Geographic Surfaces

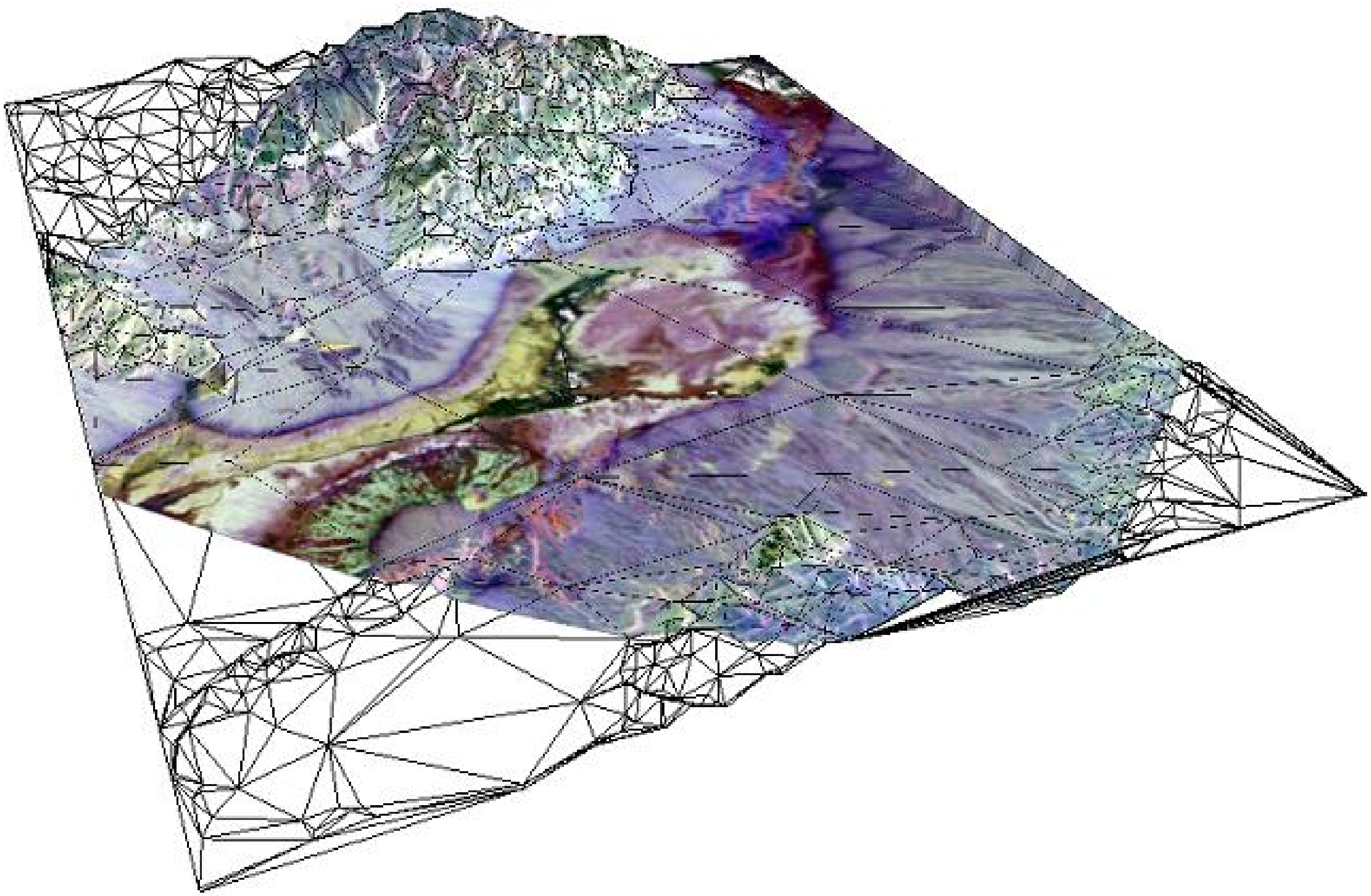
- Up to this point, we have talked about spatial data models that operate in **two dimensions**
- How about the **3rd** dimension?
  - **Surface** – the continuous variation in space of a third dimension (elevation in a physical context, but it could be other 'virtual' 3rd dimensions for other purposes, e.g. modeling population density using a surface)
- We can use either the vector or raster data model to represent a surface, but **raster** models are **most commonly** used for because they are good at representing **continuous variation**

Representing terrain using data

- We can **represent terrain** using various sorts of digital elevation models (DEMs). We will briefly look at each of these representations:
  - **Triangulated Irregular Network** (TIN) – a model made up of triangular facets
  - **Contours** – a vector/arc based model with elevations associated with each contour
  - **Raster grid** – a cell-based model with elevations associated with each cell
- From DEMs, we can derive **how water moves through a landscape** (via drainage networks) by using a variety of **spatial analysis** operations

