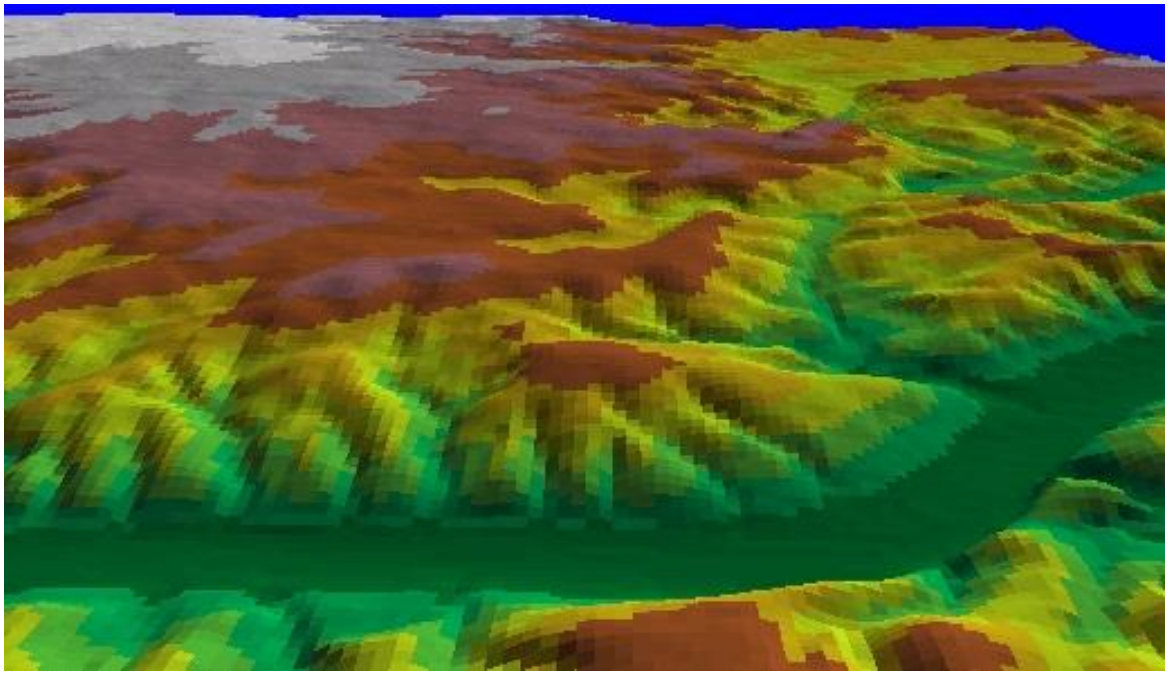
The Raster Data Model

5	5	5	5	5	5	5	5
5	5	5	5	2	2	5	5
5	5	5	5	2	2	8	8
5	5	5	5	2	2	8	8
2	2	2	2	2	2	8	8
2	2	5	5	5	5	5	5
2	2	2	2	5	5	5	5
5	2	2	2	5	5	5	5



Llano River, Mason Co., TX

Rasters are:

- Tessellations of square cells
- Arrays of values distributed among equal-sized, square cells

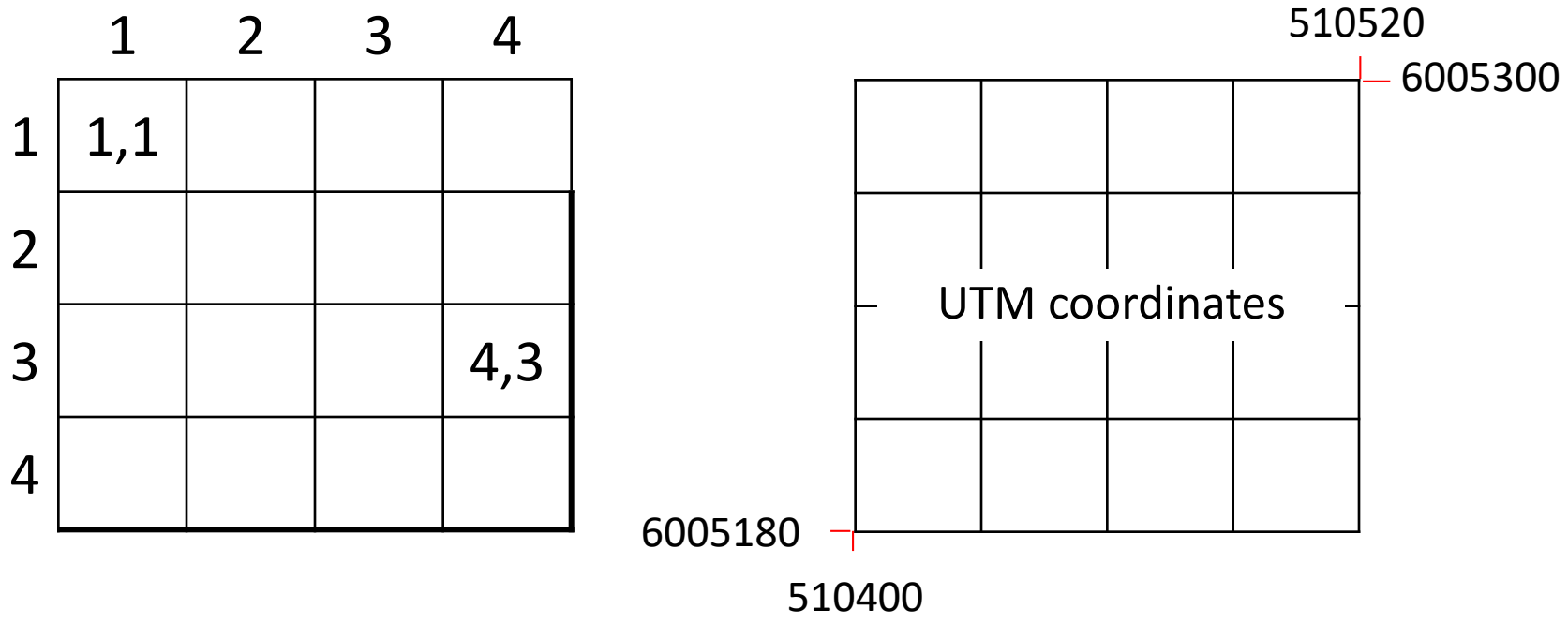
565	573	582	590
575	580	595	600
579	581	597	601
580	600	620	632

Why squares?

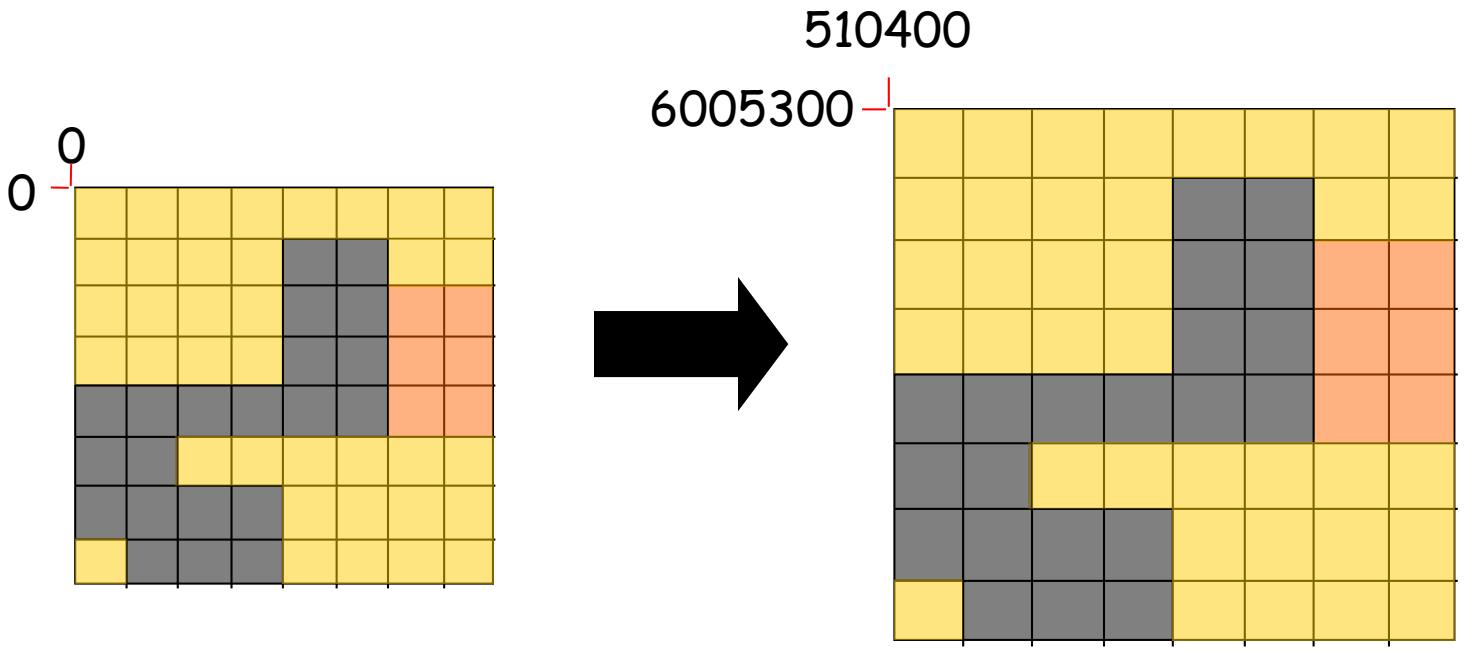
- Computer scanners and output devices use square pixels
- Bit-mapping technology/theory can be adapted from computer sciences
- 1-to-1 integer mapping to grid coordinate systems!

