**PRECISION AG 2.0 Conference**

***February 11-12, 2014 — Calgary, Alberta, Canada***

# Returning the Scientific Horse to in Front of the Technical Cart

*Taking **Traditional Science**…*

*…is the **Technical Cart** in front of the **Scientific Horse**?*

*… to a **New Level***

*…this presentation suggests that is a new "map-ematics" that **extends traditional math/stat concepts and procedures for the quantitative analysis of map variables** (spatial data) which promises to change STEM education, science and innovation in general, and the agricultural sciences in particular—*

***SpatialSTEM** the "new math" of the 21st Century*


***Breakout session by** **Joseph K. Berry***

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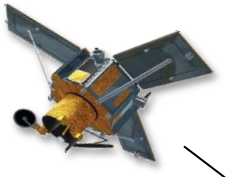
*Principal, Berry & Associates // Spatial Information Systems*
*Email **jberry@innovativegis.com** — Website **www.innovativegis.com/basis/***


*(See **http://www.innovativegis.com/basis/present/PAconf_Calgary2014/** to access support materials including PowerPoint)*

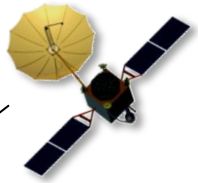
# Geotechnology as a Mega-Technology

***Geotechnology*** is one of the three "**mega -technologies**" for the 21st century and promises to <u>forever change how we conceptualize, utilize and visualize</u> spatial relationships in scientific research and commercial applications *(U.S. Department of Labor)*

***…recall from the earlier overview discussion***



***Geographic Information Systems*** ***(map and analyze)***



***Remote Sensing***
***(measure and classify)***

***Global Positioning System*** ***(location and navigation)***

**GPS/GIS/RS**

**The Spatial Triad**

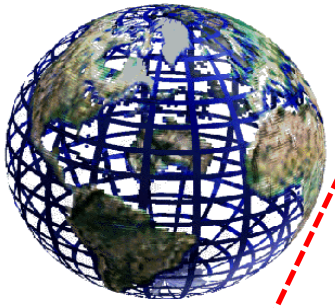
***Computer Mapping (70s)***
***Spatial Database Management (80s)***

<u>**Technological Tool**</u>

***Mapping*** *involves <u>precise placement</u> (delineation) of physical features*

*(graphical inventory)*

is



<u>**Where**</u>

<u>**What**</u>

*Descriptive Mapping*

*Prescriptive Modeling*

<u>**Why**</u> <u>**So What**</u> and <u>**What If**</u>

***Map Analysis (90s)***
***GeoWeb Interactions (00s)***

<u>**Analytical Tool**</u>

***Modeling*** *involves <u>analysis</u> of spatial patterns and relationships*

*(map analysis/modeling)*

*(Berry)*

# Is GIS Technology Ahead of Science?

*...is the **Technical Cart** in front of the **Scientific Horse**?*

*Five critical questions underlying Precision Agriculture…*

*1) Is the "**scientific method**" relevant in the data-rich age of knowledge engineering?*

*2) Is the "**random thing**" pertinent in deriving mapped data?*

*3) Are **geographic distributions** a natural extension of numerical distributions?*

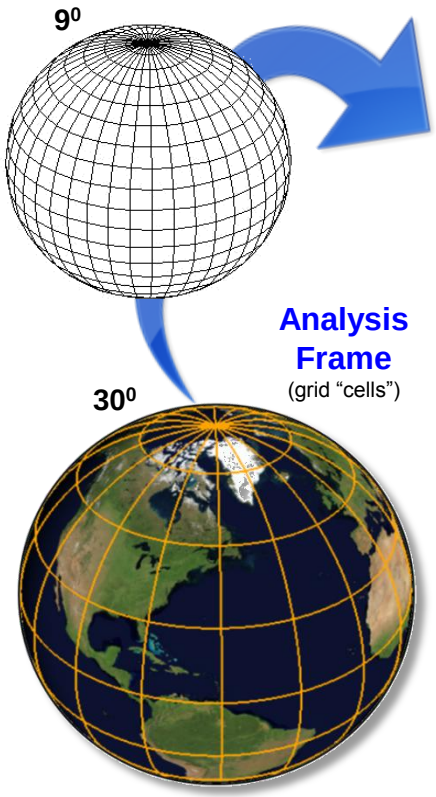
*4) Can **spatial dependencies** be modeled within a map variable (spatial autocorrelation) and among map variables (spatial correlation)?*

*5) How can "site-specific" analysis and on-farm studies contribute to the **scientific body of knowledge**?*

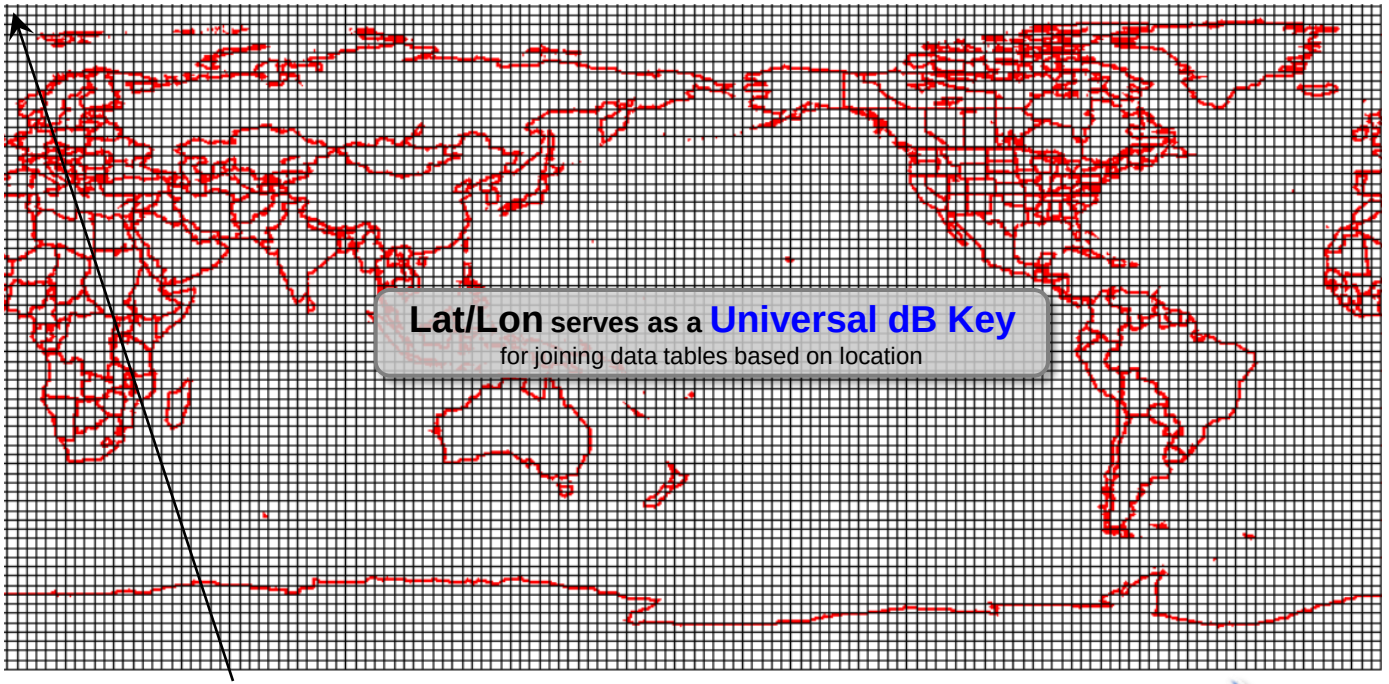
…turning traditional science on its head by extending math/stat operations for quantitative analysis of mapped data