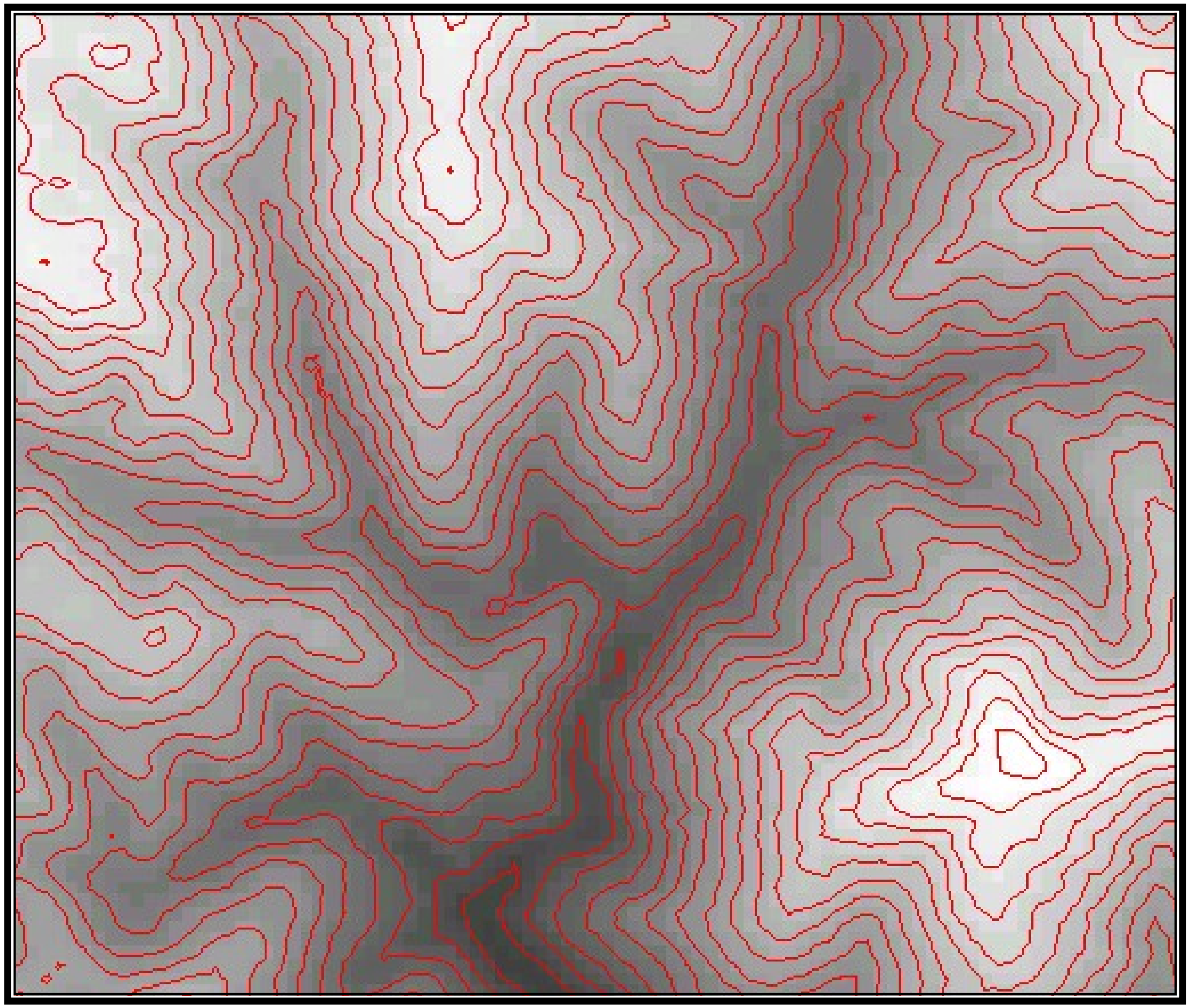
Digital Elevation Models

Triangulated Irregular Network (TIN)



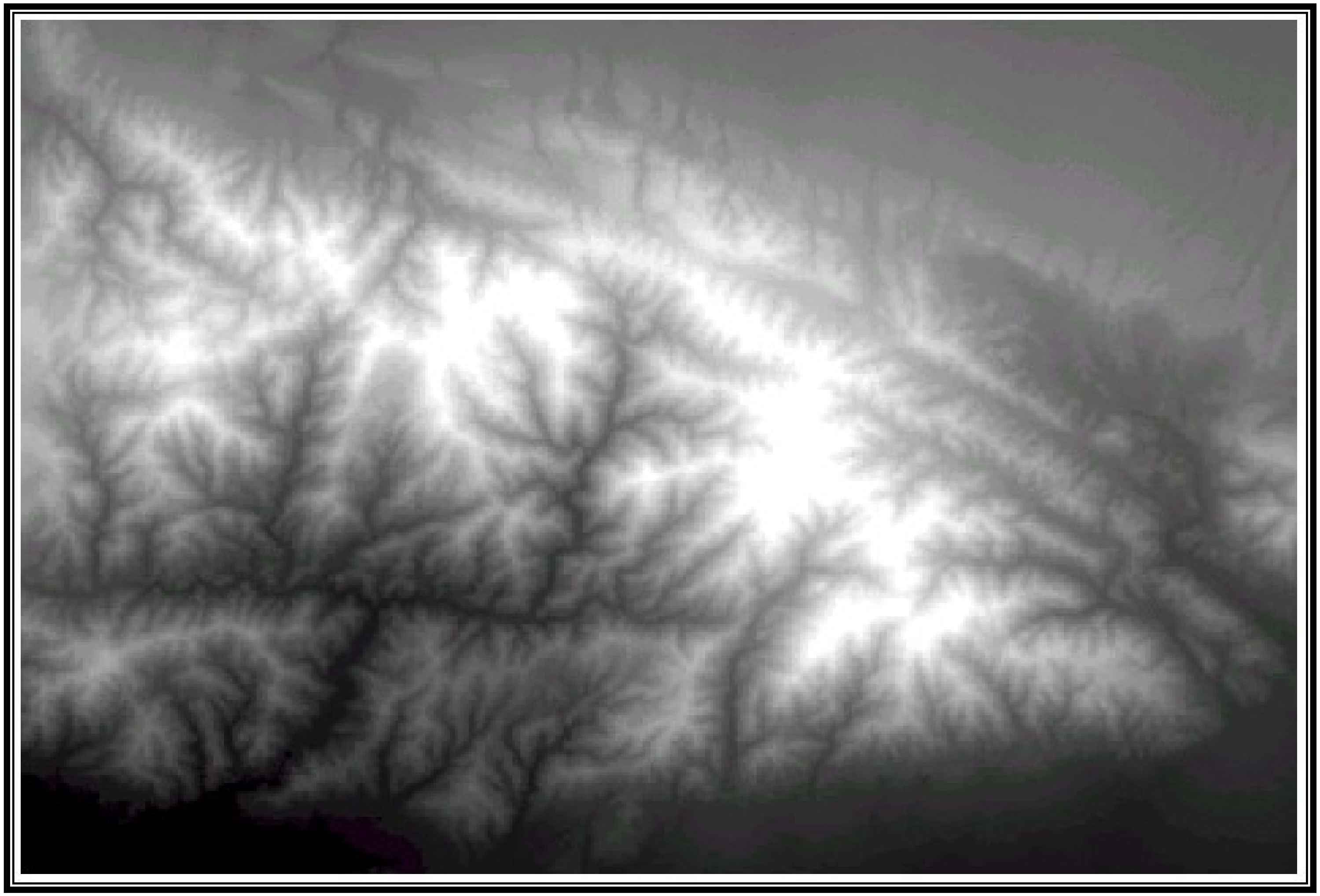
Digital Elevation Models

Contours



Digital Elevation Models

Raster Grid



Governing Rules of Water Movement

- Like all physical processes, the flow of water always occurs across some form of **energy gradient** from high to low…
  - e.g., a topographic (slope) gradient from high to low elevation
  - Or a **concentration gradient, pressure gradient**, etc.
- All other things being equal, in a fluvial landscape that **has some relief**, water movement near the surface is going to follow the **topographic gradient downhill**
- Thus, by **modeling terrain** using a continuous surface, we can learn some useful things about the **movement of water** through a landscape

Watershed (a.k.a. Drainage Basin, Catchment)

- A geomorphically distinct **landscape unit** defined by topographic boundaries, or drainage 'divides' that acts as a spatially discrete hydrological system

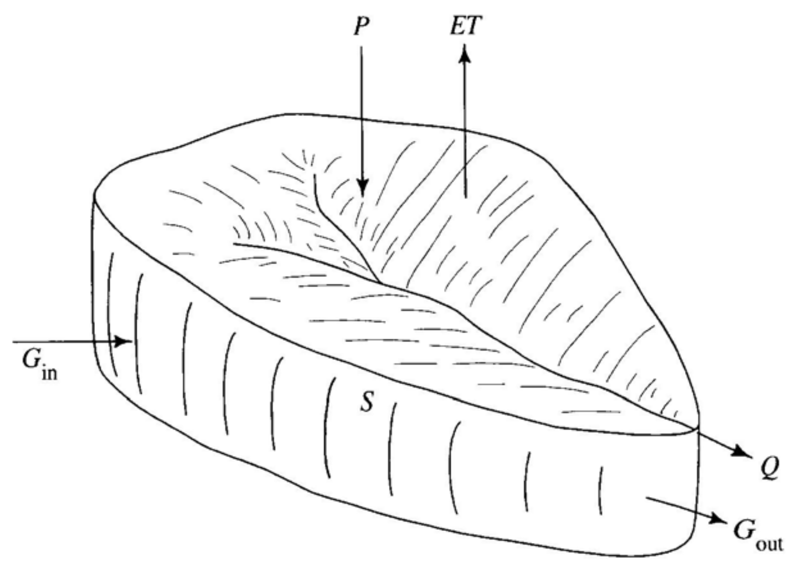
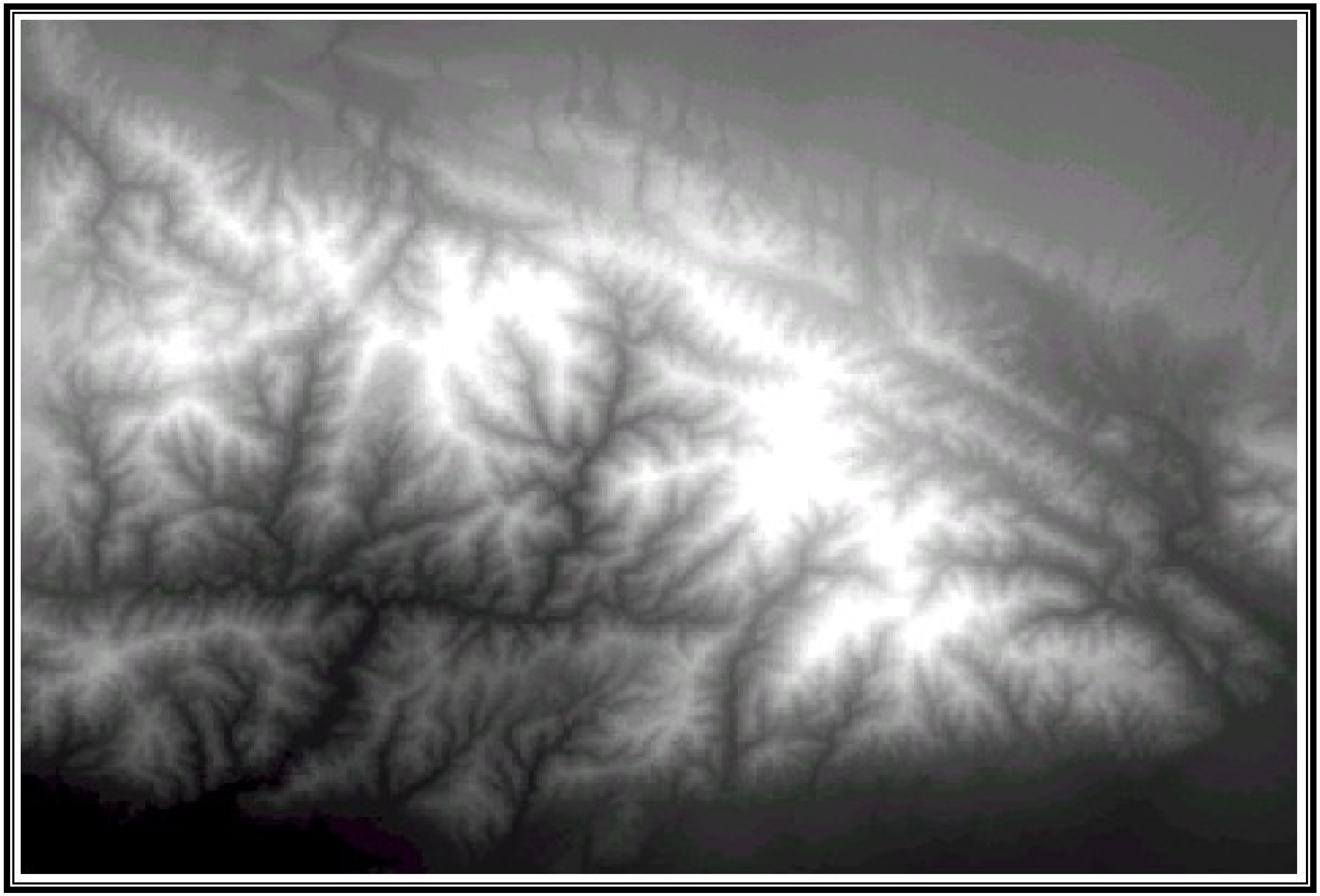


FIGURE 2-3
Schematic diagram of a watershed, showing the components of the regional water balance: P = precipitation, ET = evapotranspiration, Q = stream outflow, G_{in} = ground-water inflow, G_{out} = ground-water outflow.

Digital Elevation Models

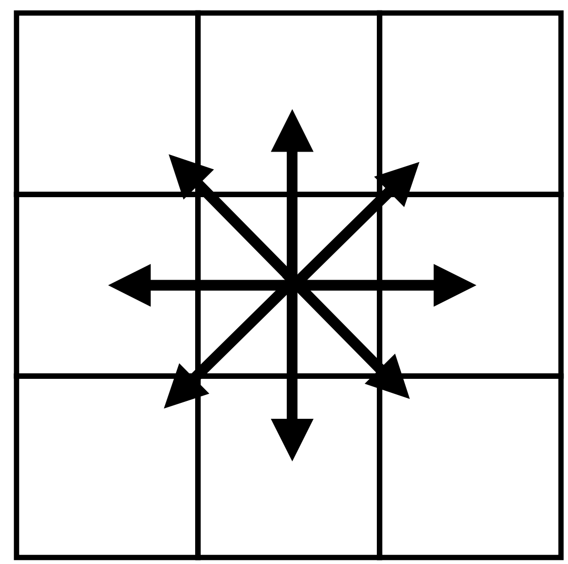
Raster Grid



D8 Analysis Sequence

- Assume we now have a raster DEM and we want to use it **find a watershed and drainage network** through D8 analysis
- We can follow this **sequence of analysis** steps, each of which involves a neighborhood analysis operation:
  - Fill Sinks
  - Slope
  - Aspect
  - Flow Direction
  - Flow Accumulation
  - StreamLink & StreamOrder
  - Watershed

D8 Analysis



Algebraic Operations w/ Raster Layers

- We can **extend** this concept from Boolean logic to **algebra**
- Map algebra:
  - Treats input layers as **numeric inputs** to mathematical operations (each layer is a separate numeric input)
  - The result of the operation on the inputs is calculated on a **cell-by-cell basis**
- This allows for **complex overlay analyses** that can use as many input layers and operations as necessary
- A common application of this approach is **suitability analysis** where multiple input layers determine suitable sites for a desired purpose by **scoring cells** in the input layers according to their effect on suitability and combining them, often **weighting layers** based on their importance