Cell Location Specified by:

- Row/column (R/C) address
- Origin is upper left cell (1,1)
- Relative or geographic coordinates can be specified



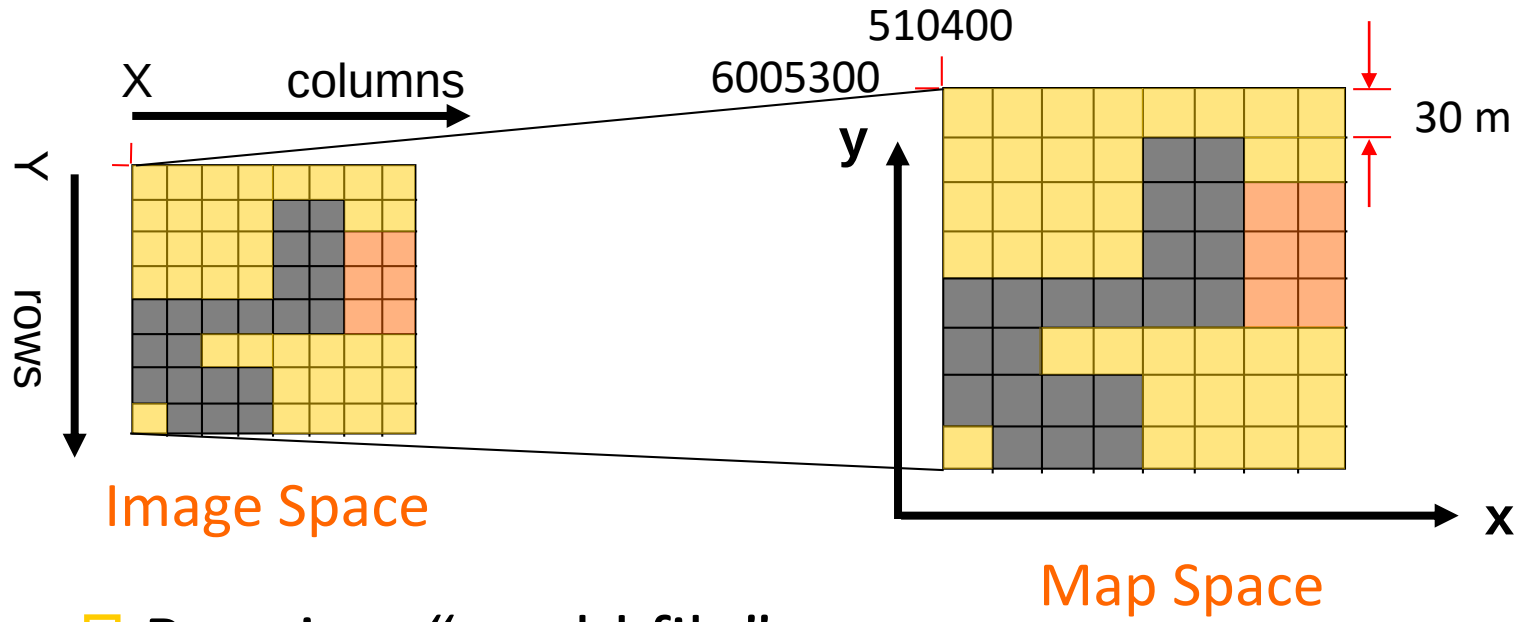
Registration to "World" Coordinates



Unregistered (relative)

Registered (Geographic)

Registration to "World" Coordinates



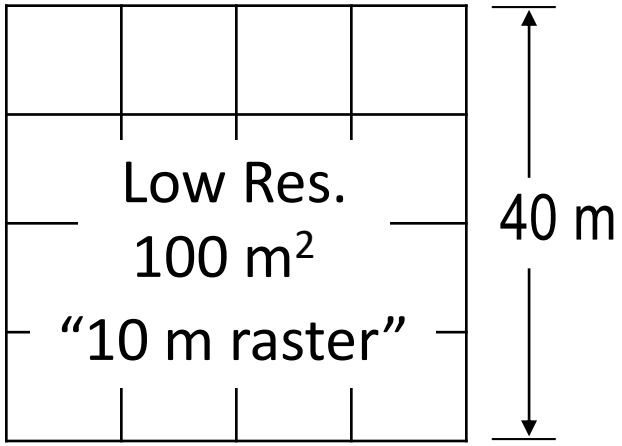
- Requires "world file":
  - Specify coords. of upper left corner
  - Specify ground dimensions of cell, in same units

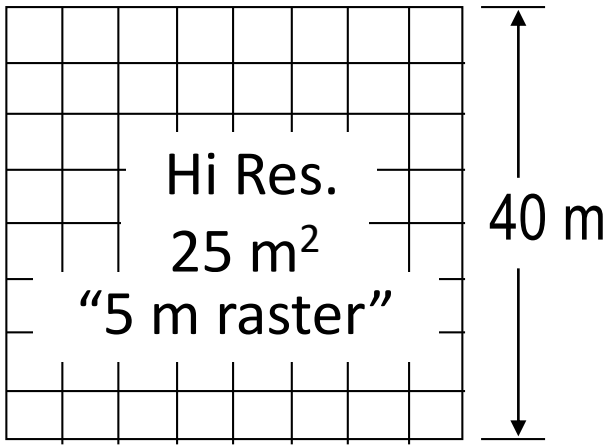
World File – DRG Example

- 2.43840000000000 — **CELL SIZE IN X DIRECTION (m)**
- 0.00000000000000 — **ROTATION TERM**
- 0.00000000000000 — **ROTATION TERM**
- -2.43840000000000 — **CELL SIZE IN Y DIRECTION (m)**
- 487988.64154709835000 — **UTM EASTING OF UPPER LEFT CORNER (m)**
- 3401923.72301301550000 — **UTM NORTHING OF UPPER LEFT CORNER (m)**
- /* UTM Zone 14 N with NAD83
- /* This world file shifts the upper left image coordinate to the corresponding
- /* NAD83 location, resulting in an approximated NAD83 image.
- /* Map Name: Art
- /* Map Date: 1982
- /* Map Scale: 24000

Spatial Resolution

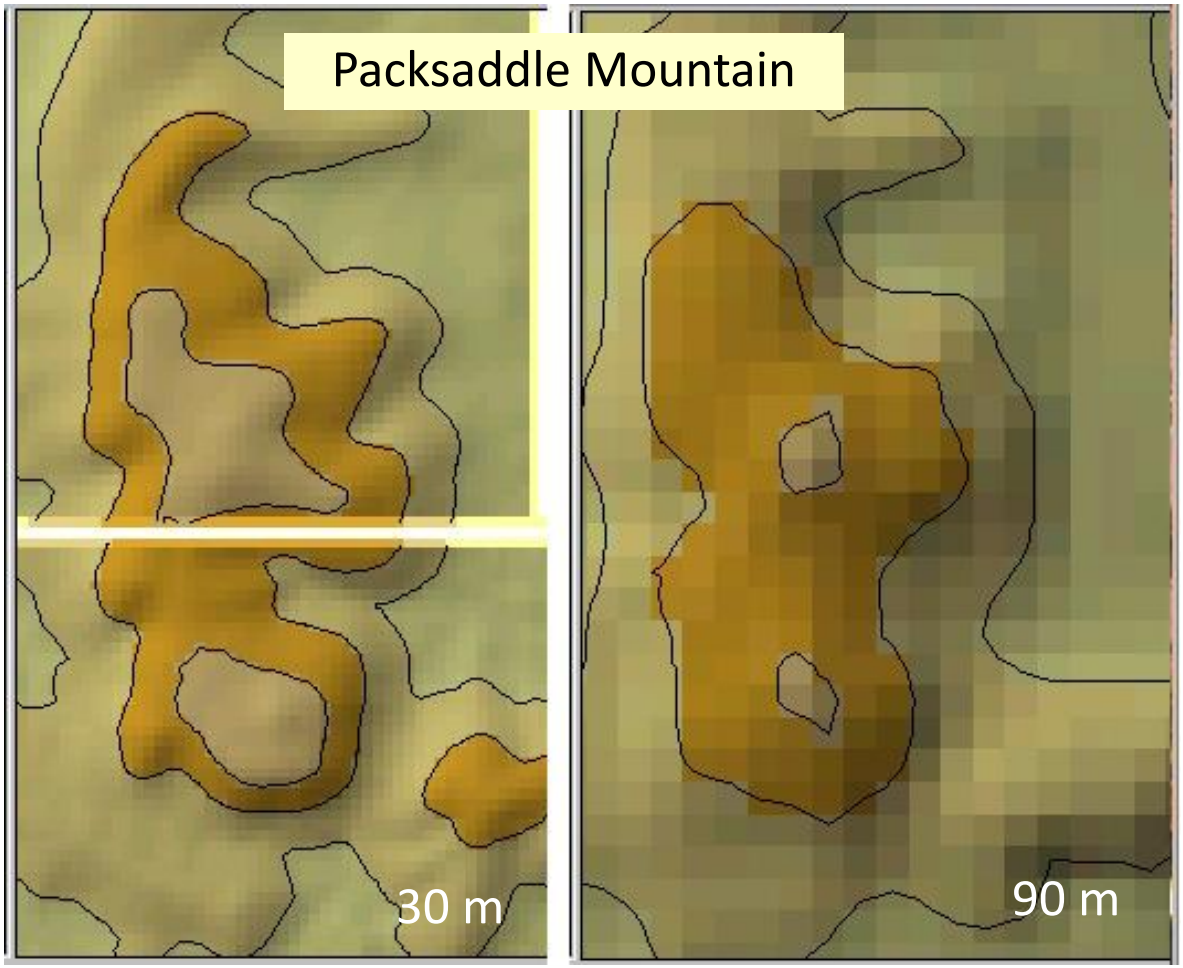
- Defined by area or dimension of each cell
  - Spatial Resolution = (cell height) X (cell width) e.g. "5m^2"
  - High resolution: cell represent small area
  - Low resolution: cell represent larger area
- Abbreviated by size of one edge of cell (e.g. "5m DEM")
- For fixed area, file size increases with resolution





30 m vs. ~90 m Pixel Size

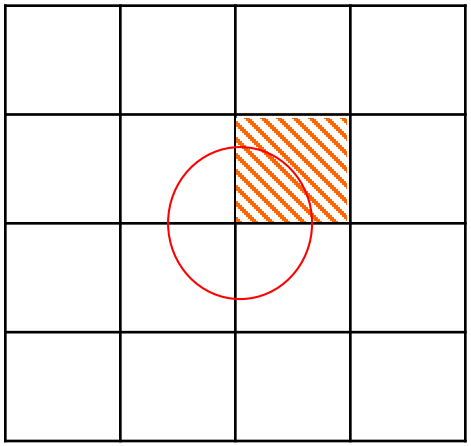
- Resolution of 30 m data is 9 times better (9X as many pixels) than 90 m data



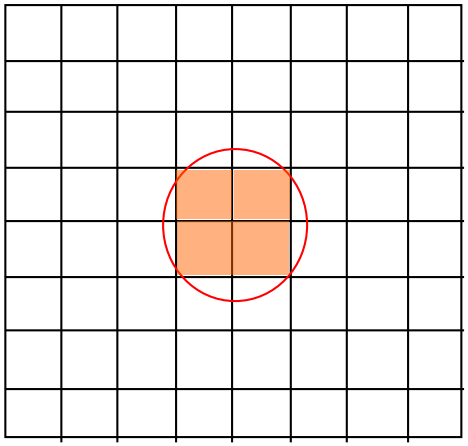
(50 m contours, vector data layer)

Resolution Constraint

- Cell size should be less than half of the size of the smallest object to be represented (e.g. the circle below)
- Size of smallest recognizable object at any resolution is the "Minimum mapping unit; MMU"



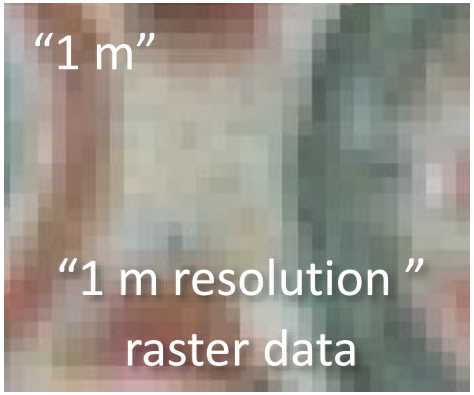
Cell size = MMU



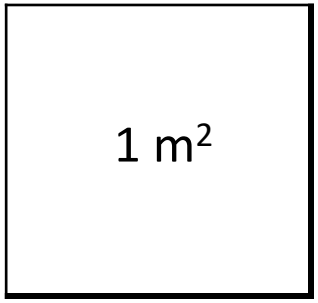
Cell size ~ ½ MMU

e.g. DOQQ Resolutions

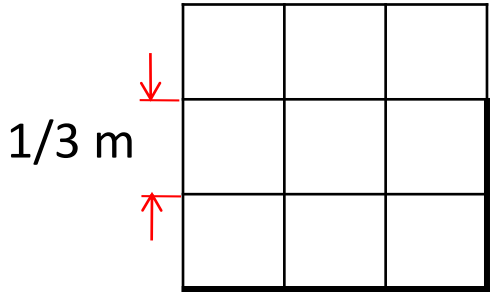
- Resolution is size of sampled area on ground, not MMU



(E. Mall Circle Drive)



MMU= 2 m



MMU= ~ 2/3 m

Raster Dimension:

- Number of rows x columns
  - E.g. Monitor with 1900 x1200 pixels

Dimension = 4 x 4

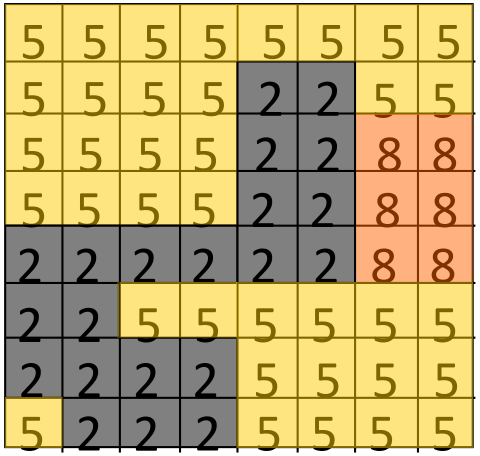
565	573	582	590
575	580	595	600
579	581	597	601
580	600	620	632

Raster Attributes – What's Stored in the Cells

- Two types:
  1. *Integer codes* assigned to raster cells
     - E.g. rock type, land use, vegetation
     - Codes are technically *nominal* or *ordinal* data
  2. Measured *"real"* values
     - Can be integer or "floating-point" (decimal) values; technically *interval* or *ratio* data
     - E.g. topography, em spectrum, temperature, rainfall, concentration of a chemical element

Integer Code Attributes

- Code is referenced to attribute via a “look-up table” or “value attribute table” – VAT
- Commonly many cells with the same code
- Different attributes must be stored in different raster layers



Nominal Coded Raster

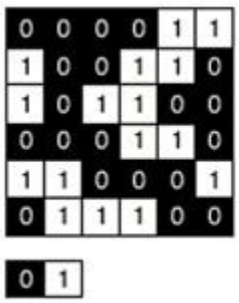
VAT

Value	Count	Rock Type
2	21	Marble
5	37	Gneiss
8	6	Granite

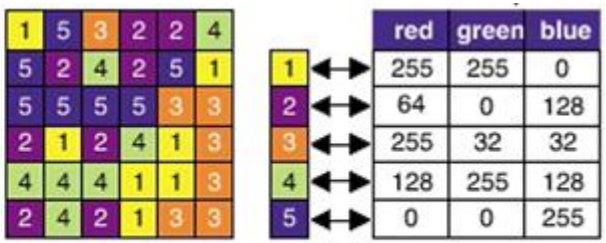
Coded Value Raster Types

- Single-band: Single raster; *Thematic data*
  - **Black & White**: binary (1 bit) (0 = black, 1 = white)
  - **Panchromatic:** ("Grayscale") (8 bit): 0 (black) – 255 (white) or graduated color ramps (e.g. blue to red, light to dark red)
  - **Colormaps:** ("Indexed Color") (8 bit): code cells by values that match prescribed R-G-B combinations in a lookup table

B & W | **Panchromatic** | **Color Map**

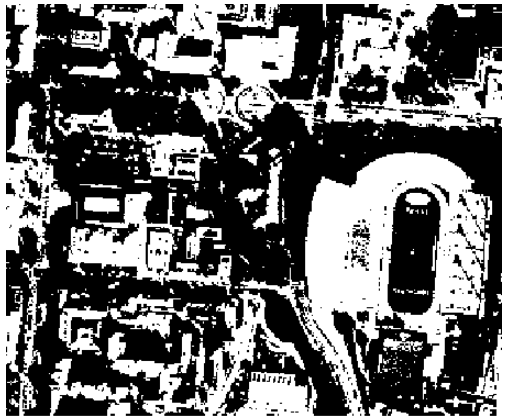


Lookup/index table

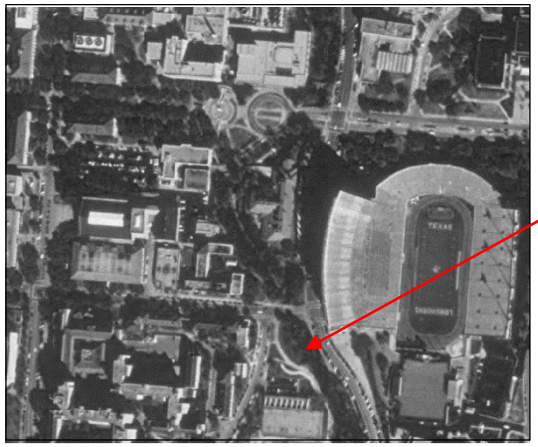


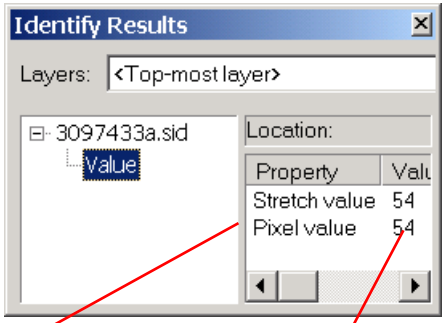
Figures from: Modeling our World, ESRI press

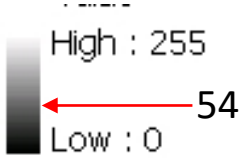
Single Band
Examples – Black & White vs. Grayscale



Black & White - 1 bit



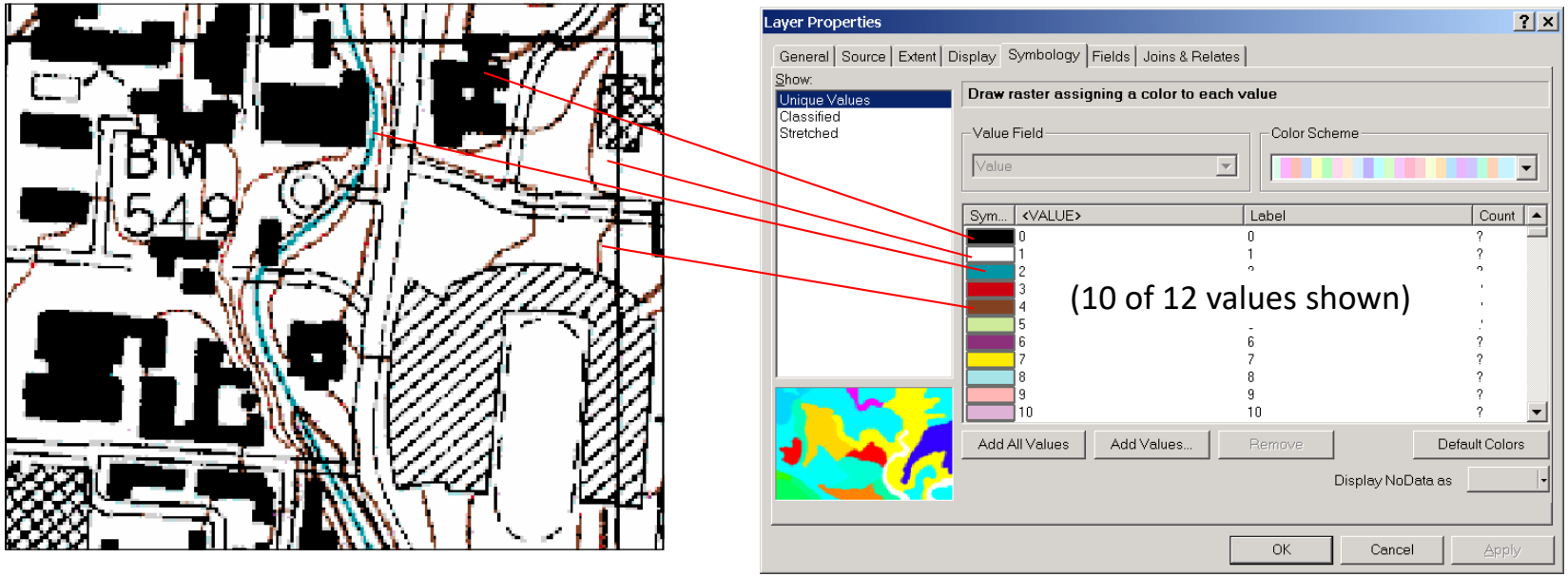




Grayscale – 8 bit;
black, white & 254 shades of gray

Single Band
Example Color Map (Indexed Color)

E.g. Austin East 7.5’ Digital Raster Graph



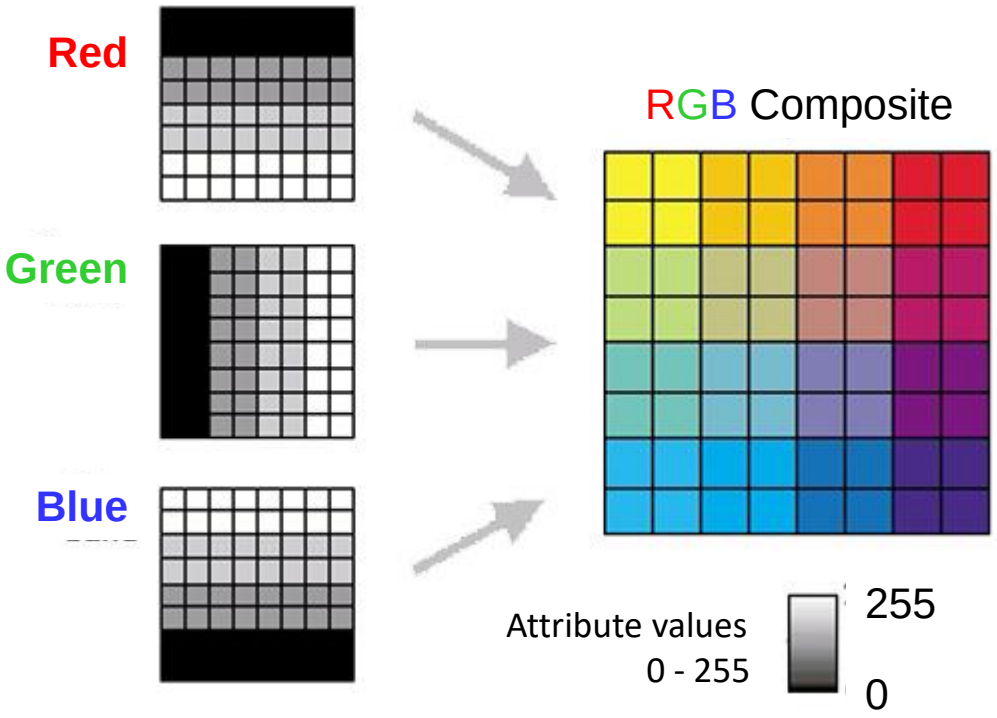
- Each pixel contains one of 12 unique values, each corresponding to a prescribed color (Red, Green & Blue combination). Could have 254 prescribed colors this way.

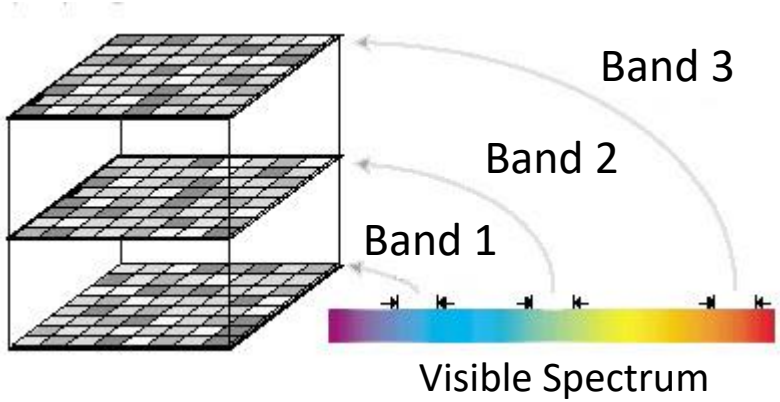
Measured, “Real Value” Attributes

- Commonly stored as floating point values
- Different attributes must be stored in different layers, e.g. spectral bands in satellite imagery
- Compression techniques for rasters of integer-valued cells, but not floating point (see below)

Multiband
Image Raster Attributes

- *Multi-band Spectral* Data



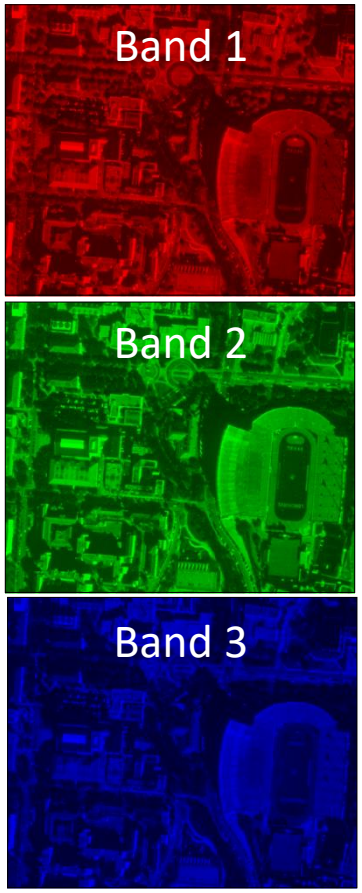


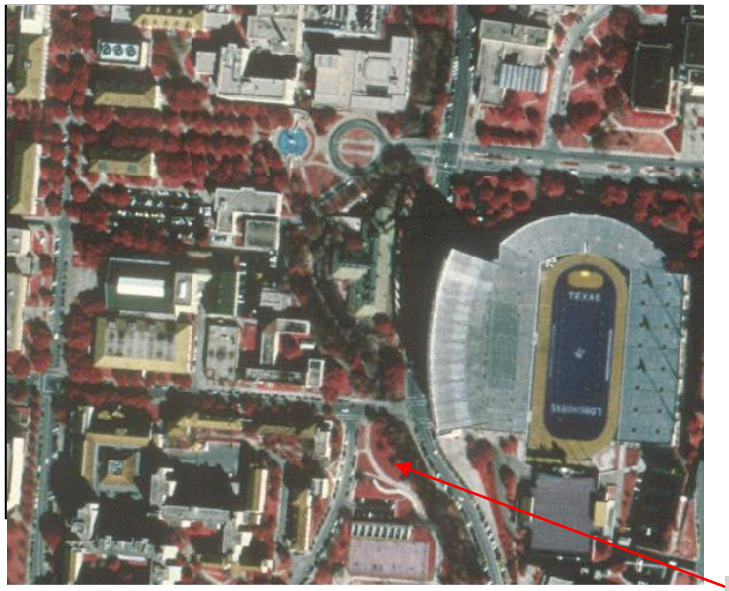
- Band = segment of Em spectrum
- Map intensities of each band as red, green or blue
- Display alone or as composite

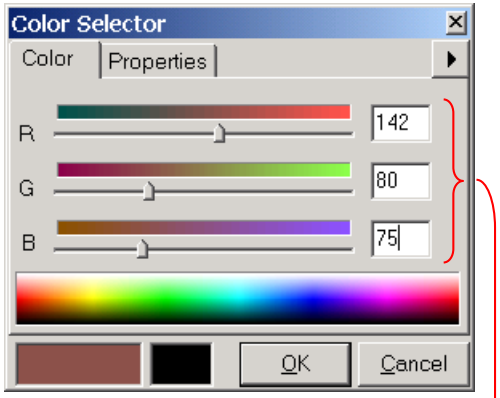
Figures from: Modeling our World, ESRI press

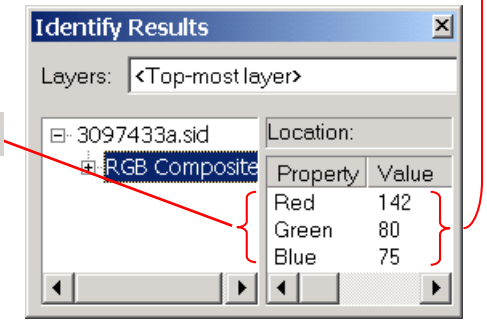
Multiband Image
8 bits/Band, 3 Band RGB

E.g. Austin East 7.5' Color Infrared Digital Orthophotograph ("CIR DOQ")



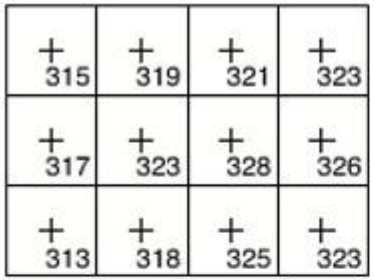


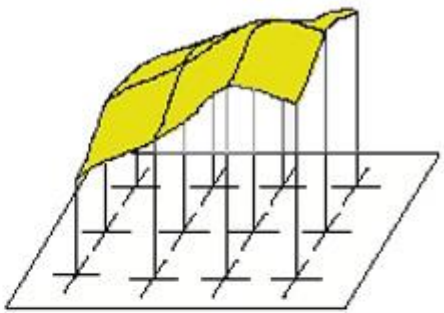




Cell Values Apply To:

- Middle of cell, e.g. Digital Elevation Models (DEM)

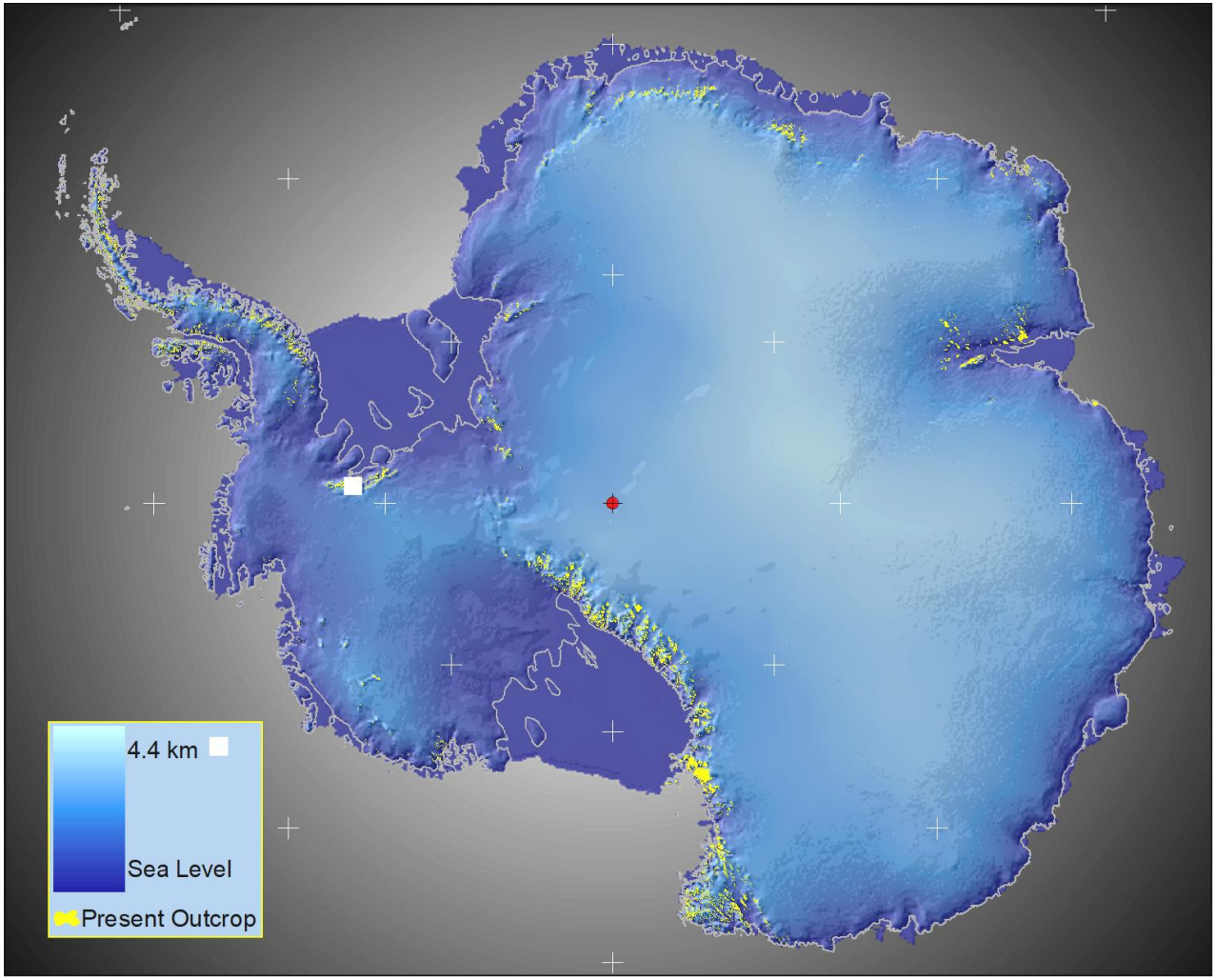




- Whole cell, e.g. most other data

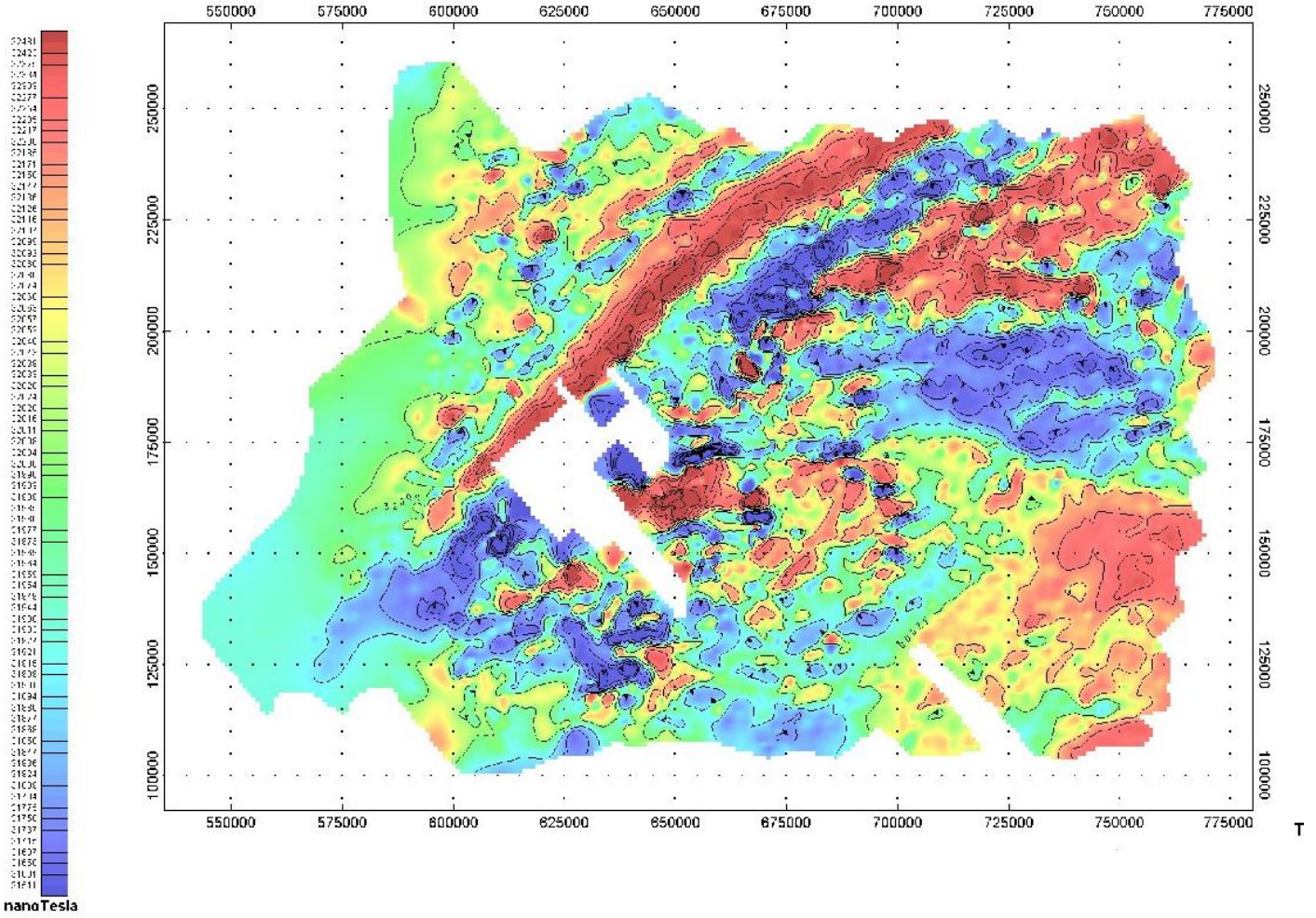
Source: Modeling our World, ESRI press

Digital Elevation Model



Airborn Magnetic (TFI) Map

TFI Pixel Values



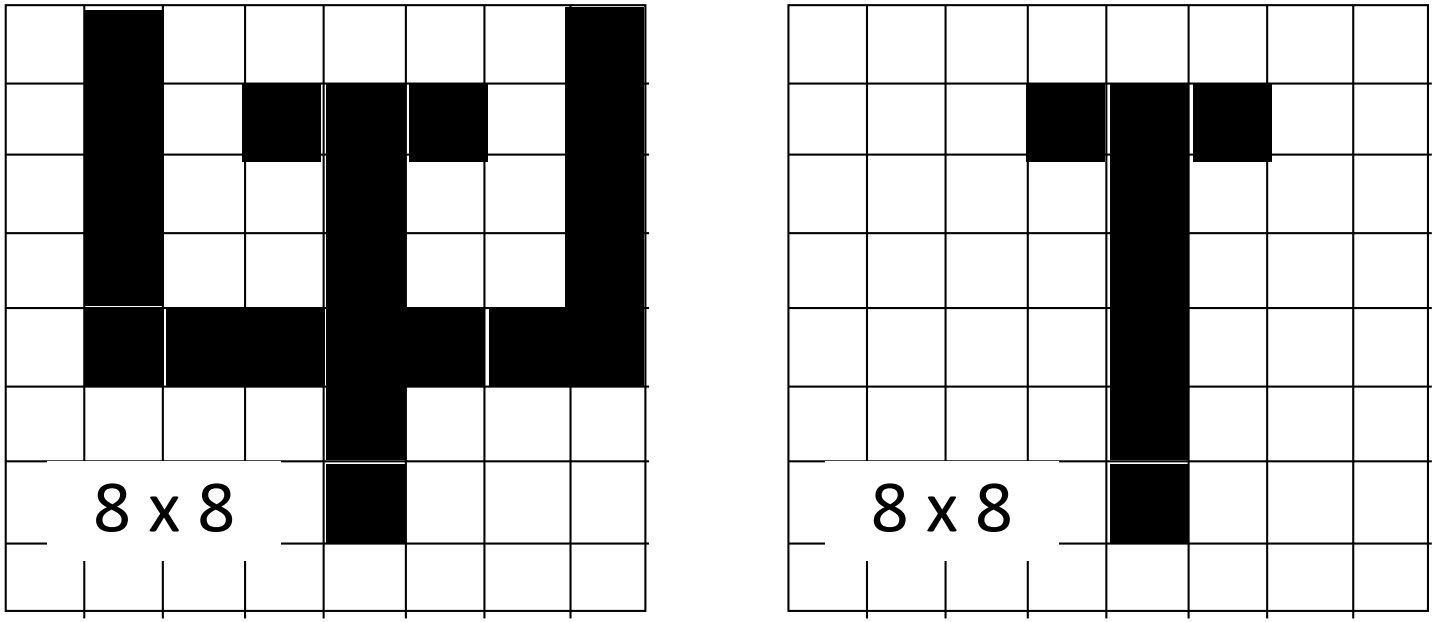
How Are Rasters Projected?

- Problem: Square cells must remain square after projection.

- Solution: Resampling (interpolation); add, remove, reassign cells to conform to new spatial reference.

Raster File Size

- fixed by dimension, not information



At 1 bit/cell, file size = 8 x 8 x 1 = 64 bits (8 bytes)

Raster File Size

File Size = Rows x columns x bit-depth

- Bit depth: number of bits used to represent pixel value
  - "8-bit" data can represent 256 values (2^8)
  - "16-bit" data (2^{16}) allows 65,536 values
  - "32-bit" data allows ~4.3 billion values

File Structure

Header: (dimension, max. cell value) ± resolution, coordinate of one corner pixel, etc.

5	5	5	5	5	5	5	5
5	5	5	5	2	2	5	5
5	5	5	5	2	2	8	8
5	5	5	5	2	2	8	8
2	2	2	2	2	2	8	8
2	2	5	5	5	5	5	5
2	2	2	2	5	5	5	5
5	2	2	2	5	5	5	5

8 x 8 raster

8, 8, 8

5 5 5 5 5 5 5 5

5 5 5 5 2 2 5 5

5 5 5 5 2 2 8 8

5 5 5 5 2 2 8 8

2 2 2 2 2 2 8 8

2 2 5 5 5 5 5 5

2 2 2 2 5 5 5 5

5 2 2 2 5 5 5 5

Data File (linear array)

File Compression

- E.g. Run-length encoding

5	5	5	5	5	5	5	5
5	5	5	5	2	2	5	5
5	5	5	5	2	2	8	8
5	5	5	5	2	2	8	8
2	2	2	2	2	2	8	8
2	2	5	5	5	5	5	5
2	2	2	2	5	5	5	5
5	2	2	2	5	5	5	5

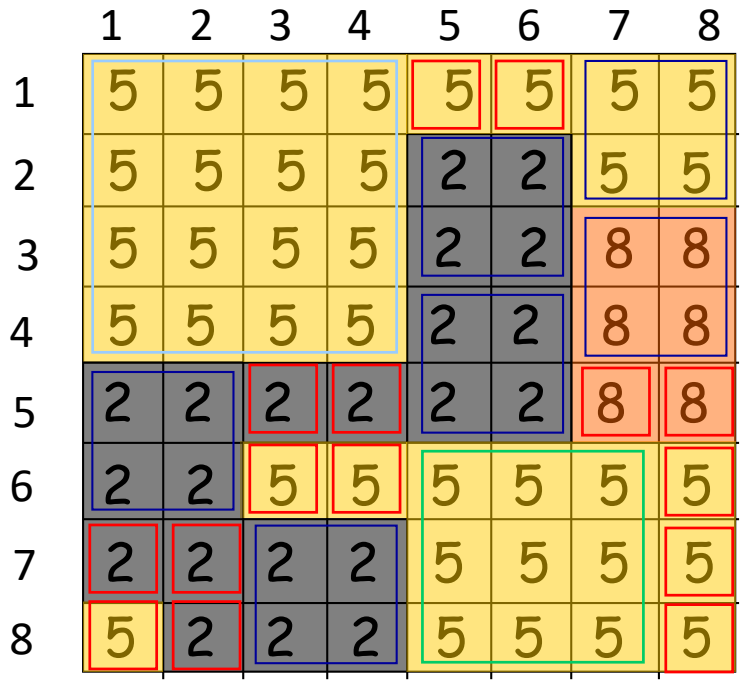
Before: 64 characters

Row, Run	Freq., Value		
1,1	8,5		
2,3	4,5	2,2	2,5
3,3	4,5	2,2	2,8
4,3	4,5	2,2	2,8
5,2	6,2	2,8	
6,2	2,2	6,5	
7,2	4,2	4,5	
8,3	1,5	3,2	4,5

After: 46 characters
(28% reduction; ratio of 1.4: 1)

File Compression

- E.g. Block encoding



Before: 64 characters

Block Size	Value	Coordinates
1	5	5,1 6,1 3,6 4,6 8,6 8,7
1	8	7,5 6,5 1,8 8,8
1	2	3,5 4,5 1,7 2,7 2,8
4	5	7,1
4	2	5,2 5,4 1,5 3,7
4	8	7,3
9	5	5,6
16	5	1,1

After: 61 characters
(5% reduction ratio of 1.05: 1)

MrSID or ECW (Wavelet) Compression

- - Multi-resolution Seamless Image Database – commercialized by LizardTech (now Extensis)
- Compression ratios of 15-20:1 for single band 8-bit images
- Ratios of 2-100:1 (!) for multiband color images
- also ECW by ER Mapper Ltd. (now Intergraph/ERDAS)

*** Enormous raster data sets now manageable on PCs and across web with this technology ***

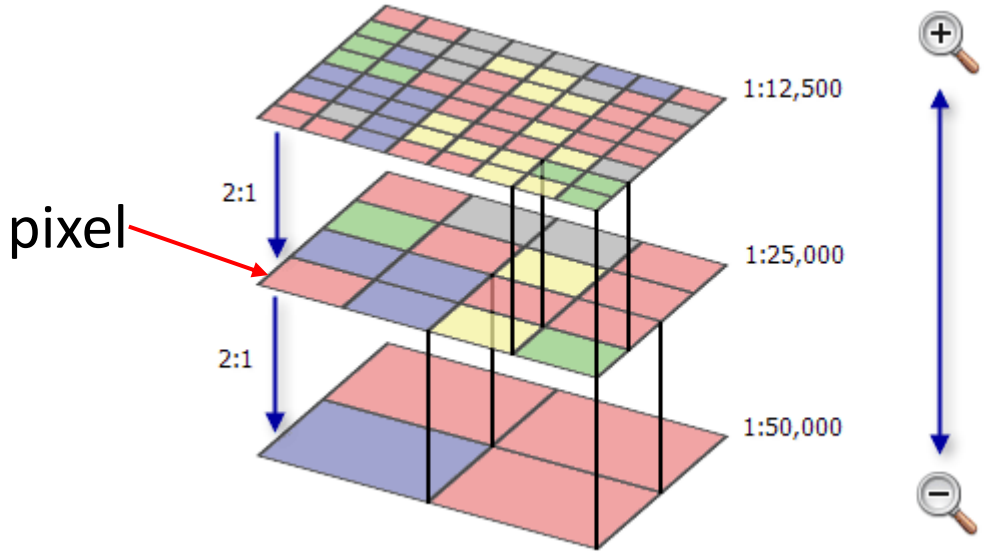
“Lossy” vs. Lossless Compression

- Techniques that combine similar attribute information to reduce file size are “lossy” e.g. JPEG, GIFF, PNG, MrSID, ECW

- Lossless formats; TIFF, BMP, GRID

Raster Pyramids

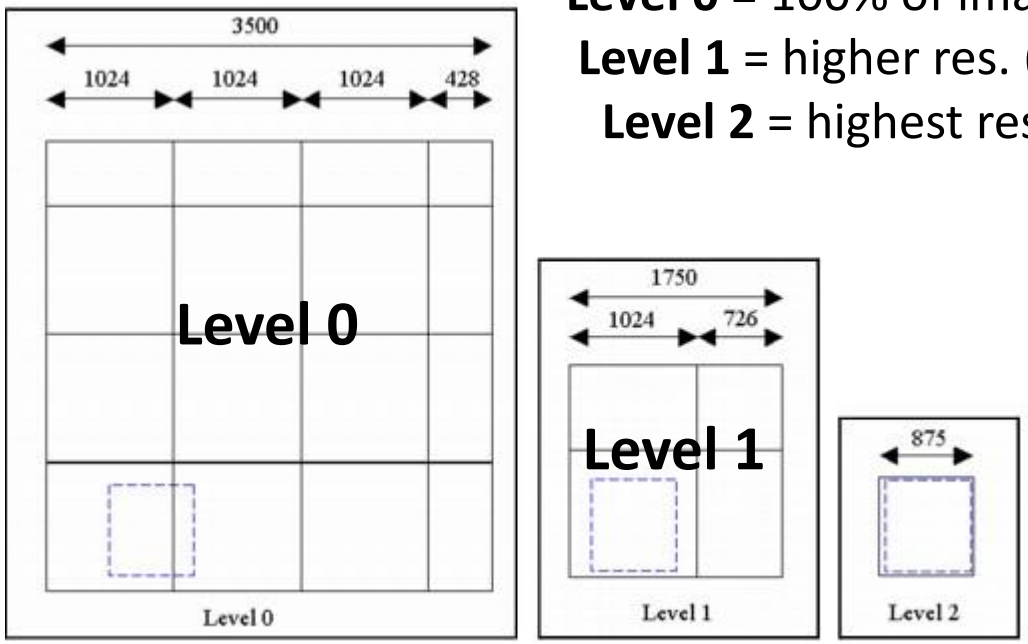
- Store reduced-resolution copies of a raster for rapid display – e.g ArcGIS, Google, many others
- Often combined with image tiling and compression for rapid rendering of images



Source: ESRI ArcGIS Help file

Image "Tiling"

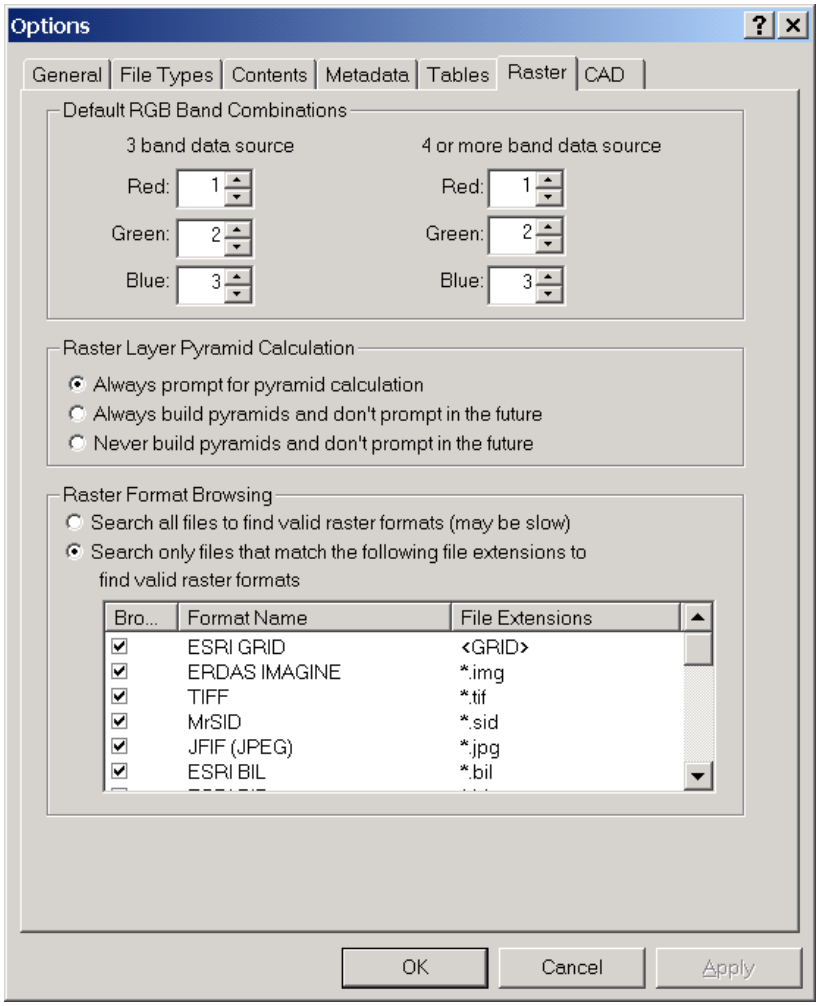
- Split raster into small contiguous rectangles or squares = Tiles
- Display only the tile required upon zooming

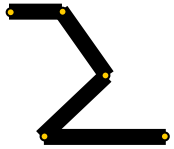


Level 0 = 100% of image = 16 low res. tiles
Level 1 = higher res. (parts of 4 med. res. tiles)
Level 2 = highest res. (1+ high res. tiles), res. of image

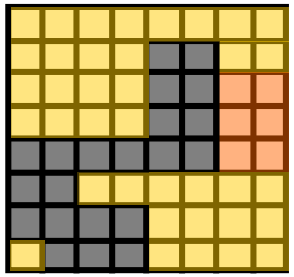
Supported Raster Formats

- See ArcCatalog>Tools> Options
- Each explained in Help
  - 24 supported formats





Vector or Raster?



- Spatially continuous data = raster
- Modeling of data with high degree of variability = raster
- Objects with well defined boundaries = vector
- Geographic precision & accuracy = vector
- Topological dependencies = vector or raster

Raster or Vector?

Raster

- Simple data structure
- Ease of analytical operation
- Format for scanned or sensed data – easy, cheap data entry

But…….

- Less compact
- Querry-based analysis difficult
- Coarser graphics
- More difficult to transform & project

Vector

- Compact data structure
- Efficient topology
- Sharper graphics
- Object-orientation better for some modeling

But….

- More complex data structure
- Overlay operations computationally intensive
- Not good for data with high degree of spatial variability
- Slow data entry

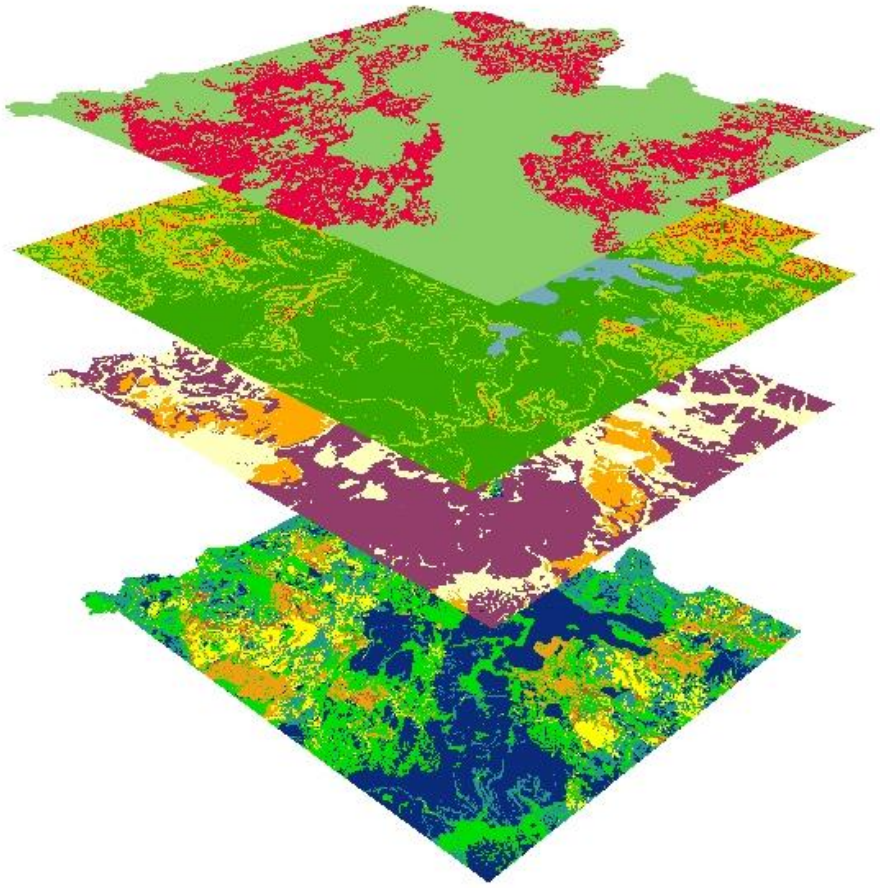
Raster Spatial Analysis, e.g. “Map Algebra”

Fires (1 or 4)

Slope (1-4)

\+ Geology (1-4)

Erosion Ranking (3-12)



FIRES
VALUE
0: Unburnt
4: Burned
SLOPE
<VALUE>
1: 0 - 10 degrees
2: 11 - 20 degrees
3: 21 - 30 degrees
4: 31 - 62 degrees
GEOLOGY: Erosivity
VALUE
1: Refractory
2: Hardly erodable
3: Moderately erodable
4 Easily eroded
RESULT of Summation
Value
1 - 2: Erosion at a minimum
3 - 4
5 - 6
7 - 8
9
10 - 12: Erosion maximized