*(Berry)*

# Grid-based Map Data *(geo-registered matrix of map values)*




**2.5⁰ Latitude/Longitude Grid** (140mi grid cell size)




**Coordinate of first grid cell is 90⁰ N 0⁰ E** **#Rows= 73 #Columns= 144 = 10,512 grid cells**

The **Latitude/Longitude** grid forms a continuous surface for geographic referencing where each **grid cell** represents a given portion of the earth' surface.

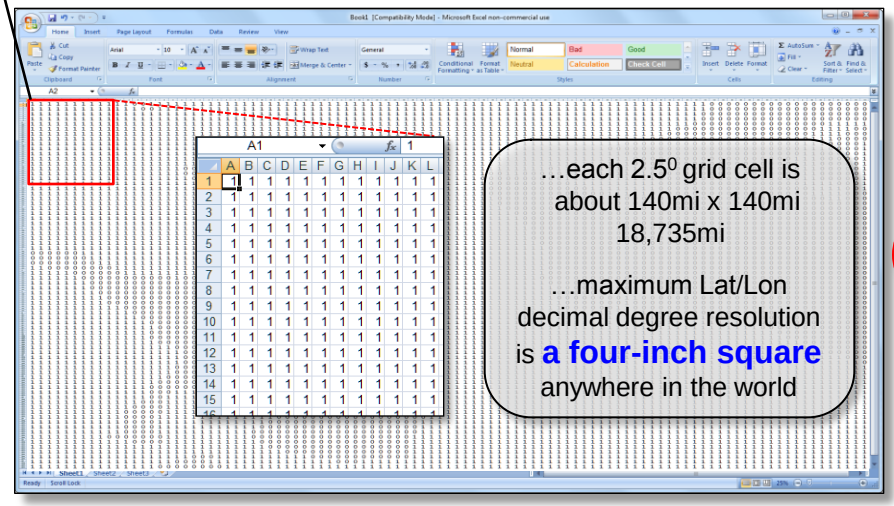
---

The easiest way to conceptualize a grid map is as an Excel spreadsheet with each **cell** in the table corresponding to a Lat/Lon grid space (*location*) and each **value** in a cell representing the characteristic or condition (*information*) of a mapped variable occurring at that location. →

*…the bottom line is that…*

*All **spatial topology** is inherent in the grid.*

**Conceptual Spreadsheet** (73 x 144)




**Lat/Lon**

**…from Lat/Lon "crosshairs to grid cells"**

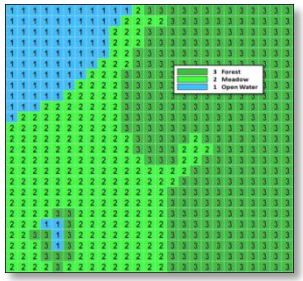
that contain map **values** indicating characteristics or conditions at each location

*(Berry)*

# A Mathematical Structure for Map Analysis/Modeling

**Technological Tool** — **Geotechnology** → RS – **GIS** – GPS — **Analytical Tool**

**Mapping/Geo-Query** *(**Discrete**, Spatial Objects)* (*Continuous*, *Map Surfaces*) **Map Analysis/Modeling**



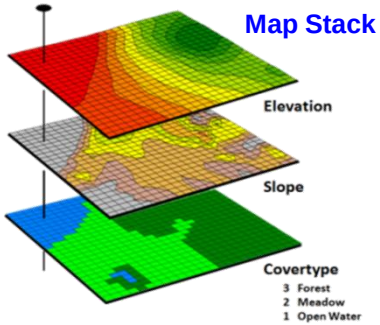

*…organized set of numbers*

*Geo-registered*
**Analysis Frame → Matrix**
*of Numbers*

"**Map-*ematics***"

## Maps as Data, not Pictures

*Vector & **Raster** — Aggregated & **Disaggregated***
*Qualitative & **Quantitative***




## Spatial Analysis Operations

**GISer's Perspective:**

***Reclassify** and **Overlay***
***Distance** and **Neighbors***

**Mathematician's Perspective:**

***Basic GridMath & Map Algebra***
***Advanced GridMath***
***Map Calculus***
***Map Geometry***
***Plane Geometry Connectivity***
***Solid Geometry Connectivity***
***Unique Map Analytics***

*Grid-based*
*Map Analysis*
*Toolbox*

**The SpatialSTEM Framework**

Traditional math/stat procedures can be extended into **geographic space** to stimulate those with diverse backgrounds and interests for…

"***thinking analytically with maps***"

## Spatial Statistics Operations

**GISer's Perspective:**

***Surface Modeling***
***Spatial Data Mining***

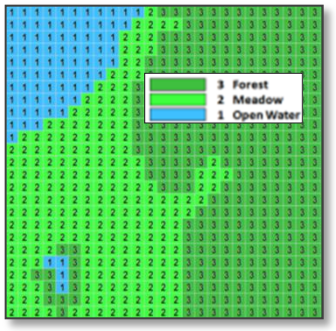
**Statistician's Perspective:**

***Basic Descriptive Statistics***
***Basic Classification***
***Map Comparison***
***Unique Map Statistics***
***Surface Modeling***
***Advanced Classification***
***Predictive Statistics***

*(Berry)*

# Spatial Analysis Operations *(Geographic Context)*

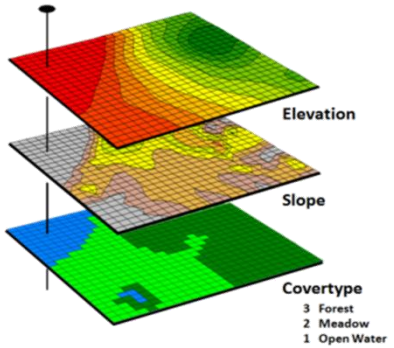
GIS as "Technical Tool" *(Where is What)* vs. "**Analytical Tool**" *(Why, So What and What if)*




Grid Layer

**Spatial Analysis**

Map Stack




**Spatial Analysis** extends the basic set of discrete map features (points, lines and polygons) to map **surfaces** that represent continuous geographic space as a set of contiguous grid cells (matrix), thereby providing a **Mathematical Framework** for *map analysis* and *modeling* of the

**Contextual Spatial Relationships** within and among grid map layers

Map Analysis Toolbox

## Mathematical Perspective:

***Basic GridMath & Map Algebra*** *( + - * / )*

***Advanced GridMath*** *(Math, Trig, Logical Functions)*

***Map Calculus*** *(Spatial Derivative, Spatial Integral)*

✓ ***Unique spatial operations***

***Map Geometry*** *(Euclidian Proximity, Effective Proximity, Narrowness)*

***Plane Geometry Connectivity*** *(Optimal Path, Optimal Path Density)*

***Solid Geometry Connectivity*** *(Viewshed, Visual Exposure)*

✓ ***Unique Map Analytics*** *(Contiguity, Size/Shape/Integrity, Masking, Profile)*

*(Berry)*

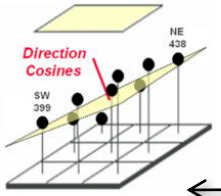
# Spatial Analysis Operations *(Math Examples)*

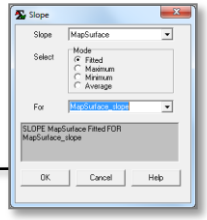
***Advanced Grid Math*** — *Math, Trig, Logical Functions*

***Map Calculus*** — *Spatial Derivative, Spatial Integral*

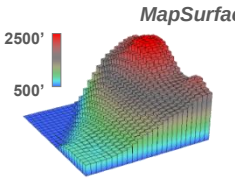
## Spatial Derivative

*…is equivalent to the slope of the* ***tangent plane*** *at a location*



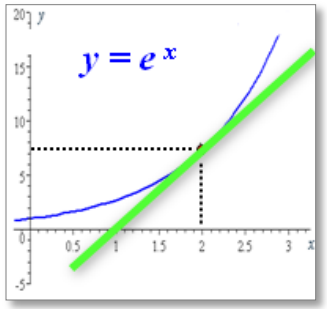




*SLOPE MapSurface* ***Fitted*** *FOR MapSurface_slope*

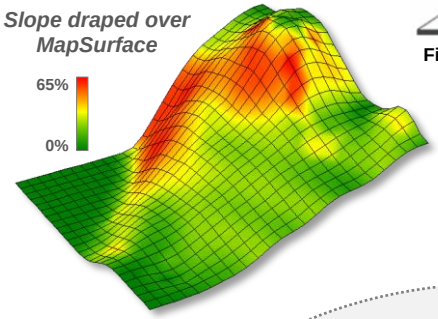



***Surface***

***Curve***



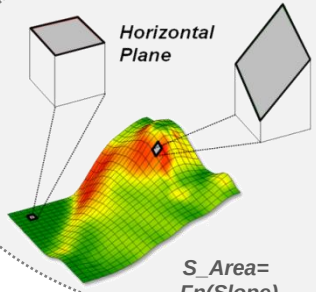

*The* ***derivative*** *is the instantaneous "rate of change" of a function and is equivalent to the slope of the* ***tangent line*** *at a point*




**$D_z$xy Elevation**

**$\int$ *Districts_Average* Elevation**

## Advanced Grid Math



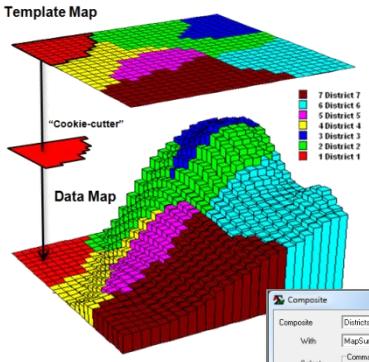

### Surface Area

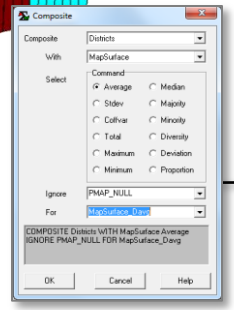
*…increases with increasing inclination as a Trig function of the* ***cosine of the slope angle***

**S_area= cellsize / cos($D_z$xy Elevation)**

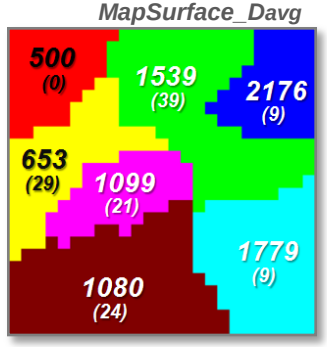
## Spatial Integral

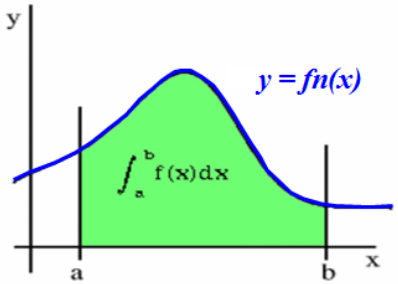
*…summarizes the values on a surface for specified map areas (Total=* ***volume*** *under the surface)*




***COMPOSITE Districts WITH MapSurface Average FOR MapSurface_Davg***




*The* ***integral*** *calculates the* ***area*** *under the curve for any section of a function.*

***Surface***

***Curve***

*(Berry)*

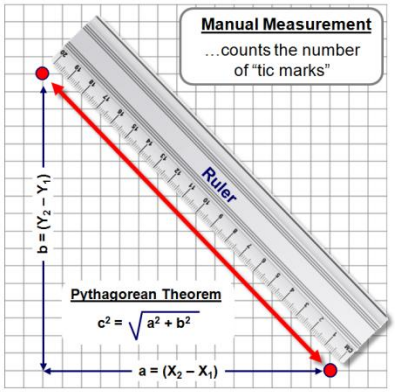
# Spatial Analysis Operations *(Distance Examples)*

***Map Geometry*** *— (Euclidian Proximity, Effective Proximity, Narrowness)*

***Plane Geometry Connectivity*** *— (Optimal Path, Optimal Path Density)*

***Solid Geometry Connectivity*** *— (Viewshed, Visual Exposure)*

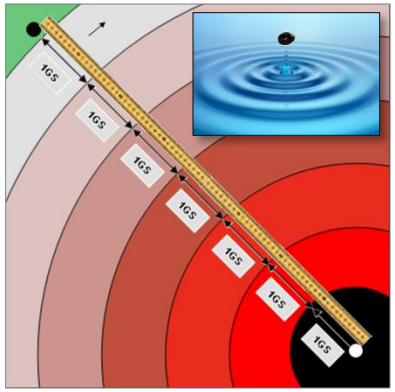
## Distance




**Mathematical Measurement**
…solves the Pythagorean Theorem

**Shortest straight line between two points…**

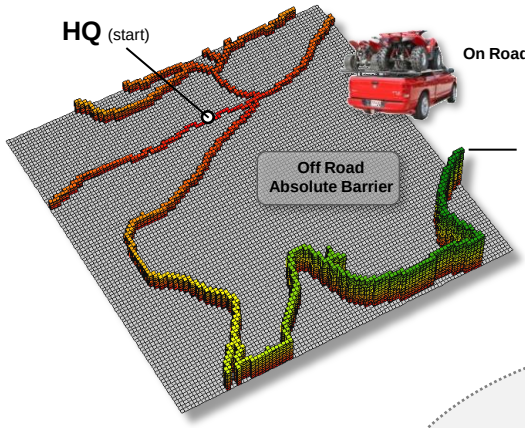
## Euclidean Proximity



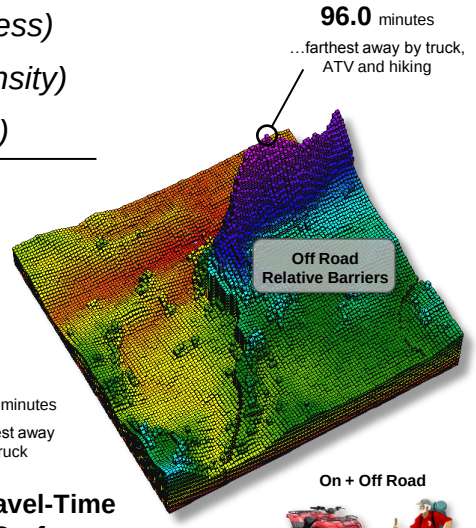

**Splash Algorithm**
…like tossing a rock into a pond— ripples

**…from a point to everywhere…**

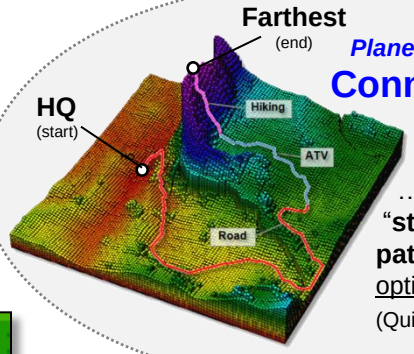
## Effective Proximity




**…not necessarily straight lines (movement)**




**Travel-Time Surface**




***Plane Geometry***
## Connectivity

**Truck** = 18.8 min
**ATV** = 14.8 min
**Hiking** = 62.4 min

…like a raindrop, the "**steepest downhill path**" identifies the optimal route
(Quickest Path)

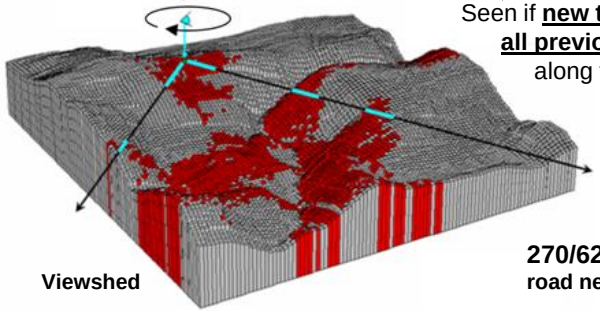
## *Solid Geometry* Connectivity



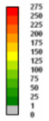


**Tan = Rise/Run**

Seen if **new tangent exceeds all previous tangents** along the line of sight





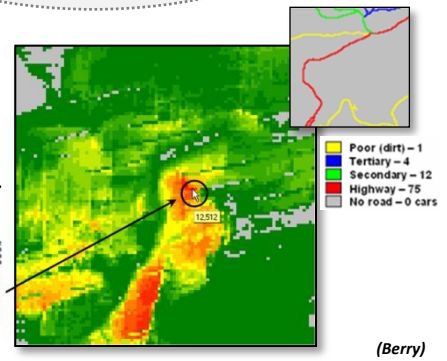


**270/621= 43%** of the entire road network is connected




← **Counts**
# Viewers

**Sums**
Viewer
Weights →

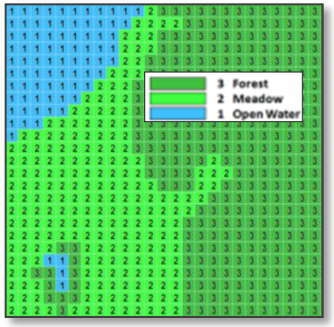



**Highest Weighted Exposure**

*(Berry)*

# Spatial Statistics Operations *(Numeric Context)*

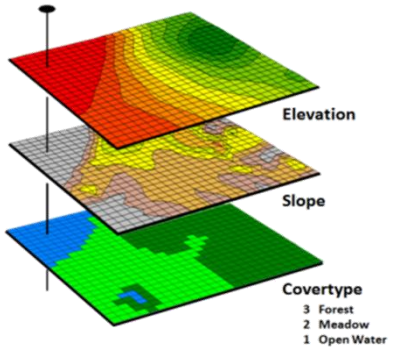
GIS as "Technical Tool" *(Where is What)* vs. "**Analytical Tool**" *(Why, So What and What if)*




**Grid Layer**

**Spatial Statistics**

**Map Stack**




**Spatial Statistics** seeks to map the **variation** in a data set instead of focusing on a single typical response (central tendency), thereby providing a **Statistical Framework** for *map analysis* and *modeling* of the

**Numerical Spatial Relationships** within and among grid map layers

Map Analysis Toolbox

✓ *Unique spatial operations*

## Statistical Perspective:

***Basic Descriptive Statistics*** *(Min, Max, Median, Mean, StDev, etc.)*

***Basic Classification*** *(Reclassify, Contouring, Normalization)*

***Map Comparison*** *(Joint Coincidence, Statistical Tests)*

✓ ***Unique Map Statistics*** *(Roving Window and Regional Summaries)*

✓ ***Surface Modeling*** *(Density Analysis, Spatial Interpolation)*

***Advanced Classification*** *(Map Similarity, Maximum Likelihood, Clustering)*

***Predictive Statistics*** *(Map Correlation/Regression, Data Mining Engines)*

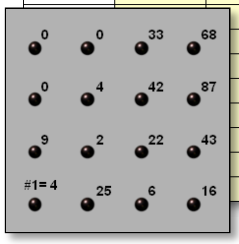


*(Berry)*

# Spatial Statistics *(Linking Data Space with Geographic Space)*

## Geo-registered Sample Data

| Sample | X | Y | P1 | P2 |
|---|---|---|---|---|
| #1 | 1000 | 1000 | 11 | 4 |
| 2 | 1000 | 1500 | 19 | 9 |
| 3 | 1000 | 2000 | 8 | 0 |
| 4 | 1000 | 2500 | 0 | 0 |
| 5 | 1500 | 1000 | 27 | 25 |
| 6 | 1500 | 1500 | 12 | 2 |
| 7 | 1500 | 2000 | 14 | 4 |
| 8 | 1500 | 2500 | 2 | 0 |
| | | 1000 | 10 | 6 |
| | | 1500 | 17 | 22 |
| | | 2000 | 34 | 42 |
| | | 2500 | 22 | 33 |
| | | 1000 | 20 | 16 |
| | | 1500 | 28 | 43 |
| | | 2000 | 42 | 87 |
| | | 2500 | 34 | 68 |

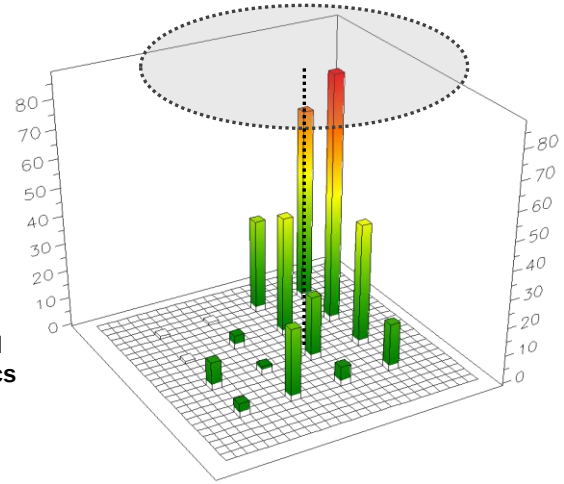



Non-Spatial Statistics

## Standard Normal Curve

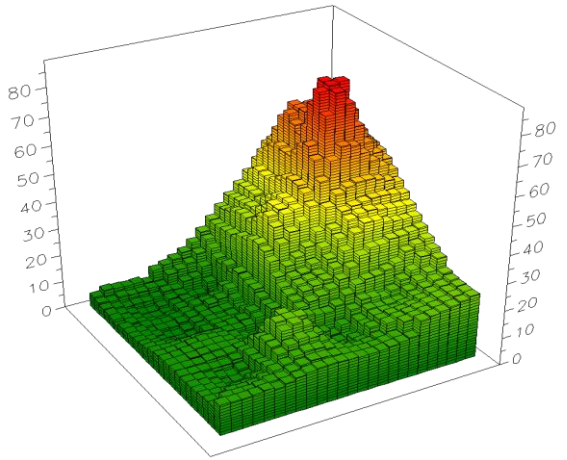
Spatial Statistics

**Roving Window** (weighted average)




***Discrete Sample Map***

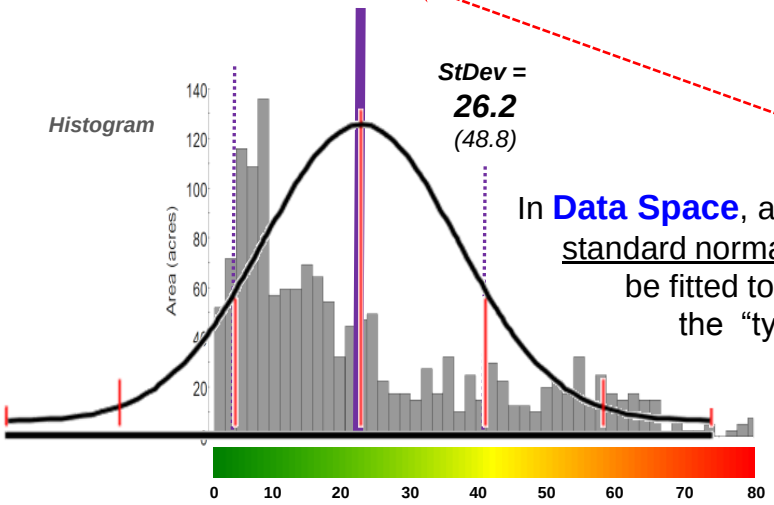
## Spatial Distribution




***Continuous Map Surface***

**Surface Modeling** techniques are used to derive a continuous map surface from discrete point data– fits a *Surface* to the data (maps the variation).

***Average = 22.6***

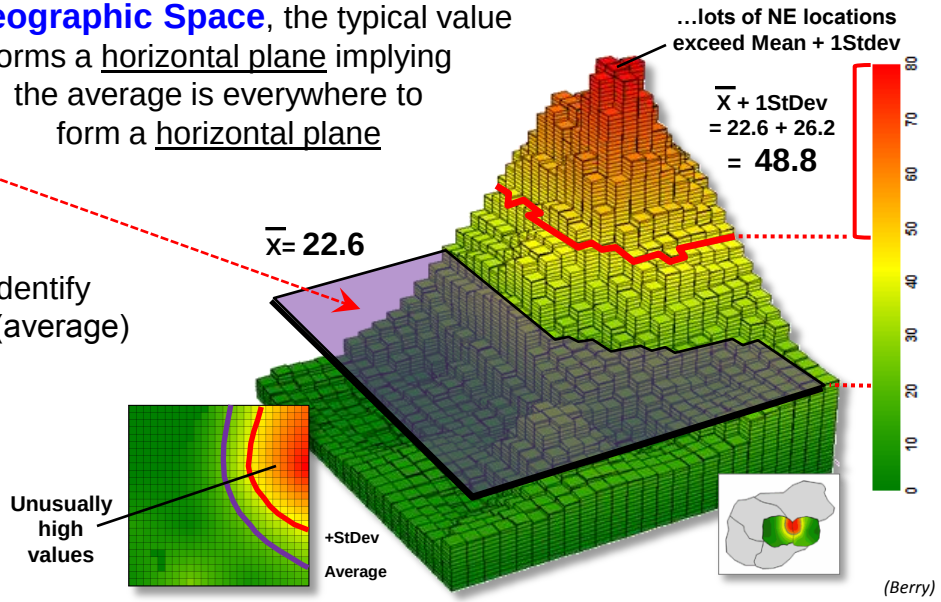



***StDev = 26.2 (48.8)***

In **Data Space**, a standard normal curve can be fitted to the data to identify the "typical value" (average)

## Numeric Distribution

In **Geographic Space**, the typical value forms a horizontal plane implying the average is everywhere to form a horizontal plane

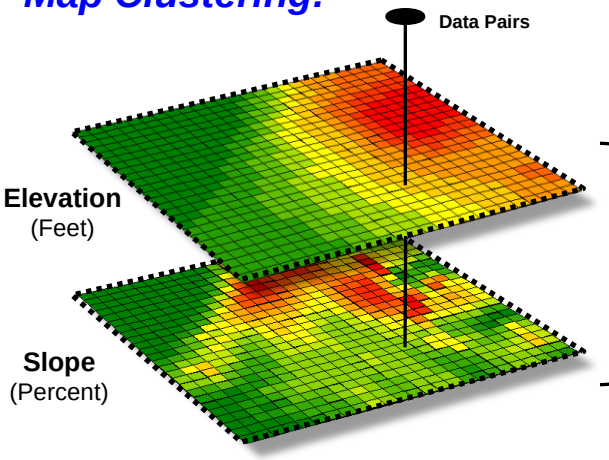


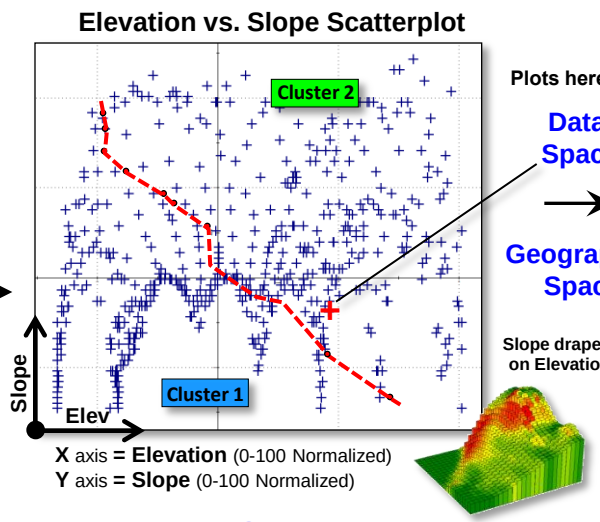

(Berry)

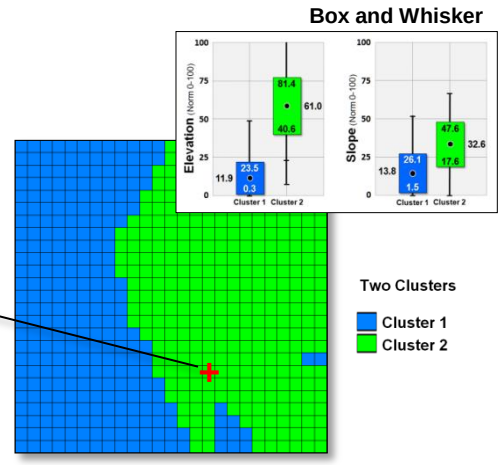
(Berry)

# Spatial Statistics Operations *(Data Mining Examples)*

## *Map Clustering:*




**Geographic Space**

## Advanced Classification *(Clustering)*

**Data Space**

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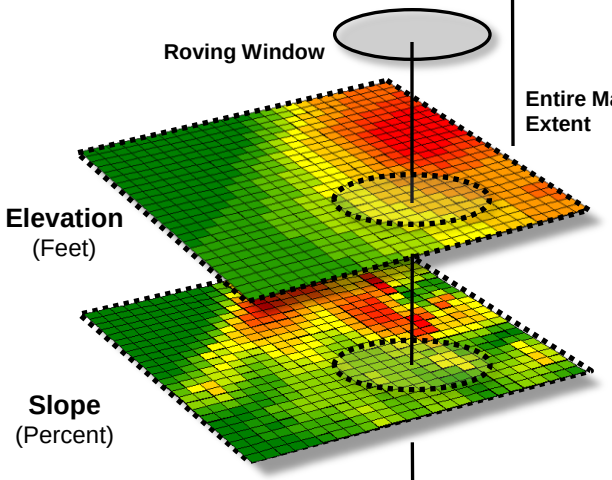
## *Map Correlation:*




### Spatially Aggregated Correlation

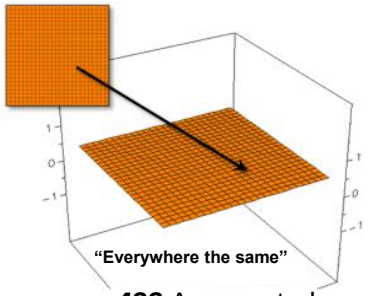
**Scalar Value** – one value represents the overall non-spatial relationship between the two map surfaces

**…1 large data table**
with 25rows x 25 columns =
625 map values for **map wide summary**

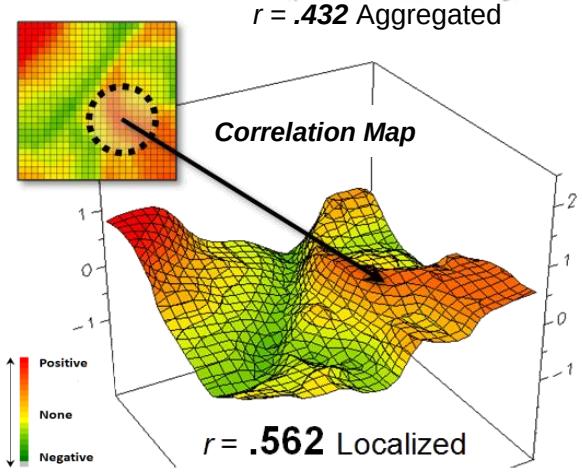
$$r = \frac{n\Sigma xy - (\Sigma x)*(\Sigma y)}{\mathrm{Sqrt}([n\Sigma x^2 - (\Sigma x)^2]*[n\Sigma y^2 - (\Sigma y)^2])}$$

…where **x** = Elevation value and **y** = Slope value and **n** = number of value pairs

**…625 small data tables**
within 5 cell reach =
81map values for **localized summary**




*r* = ***.432*** Aggregated




### Localized Correlation

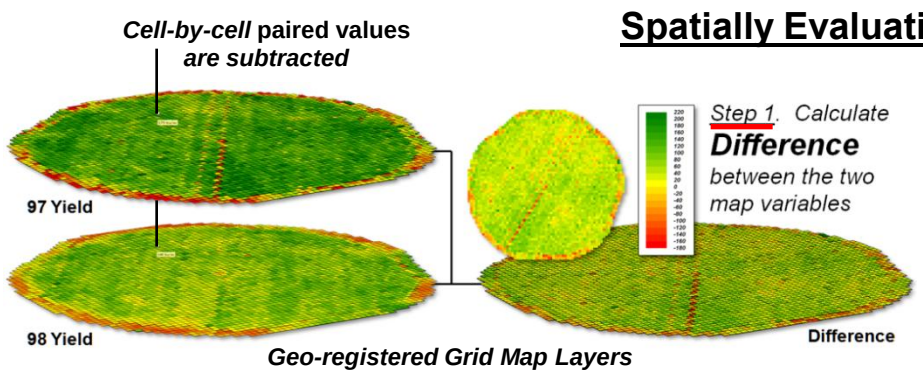
**Map Variable** – continuous quantitative surface represents the localized spatial relationship between the two map surfaces

## Predictive Statistics *(Correlation)*

*(Berry)*

# Spatial Statistics Operations *(Data Mining Examples)*

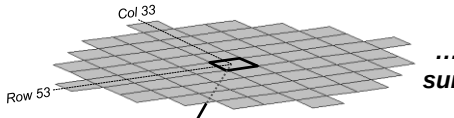
## Spatially Evaluating the "T-Test"





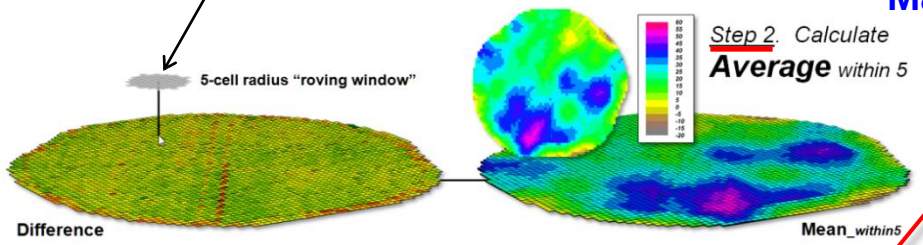
*The **T-statistic** equation is evaluated by first calculating a map of the **Difference** (Step 1) and then calculating maps of the **Mean** (Step 2) and **Standard Deviation** (Step 3) of the Difference within a "roving window." The **T-statistic** is calculated using the derived Mean and StDev maps using the standard equation (step 4) — spatially localized solution.*

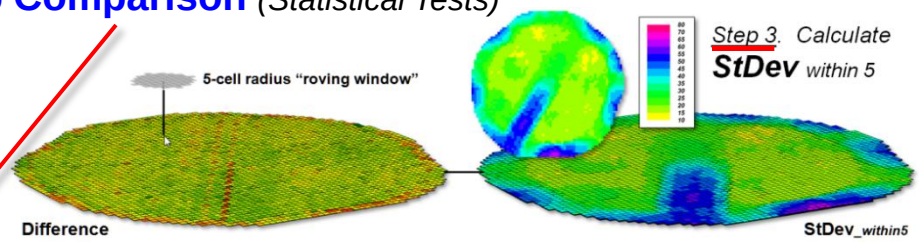
$$\textbf{T-statistic} = \frac{\textbf{Mean}_{difference}}{\textbf{StDev}_{difference} / Sqrt\ (73)}$$




***5-cell radius* "roving window"**
***…containing 73 paired values that are summarized and assigned to center cell***

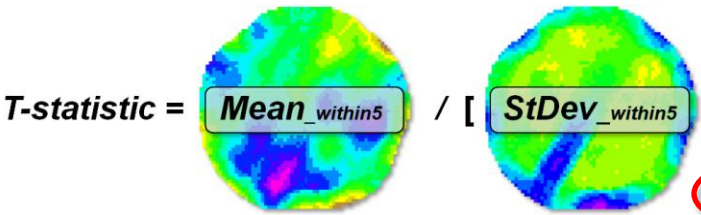
## Map Comparison *(Statistical Tests)*



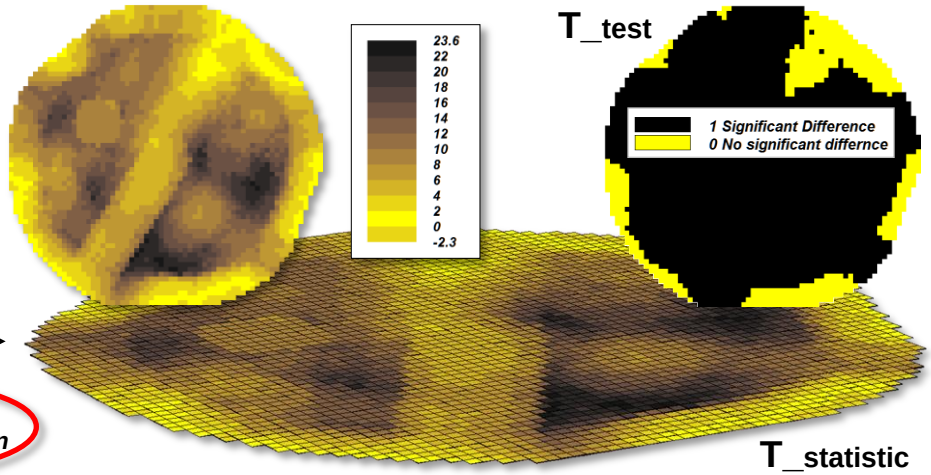




*Step 4. Calculate the **"Localized" T-statistic***
*(using a 5-cell roving window) for each grid cell location*

*…the result is map of the **T-statistic** indicating how different the two map variables are throughout geographic space and a **T-test** map indicating where they are significantly different.*




**Spatially Evaluate T-statistic Equation**



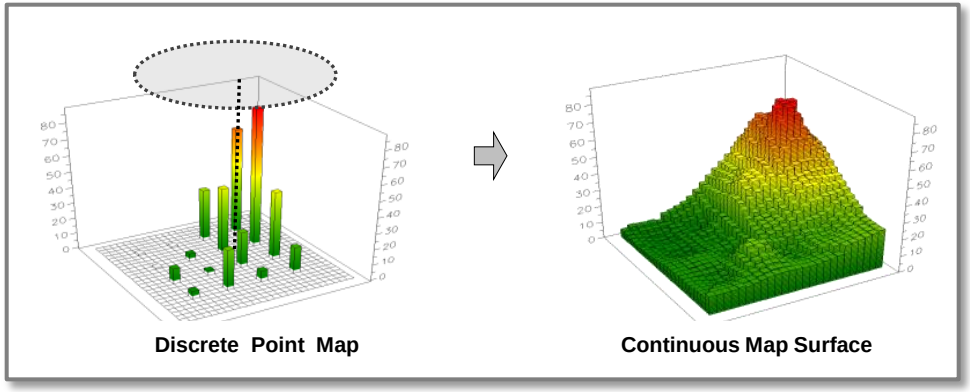

(Berry)

# Two Types of Spatial Variable Dependence

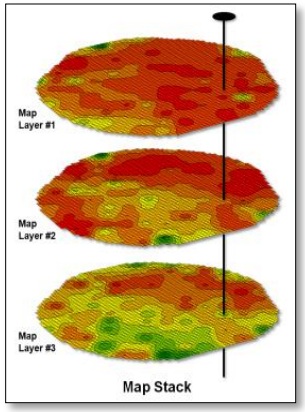
*…keep in mind that all Spatial Statistics used in Precision Ag is based upon the condition that "what occurs at a location in geographic space is related to"—*

*1) …the* ***conditions of <u>that variable</u> at nearby locations****,*
*termed* ***Spatial Autocorrelation*** *(<u>intra-variable</u> dependence; <u>within</u> a map layer)*

***Surface Modeling*** ***–*** *identifies the continuous spatial distribution implied in a set of discrete point samples*




*2) …the* ***conditions of <u>other variables</u> at that location****,*
*termed* ***Spatial Correlation*** *(<u>inter-variable</u> dependence; <u>among</u> map layers)*




***Statistical Analysis*** ***–*** *investigates spatial relationships among multiple map layers by spatially evaluating traditional statistical procedures*

***Map Stack*** *– relationships among maps are investigated by aligning grid maps with a common configuration— same* ***#cols/rows****,* ***cell size*** *and* ***geo-reference***

***Data Shish Kebab*** *– within a statistical context, each map layer represents a* ***Variable****; each grid space a* ***Case****; and each value a* ***Measurement*** *with all of the rights, privileges, and responsibilities of non-spatial mathematical , numerical and statistical analysis*

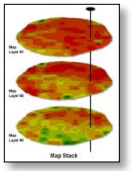
*(Berry)*

# Techniques for Accessing Multi-layered Data

*Characterization of the* ***Spatial Correlation*** *among two or more map layers involves:*

**Descriptive Spatial Statistics** involves summarizing/presenting mapped data in metric, tabular and graphic forms

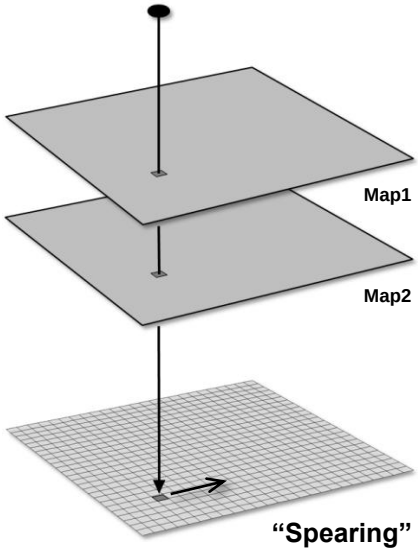
**Predictive Spatial Statistics** involves inferential analysis, e.g.,hypothesis testing, regression and spatial modeling



Assessing the spatial relationships among map layers involves spatially evaluating traditional statistical procedures using one of four basic techniques for

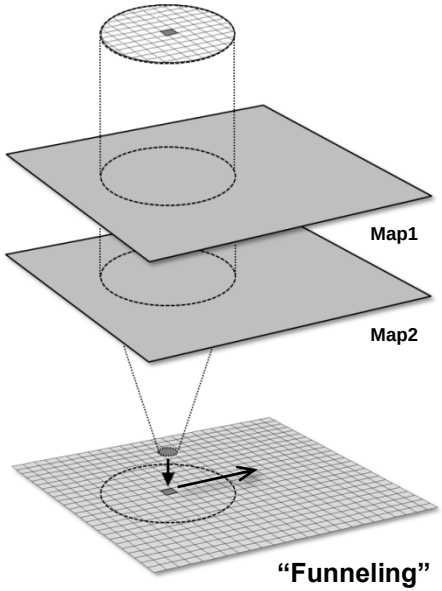
***accessing*** and ***organizing*** geo-registered data for multi-layer spatial statistics—

## Local



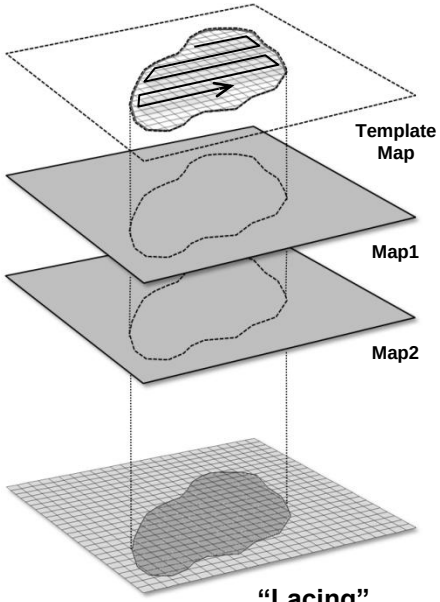

…collects data on a cell-by-cell basis and reports a single value on a cell-by-cell basis

## Focal



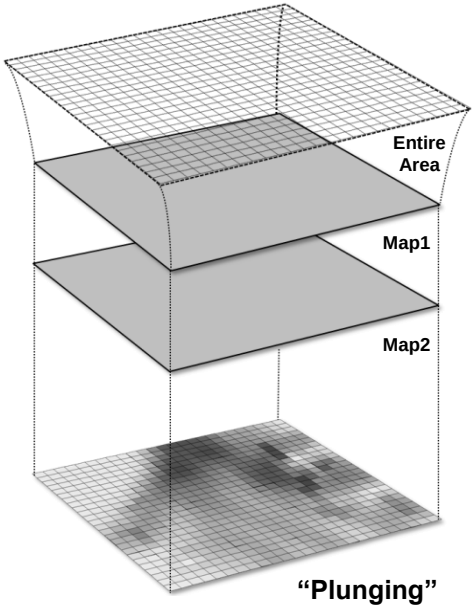

…collects data on a neighborhood basis and reports a single value on a cell-by-cell basis

## Zonal




…collects data on a region-wide basis and reports summary on a region-wide basis

## Global




…collects data on a map-wide basis and reports results on a map-wide or cell-by-cell basis

*(Berry)*

# So What's the Point? *(4 key points)*

1) Current GIS education for the most part insists that non-GIS students interested in understanding map analysis and modeling must be tracked into general **GIS courses that are designed for GIS specialists**, and material presented primarily **focus on commercial GIS software mechanics** that GIS-specialists need to know to function in the workplace.

*2)* However, solutions to complex spatial problems need to **engage "domain expertise"** through GIS–outreach to other disciplines to establish **spatial reasoning skills needed for effective solutions** that integrate a **multitude of disciplinary** and **general public perspectives**.

*3)* Grid-based map analysis and modeling involving **Spatial Analysis** and **Spatial Statistics** are in large part simply **spatial extensions of traditional mathematical and statistical** concepts and procedures.

*4)* The recognition by the **GIS community that quantitative analysis of maps is a reality** and the recognition by the **STEM community that spatial relationships exist and are quantifiable** should be the glue that binds the two perspectives– a common coherent and comprehensive *Spatial*STEM approach.

"…**map-*ematics* → quantitative analysis of mapped data**" ***— not your grandfather's map, nor his math/stat***

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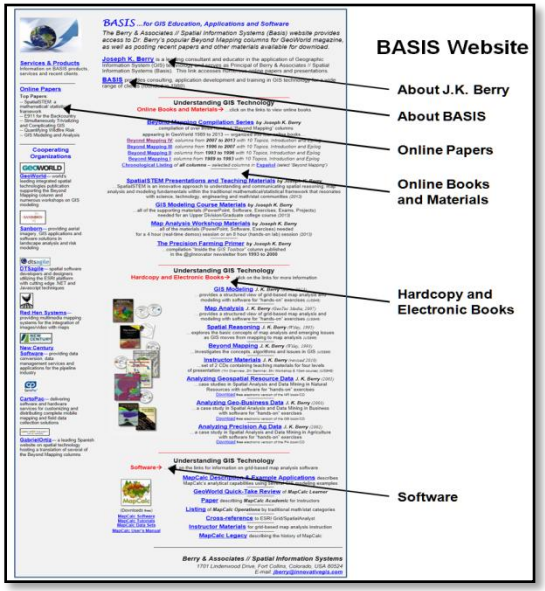
**Online Materials (www.innovativegis.com/Basis/Courses/SpatialSTEM/)**


**Website(www.innovativegis.com/)**



# Additional Information *(live links by slide #)*

*Slide 1,* **Title** – a URL link to more information on SpatialSTEM approach is posted online at—

**www.innovativegis.com/Basis/Courses/SpatialSTEM/**

The following links are to the online book Beyond Mapping III posted at **www.innovativegis.com**

– *Slide 2,* **Geotechnology –** Overview of Spatial Analysis and Statistics; Is it Soup Yet? ; What's in a Name? ; Melding the Minds of the "-ists" and "-ologists"

– *Slide 3,* **Is GIS Technology Ahead of Science? –** Making a Case for SpatialSTEM; A Multifaceted GIS Community; GIS Education's Need for "Hitchhikers"; Questioning GIS in Higher Education

– *Slide 4*, **Grid-based Mapped Data (Matrix of Map Values) –** