolution of the input datasets. Resampling alters the display of the raster dataset by interpolating new cell values while transforming the raster dataset (for example, during a geoprocessing function or a change in the coordinate space). When a raster is displayed, the cell values are resampled to the grid of pixels on your computer monitor.

In the graphic above, the cell size that was set in the analysis environment is coarser than the cell size of the input raster to the tool. On execution, the input raster will first be resampled to the coarser resolution, and then the tool is applied.

Map Algebra

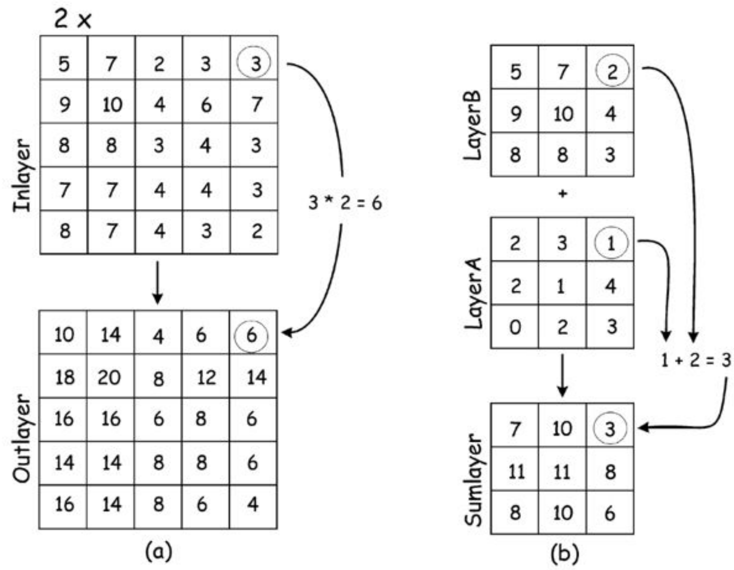
- Cell-by-cell combination of raster data layers
- Raster layers are combined through operations:
  - Addition
  - Subtraction
  - Multiplication

Map algebra is the cell-by-cell combination of raster data layers. The combination entails applying a set of local and neighborhood functions, and to a lesser extent global functions, to raster data. The concept of map algebra is based on the simple yet flexible and useful data structure of numbers stored in a raster grid. Each number represents a value at a raster cell location. Simple operations may be applied to each number in a raster. Further, raster layers may be combined through operations such as layer addition, subtraction, and multiplication.

Map Algebra

a) Inlayer * 2 = Outlayer

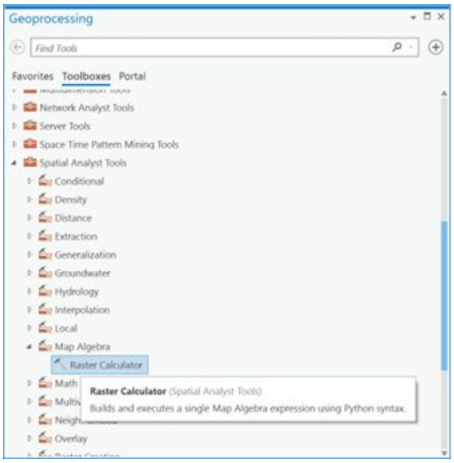
b) LayerB + LayerA = SumLayer

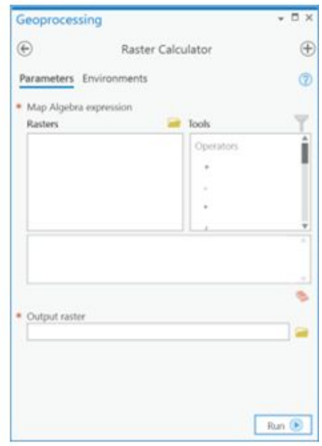


An example of raster operations. On the left side (a) each input cell is multiplied by the value 2, and the result stored in the corresponding output location. The right side (b) of the figure illustrates layer addition

Note that in our example LayerA and LayerB have the same extent – they cover the same area. This may not always be true.

ArcGIS Pro: Raster Calculator





ArcGIS Pro implementation of Map Algebra is through the ‘Raster Calculator’

The Raster Calculator is accessed by the Spatial Analyst toolbox

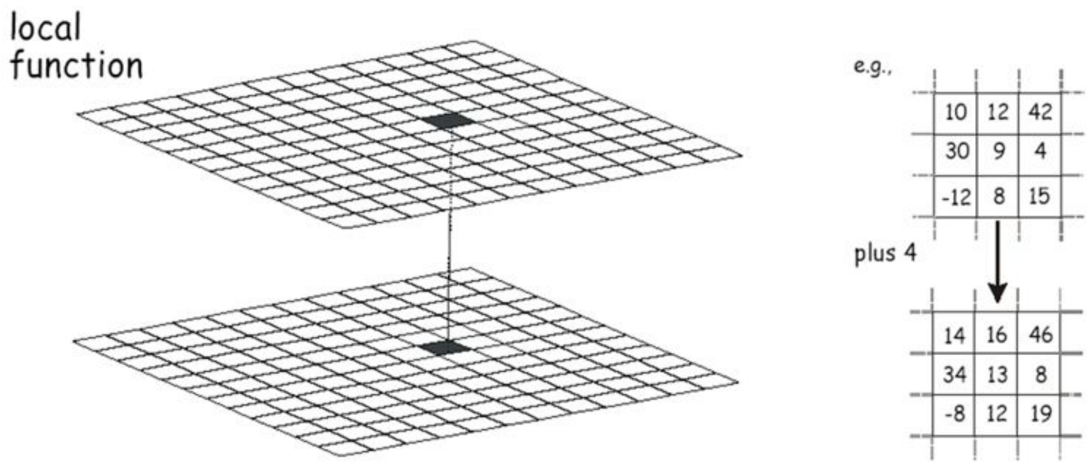
Raster Analysis: Scope

- Local operations
  - Single cell used
- Neighborhood operations
  - Set of cells in a specified arrangement
- Global operations
  - Every cell involved

As we saw with vector operations, raster operations may be categorized as local, neighborhood, or global .

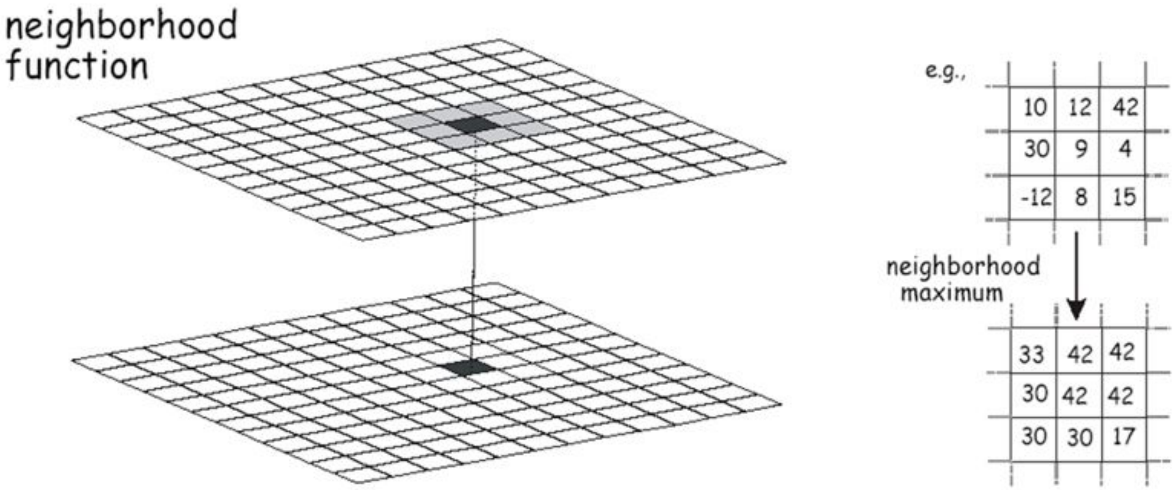
- Local operations use only the data in a single cell to calculate an output value.
- Neighborhood operations use data from a set of cells.
- global operations use all data from a raster data layer.

Scope: Local Operations



Local operations.
Here, in this schematic of a local function in Raster Analysis: Both the Target and source cells are shown in black.
Local operations show a cell-to-cell correspondence between input and output as shown in example on the right,

Scope: Neighborhood Operations



Neighborhood operations include a group of nearby cells as input.
In this schematic, the gray cells indicate the neighborhood used to operate on the target cell in black.

Local Functions/Operations

Four classes of local operations:

- Mathematical functions
- Boolean/Logical functions
- Reclassification
- Multi-layer overlay

There is a broad number of local functions (or operations) that can be conveniently placed in one of four classes:

- mathematical functions,
- Boolean or logical operations,
- reclassification, and
- multilayer overlay.

Logical Operations

- Also known as Boolean operations
- Involves comparison of a cell to single scalar value
- Outputs a “true” or “false” value
  - TRUE: represented by “1”
  - FALSE: represented by “0”
- Three types of operations: AND, OR, and NOT

There are many local functions that apply logical (also known as Boolean) operations to raster data. A logical operation typically involves the comparison of a cell to a scalar value or set of values and outputs a “true” or a “false” value. True is often represented by an output value of 1, and false by an output value of 0. There are three basic logical operations, AND, OR, and NOT

Logical Operations Example: AND

Assigns true to the output if both of the corresponding input cells is true

Input

1	3	1	1
0	N	2	-1
1	2	5	0
0	1	N	N

AND

0	1	0	9
0	5	2	5
0	2	N	2
0	-3	4	8

=

Output

0	1	0	1
0	N	1	1
0	1	N	0
0	1	N	N

Examples of logical operations applied to raster data. Operations place true (non-zero) or false values (0) depending on the input values. AND requires both corresponding input cells be true for a true output, otherwise output assigned as False. Null or unassigned cells are denoted with an N.

Raster Reclassification

- Raster reclassification assigns output values based on a specific set of input values
- Assignment can be defined by:
  - Input table
  - Range of values
  - Conditional test (“con” function)
- Used in creating raster “masks”

Raster reclassification assigns output values that depend on the specific set of input values. Assignment is most often defined by a table, ranges of values, or a conditional test.

Reclassification: Conditional

- Reclassify raster based on a condition statement
- Condition results in a TRUE or FALSE outcome

Output = CON (test, out_if_true, out_if_false)

CON: conditional function

test: condition to be tested

out_if_true: value assigned if true

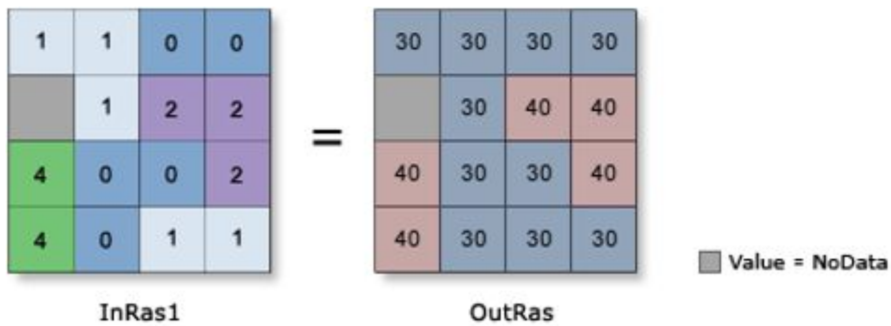
out_if_false: value assigned if false

Data can also be reclassified to select the input source based on a condition. These “conditional” functions have varying syntax, but typically require a condition that results in a true or false outcome. The value or source layer assigned for a true outcome is specified, as is the value or source layer assigned for a false outcome. An example of one conditional function may be:
Output = CON (test, out if true, out if false)

where CON is the conditional function, test is the condition to be tested, out if true defines the value assigned if the condition tests true, and out if false defines the value assigned if the condition tests false (Figure in next slide).

Example Con Function

OutRas = Con(InRas1, 40, 30, "Value >= 2")



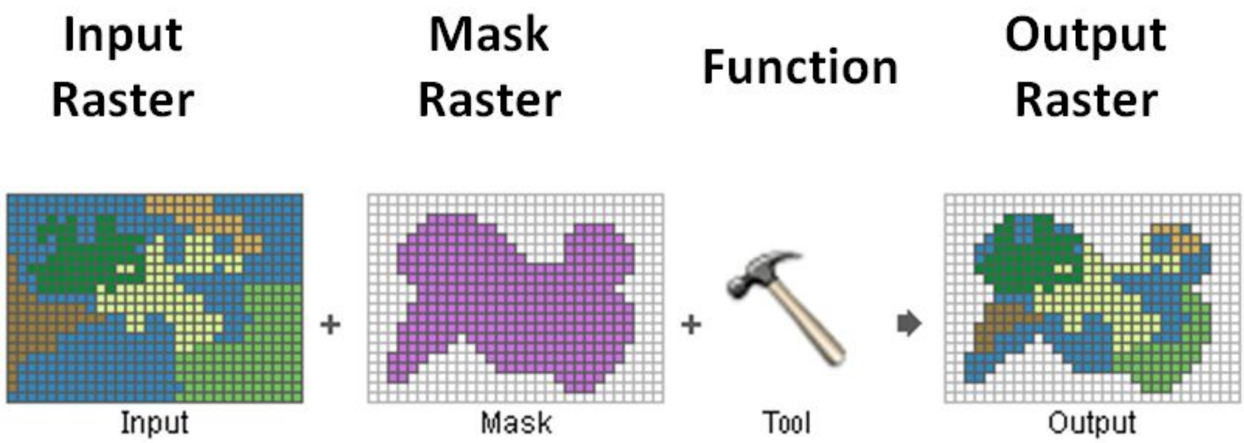
Con Example

Raster Overlay

- Raster overlay combines features from two or more layers
- Raster overlay limited to nominal data (not continuous data)
- Overlay examples
  - Clipping/Extraction
  - Union

Raster overlay combines features from two or more data layers, and is among the most useful of spatial functions.
The features in raster data correspond to cells, or perhaps groups of cells with the same values, but as with vector overlay, great utility is often gained from combining data from different layers.

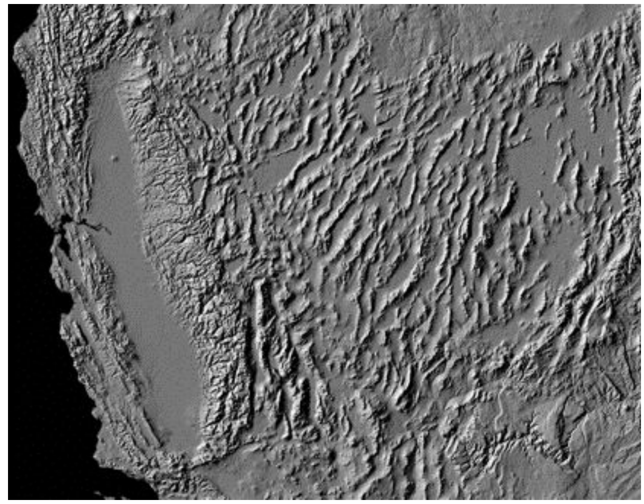
Raster Overlay: Mask Grid



Mask Raster Example

Terrain Analysis

- Digital Elevation Models (DEMs)
- Slope/Aspect
- Shaded Relief
- Contour Lines
- Viewsheds



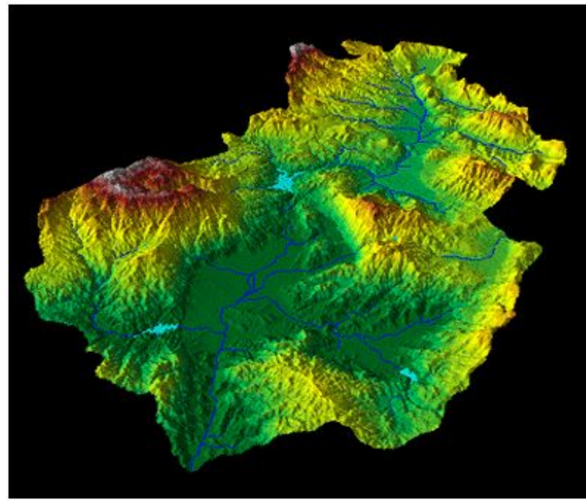
Elevation and related terrain variables are important at some point in almost everyone's life.
Elevation and slope vary across the landscape, and this variation determines where rivers flow, lakes occur, and floods are frequent.
Terrain strongly influences transportation networks and the cost and methods of building construction.
Terrain variables are frequently applied in a broad range of spatial analyses.
We will take a look at:

- Digital Elevation Models (DEMs)
- Slope/Aspect
- Shaded Relief
- Contour Lines
- Viewsheds

The image on the right shows the shaded relief of a digital elevation model of California.

Digital Elevation Models (DEM)

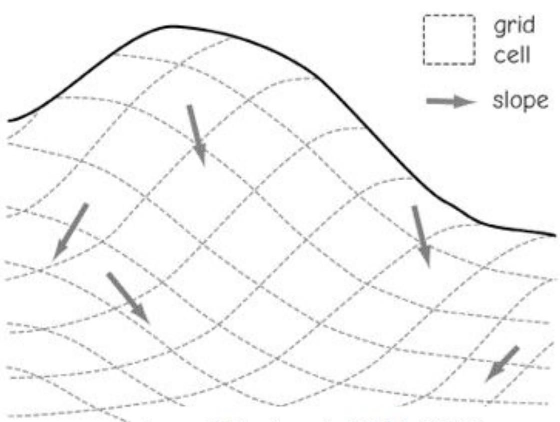
- Raster representation of the earth surface
- Cells contain continuous elevation values
- Accuracy determined by raster resolution



The 3-Dimensional surface of the earth can be represented as a cell-based digital elevation model (DEM).
A DEM is a raster representation of a continuous surface, usually referencing the surface of the earth.
The accuracy of this data is determined primarily by the resolution (the distance between sample points).
Other factors affecting accuracy are data type (integer or floating point) and the actual sampling of the surface when creating the original DEM.
Figure: Visualization of a raster DEM surface: colors represent elevations with shaded relief overlaid with watershed features

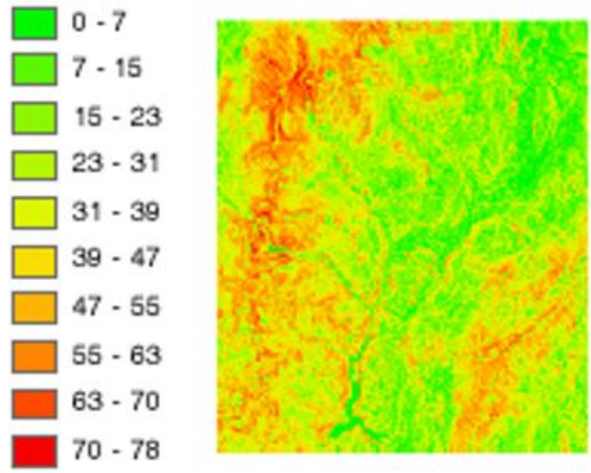
Terrain Analysis: Slope

- Slope: Rise over run



Source: GIS Fundamentals, Bolstad (2015)

- % Slope

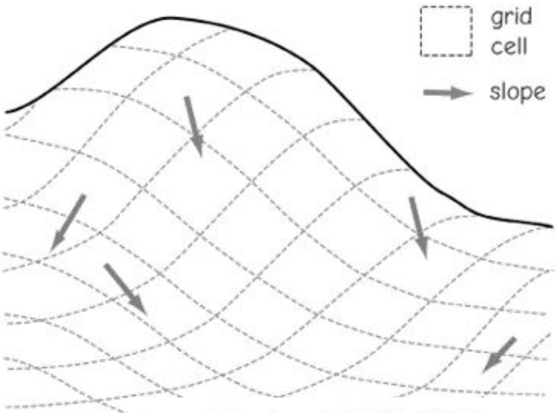


Slope and aspect are two commonly used terrain variables.
They are required in many studies of hydrology, conservation, site planning, and are the basis for many other terrain analysis functions.
Watershed boundaries, flowpaths and direction, erosion modeling, and viewshed determination (discussed later in this lecture) all use slope and/or aspect data as input.

Slope is defined as the change in elevation (a rise) with a change in horizontal position (a run).
Slope is often reported in degrees, between zero (flat), and 90 (vertical).
The slope is equal to 45 degrees when the rise is equal to the run.
Slopes expressed as a percent range from zero (flat) to 100 (vertical).

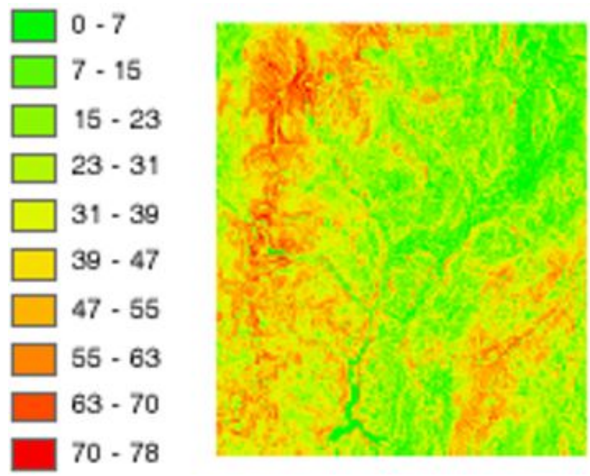
Terrain Analysis: Aspect

- Slope: Rise over run



Source: GIS Fundamentals, Bolstad (2015)

- % Slope



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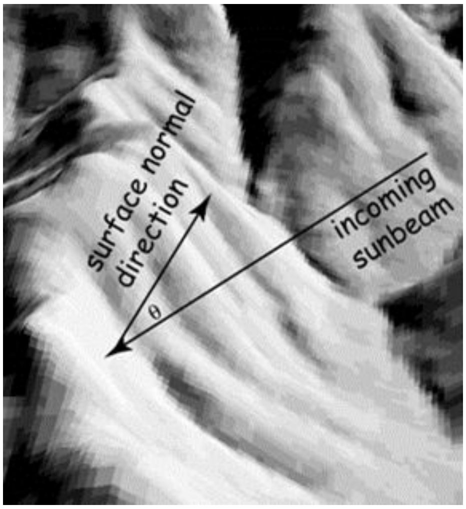
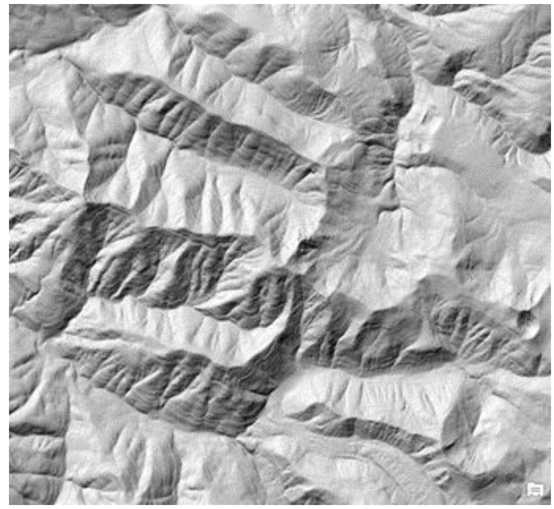
Terrain Analysis: Hillshade

- Shaded Relief = Terrain reflections

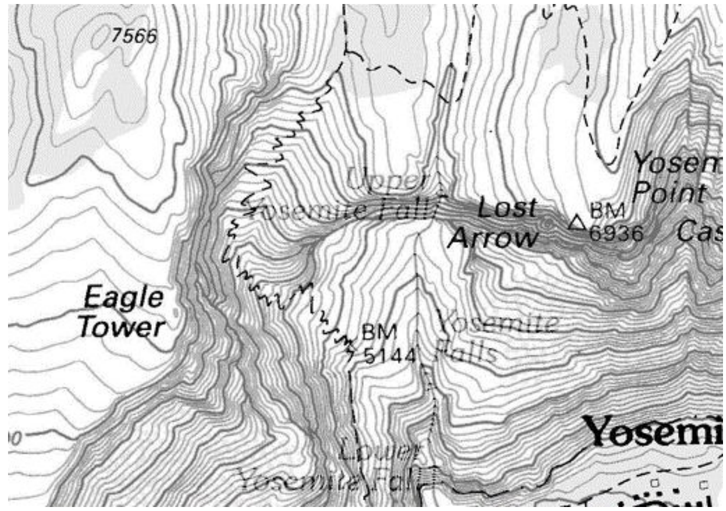




A shaded relief map, also often referred to as a hillshade map, is a depiction of the brightness of terrain reflections given a terrain surface and sun location.
Although shaded relief maps are rarely used in analyses, they are among the most effective ways to communicate the shape and structure of terrain features, and many maps include relief shading

Contour Lines

- Connected lines of uniform elevation
- Also called Isolines
- Density of lines indicate terrain steepness

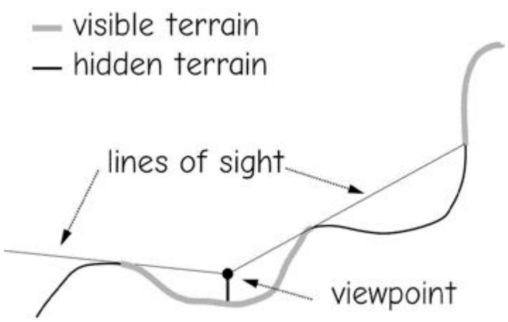


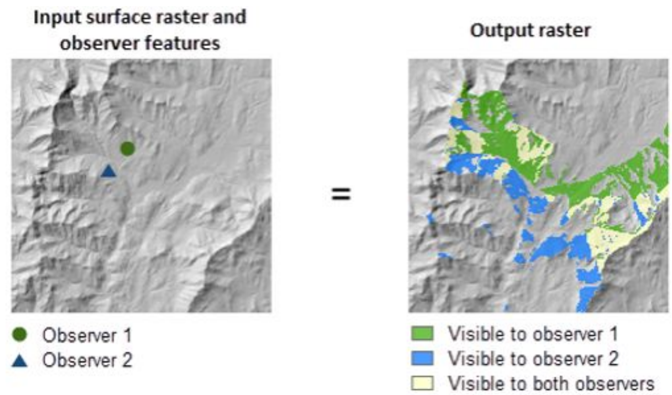
Source: GIS Fundamentals, Bolstad (2015)

Contour lines, aka isolines , are connected lines of uniform elevation that run at right angles to the local slope (Figure).
The shape and density of contour lines provide detailed information on terrain height and shape in a two-dimensional map, without the need for continuous tone shading.
Contour lines are typically created at fixed height intervals, for example, every 30 m(100 ft) from a base height (Figure).
Because each line represents a fixed elevation above or below adjacent lines, the density of contour lines indicates terrain steepness.
Contours are not only found in terrain analysis – they can be derived from any raster surface (e.g. temperature, pressure, etc)

Viewsheds

Visible lines of sight





Source: ESRI

The viewshed for a point is the collection of areas visible from that point: That is to say: Visible Line of Sight
Views from many locations are blocked by terrain.
Elevations will hide points if the elevations are higher than the line of sight between the viewing point and target point (Figure).
Viewsheds and visibility analyses are quite important in many instances when determining line of sight.
For instance: High voltage power lines or cell towers are often placed after careful consideration of their visibility, because most people are averse to viewing them.
This is a very powerful tool that is easily applied in ArcGIS Pro. My bosses have been amazed at some of the viewshed analysis I have created at the push of a button.