Simple Arithmetic Operations

Summation

0	1	1
0	0	1
1	0	1

+

0	0	0
1	1	1
0	0	1

=

0	1	1
1	1	2
1	0	2

Multiplication

0	1	1
0	0	1
1	0	1

×

0	0	0
1	1	1
0	0	1

=

0	0	0
0	0	1
0	0	1

Summation of more than two layers

0	1	1
0	0	1
1	0	1

+

0	0	0
1	1	1
0	0	1

+

0	0	0
1	1	1
0	0	1

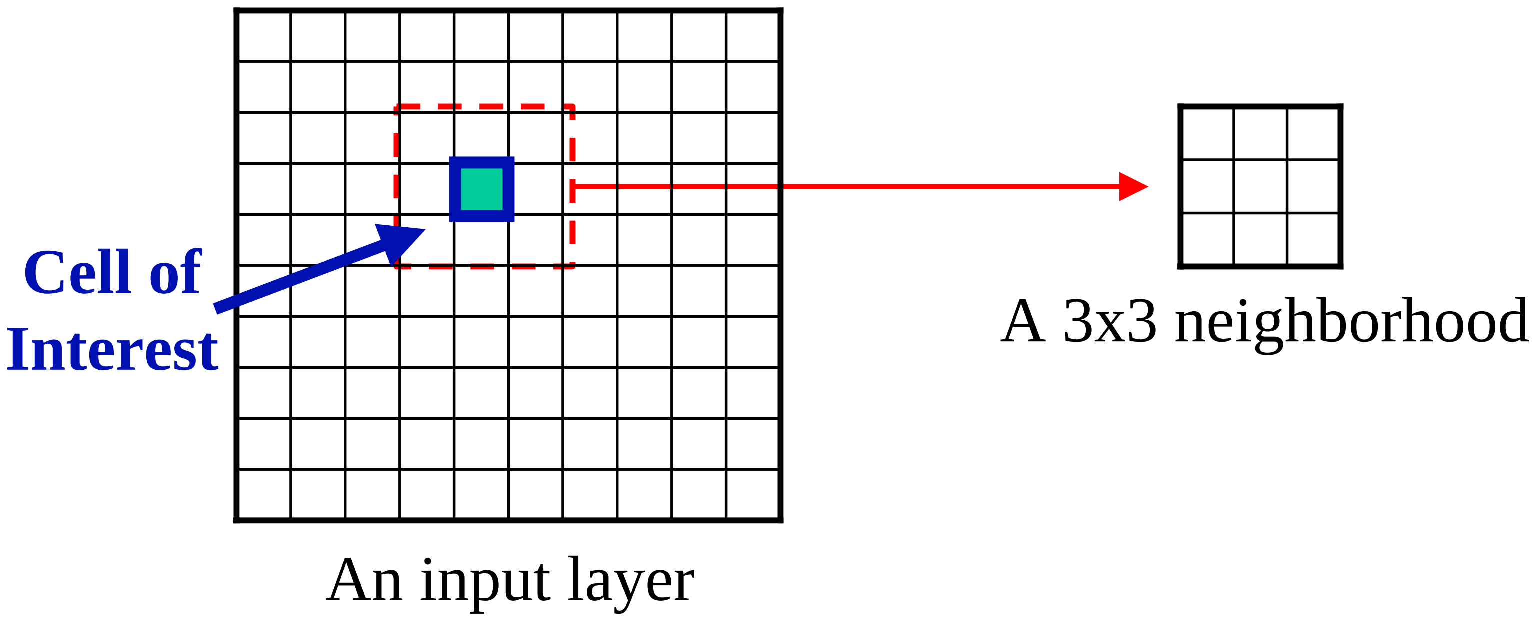
=

0	1	1
2	2	3
1	0	3

Neighborhood Operations

•In raster overlay analysis, we compared **each cell** in a raster layer with another cell in the **same position** on another layer

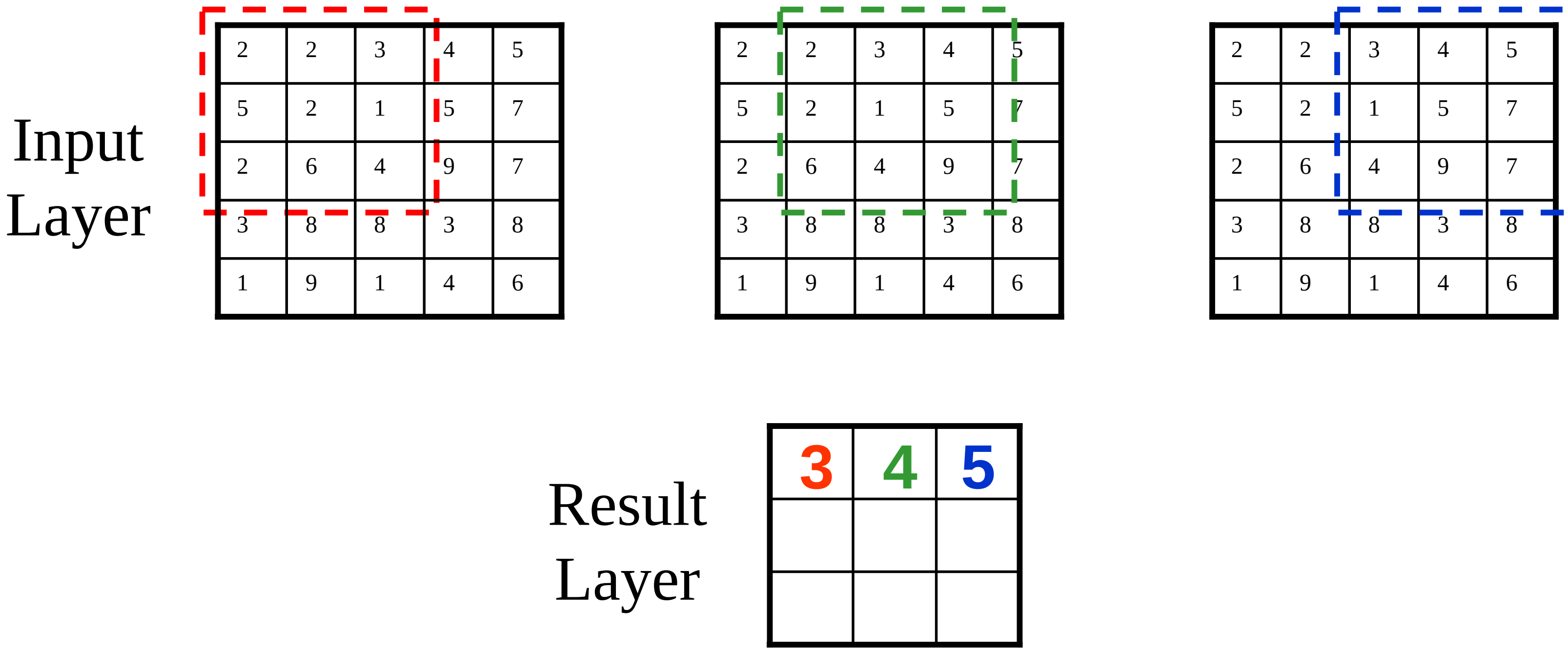
•In neighborhood operations, we look at a **neighborhood** of cells **around the cell of interest** to arrive at a new value:



•Neighborhoods can be of any possible size; we can use a 3x3 neighborhood for any cell except on the **edge** of the layer

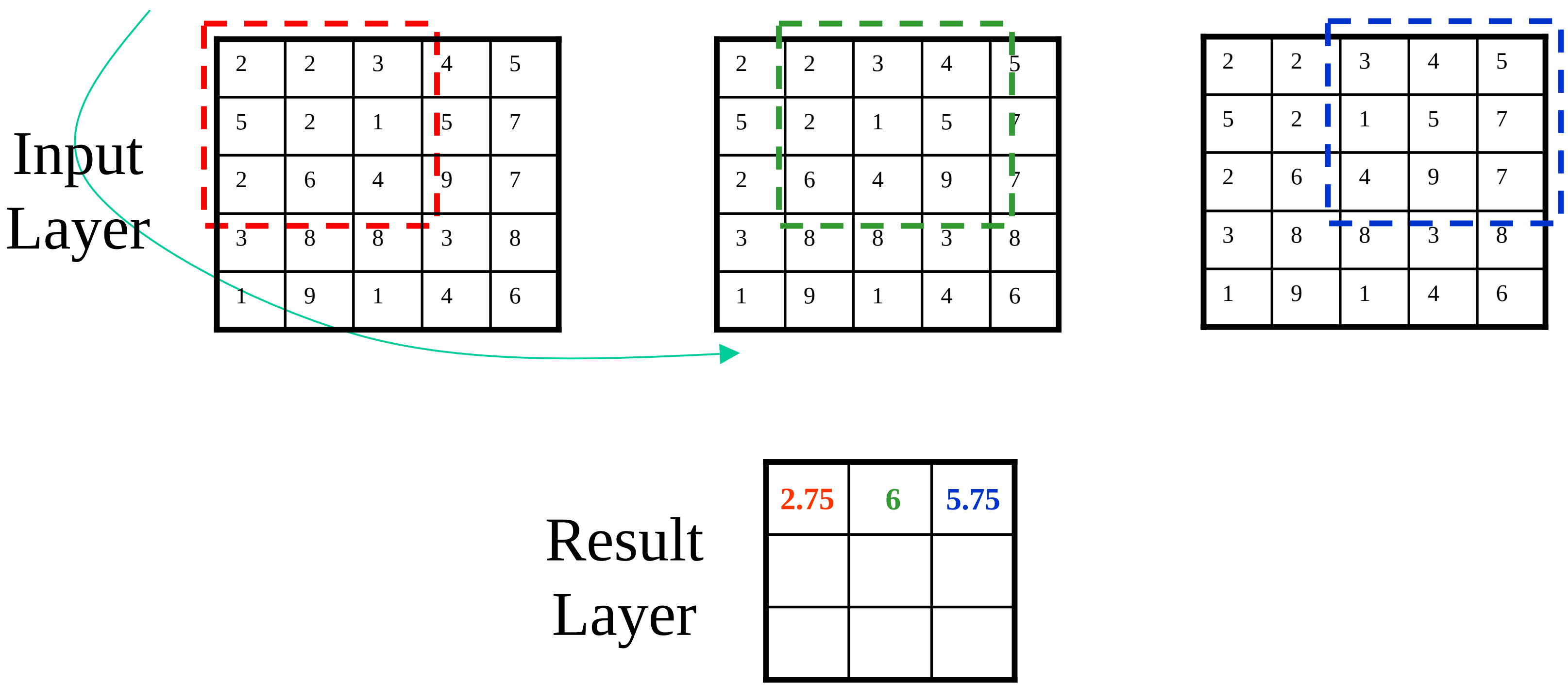
Neighborhood Operation - Mean

•One neighborhood operation is to calculate the **mean** for all pixels in the neighborhood and put the result in the center of the neighborhood. This is why a neighborhood size is often an **odd number** (3x3, 5x5, 7x7, …) because these have a well defined center for the result value:



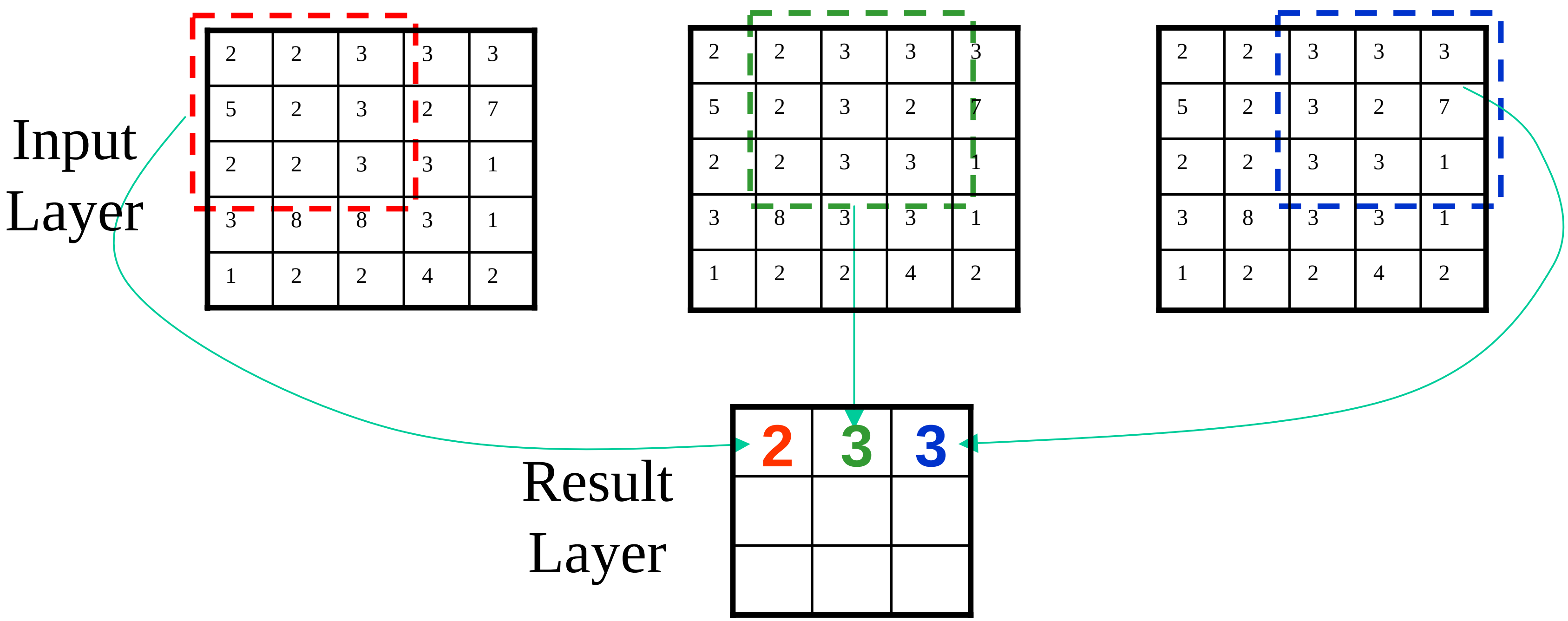
Neighborhood Operation - Variance

- Rather than calculating a mean using the 9 values from a 3x3 neighborhood, we could instead **calculate variance**
- This operates in the **same fashion**; we collect the values in the neighborhood, calculate the statistic, and write the result in the center of the neighborhood in the result layer:



Neighborhood Operation - Majority

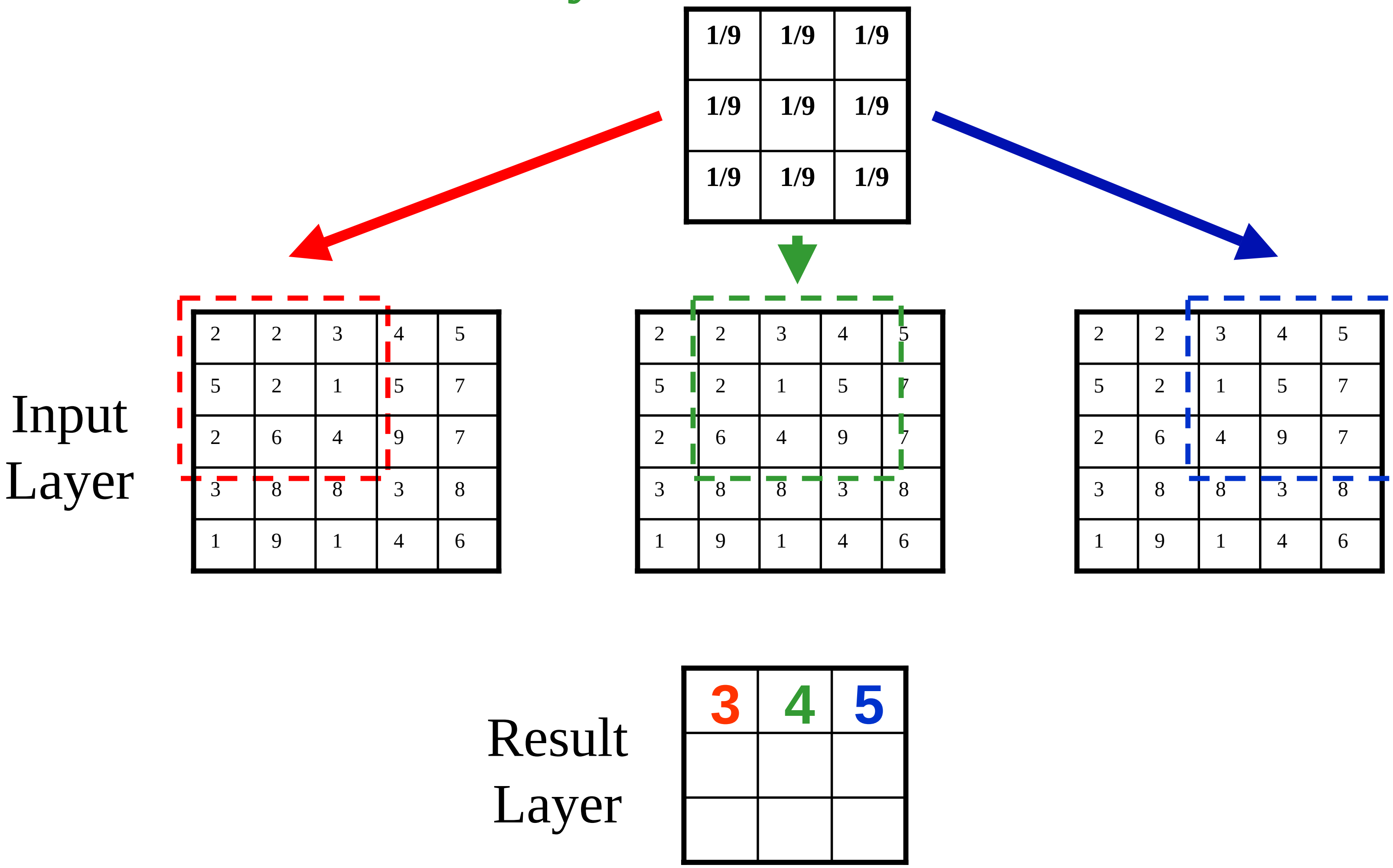
•Another operation we might use on a neighborhood is to find the **majority value** (the value that appears most often, the mode):



•Under **what circumstances** might we find this to be a useful operation to apply to a raster layer?

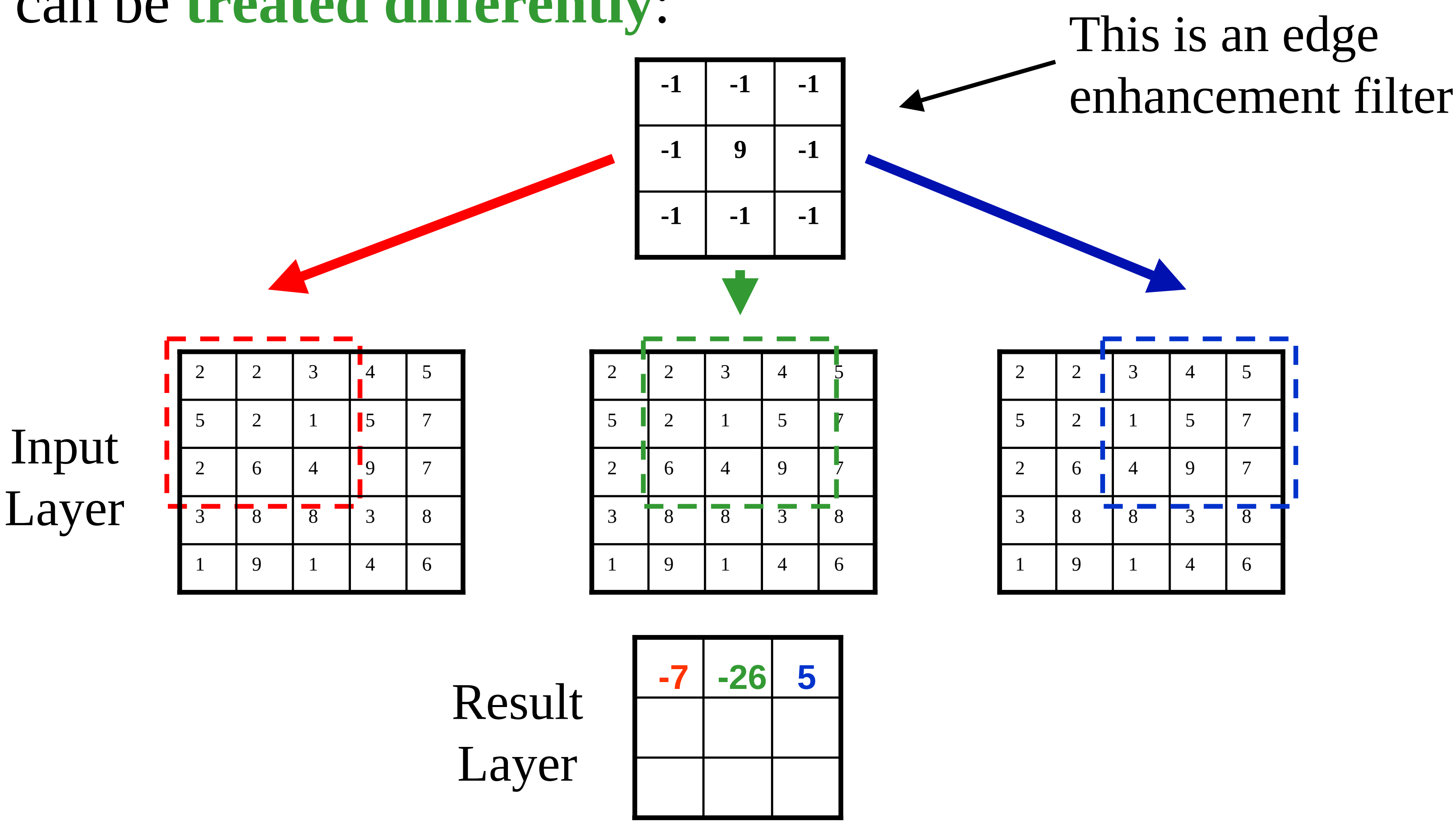
The Mean Operation Revisited

•In the mean operation, **each cell** in the neighborhood is **used in the same way**:



A More Complex Neighborhood Operation

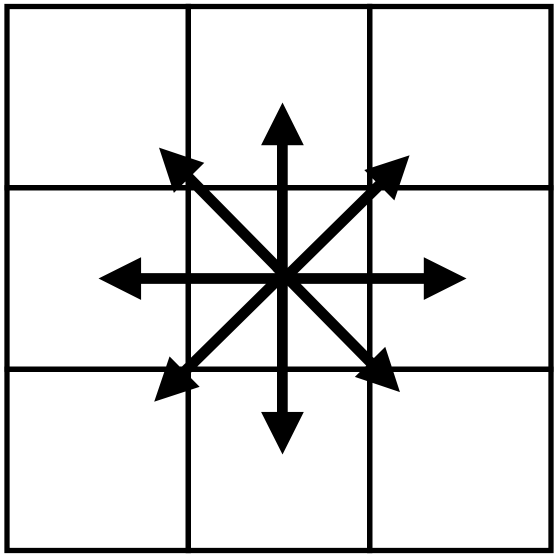
•In more complex operations, **the cells** in the neighborhood can be **treated differently**:



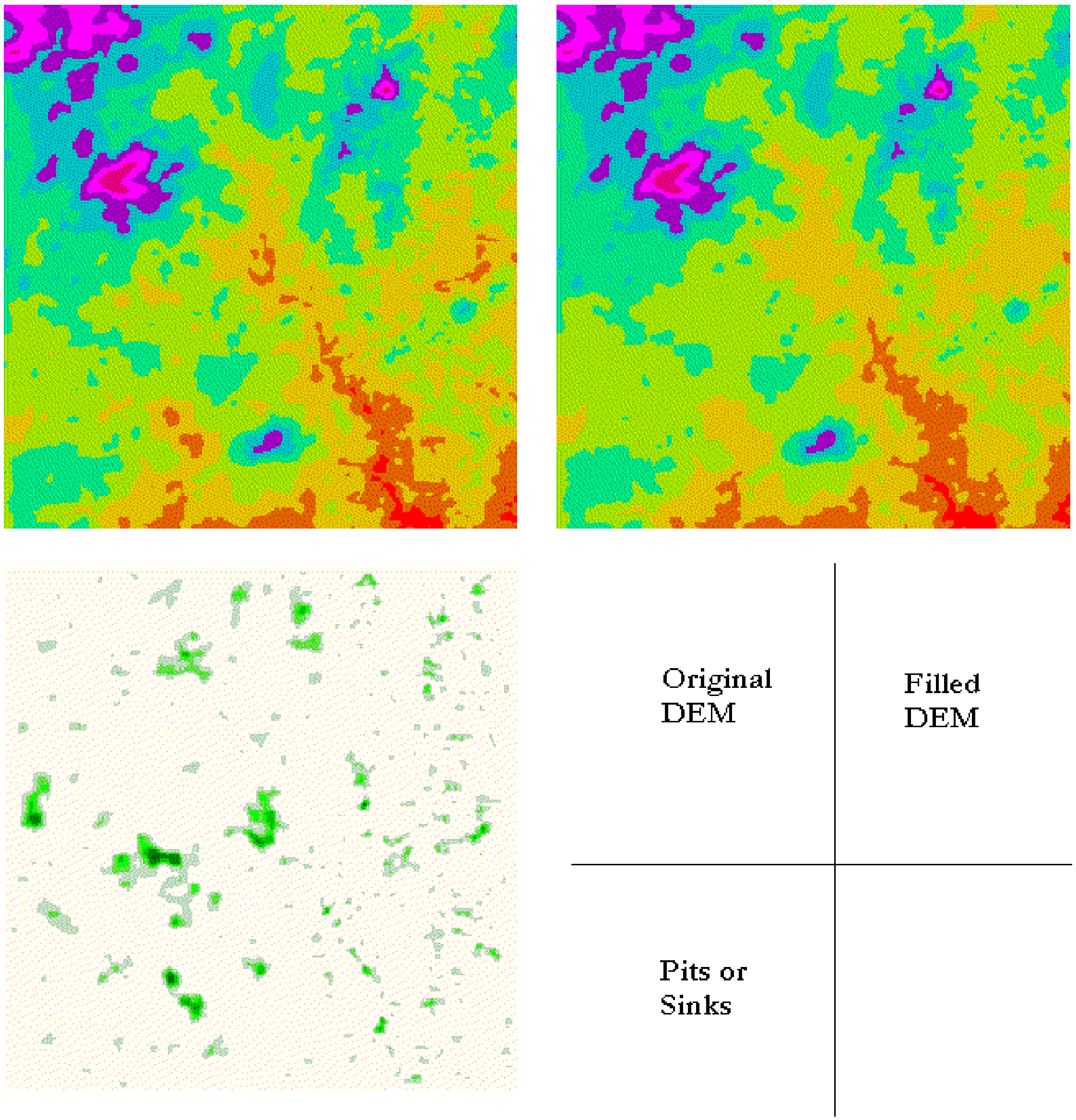
D8 Analysis Sequence

- Assume we now have a raster DEM and we want to use it **find a watershed and drainage network** through D8 analysis
- We can follow this **sequence of analysis** steps, each of which involves a neighborhood analysis operation:
  - Fill Sinks
  - Slope
  - Aspect
  - Flow Direction
  - Flow Accumulation
  - StreamLink & StreamOrder
  - Watershed

D8 Analysis



Fill Sinks



- We need a DEM that does not have any **depressions or pits** in it for D8 drainage network analysis
- The first step is to **remove all pits** from our DEM using a **pit-filling algorithm**
- This **illustration** shows a DEM of **Morgan Creek**, west of Chapel Hill

Slope and Aspect

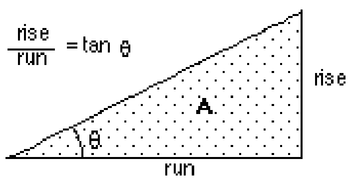
- These are **measurements of terrain attributes**, usually calculated from a digital elevation model
- **Slope and aspect** are calculated for each cell in the grid, by comparing a cell's elevation to that of its neighbors
  - Usually **eight neighbors** are used and the result is expressed as an angle, but the exact method varies
  - It is important to know exactly what method is used when calculating slope, and exactly how slope is defined, because **different methods** can give **different results**

Slope and Aspect

- We can **calculate** these topographic attributes directly from the grid-elevation values using a second-order finite difference scheme applied over a 3x3 neighborhood

From ArcView 3.2 Help

Degree of slope = θ



Degree of slope = 30
Percent of slope = 58

Slope

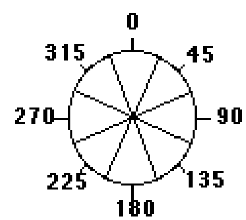
The actual algorithm that is used to calculate slope is:

```
rise_run = SQRT(SQR(dz/dx)+SQR(dz/dy))
degree_slope = ATAN(rise_run) * 57.29578
```

where the deltas are calculated using a 3x3 roving window,

```
a b c
d e f
g h I
```

```
(dz/dx) = ((a + 2d + g) - (c + 2f + i)) / (8 * x_mesh_spacing)
(dz/dy) = ((a + 2b + c) - (g + 2h + i)) / (8 * y_mesh_spacing)
```



Aspect

1	1	1	1	1	1
1	3	3	2	1	NODATA
1	1	3	2	2	2
1	2	2	2	2	2
1	1	1	2	2	2
1	1	1	1	1	2

INGRID1

=

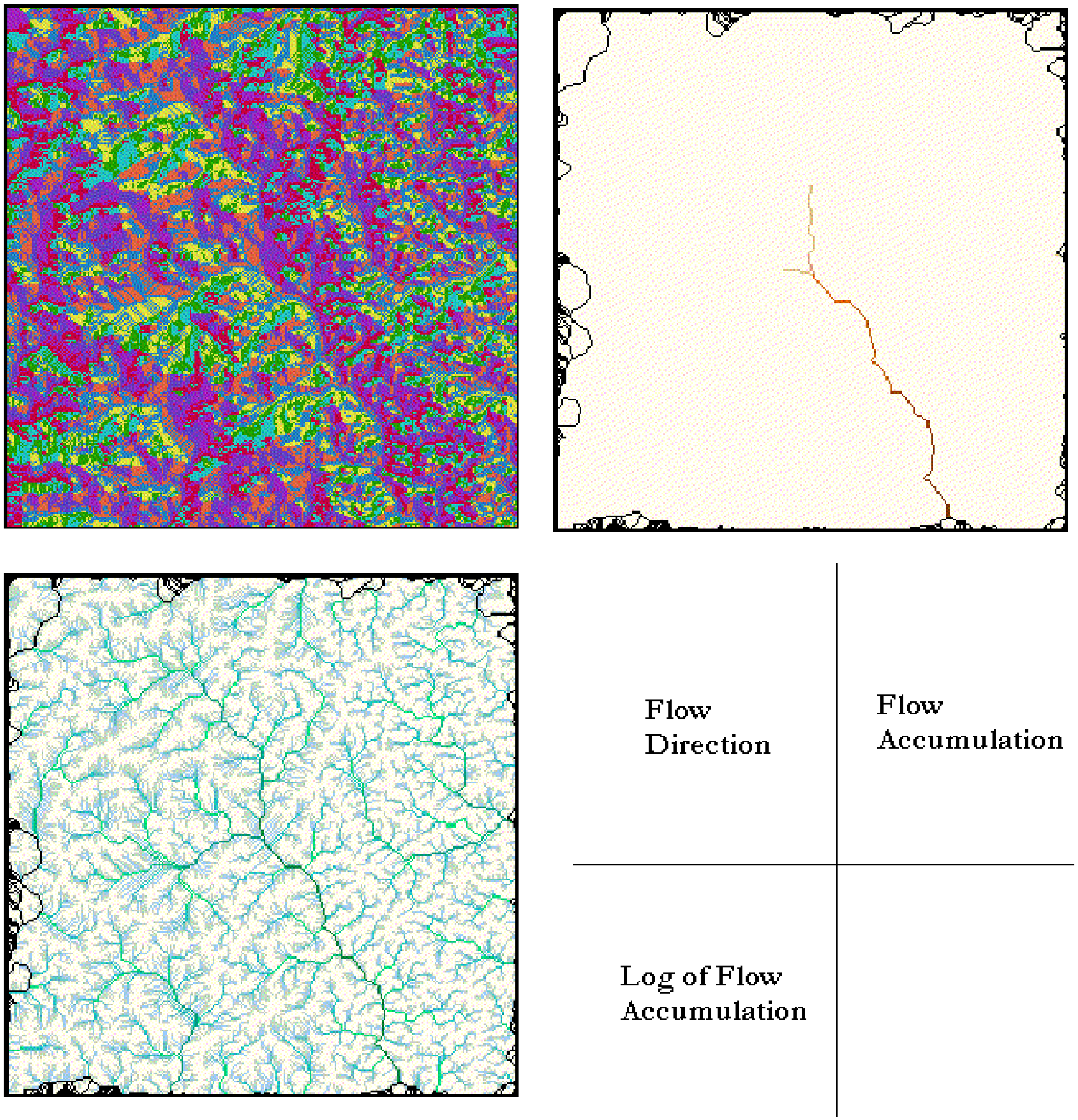
315.0	341.6	8.1	26.6	45.0	-1.0
270.0	288.4	11.3	45.0	26.6	NODATA
251.6	246.8	198.4	90.0	0.0	315.0
270.0	243.4	206.6	180.0	-1.0	-1.0
225.0	198.4	206.6	206.6	198.4	225.0
-1.0	-1.0	225.0	198.4	206.6	270.0

OUTGRID

Value = NODATA

White Cells Value = 0

Flow Direction and Accumulation



- Slope and aspect are needed to produce **flow direction**, which assigns each cell a **direction of steepest descent**
- **Flow accumulation** uses flow direction to find the **number of cells** that **drain to each cell**
- Taking the **log** of accumulation makes the **pattern** much easier to see

Flow Direction

- Flow Direction evaluates the **direction of steepest decent** for each cell in the grid by **comparing a cell with its eight neighbors** in the following fashion:
  - drop = change in z value / distance * 100
  - Note that diagonal neighbors are 1.414214 times as far away as 4-connected orthogonal neighbors
- ArcGIS **encodes** the resulting direction of steepest decent in the grid using **the following scheme**:

32	64	128
16	X	1
8	4	2

- For example:

From ArcView 3.2 Help

78	72	69	71	58	49
74	67	56	49	46	50
69	53	44	37	38	48
64	58	55	22	31	24
68	61	47	21	16	19
74	53	34	12	11	12

elevGrid

=

2	2	2	4	4	8
2	2	2	4	4	8
1	1	2	4	8	4
128	128	1	2	4	8
2	2	1	4	4	4
1	1	1	1	4	16

flowGrid

Fill Sinks

- A **sink** is a cell or set of spatially connected cells whose **flow direction cannot be assigned** one of the eight valid values in a flow direction Grid. This can occur **when all neighboring cells are higher** than the processing cell, or **when two cells flow into each other** creating a two-cell loop.
- To create an accurate representation of flow direction and therefore accumulated flow, it is best to use **a data set that is free of sinks**. A digital elevation model that has been processed to remove all sinks is referred to as a **depressionless DEM**.

From ArcView 3.2 Help

Flow Accumulation

- Flow accumulation find the **number of cells that drain to any cell** in the grid, taking the flow direction grid as input:
  - Output cells with a **high flow accumulation** are areas of concentrated flow and may be used to **identify stream channels**.
  - Output cells with a **flow accumulation of 0** are local topographic highs and may be used to **identify ridges**.
- For example:

From ArcView 3.2 Help

2	2	2	4	4	8
2	2	2	4	4	8
1	1	2	4	8	4
128	128	1	2	4	8
2	2	1	4	4	4
1	1	1	1	4	16

flowGrid

=

0	0	0	0	0	0
0	1	1	2	2	0
0	3	7	5	4	0
0	0	0	20	0	1
0	0	0	1	24	0
0	2	4	7	35	2

accumGrid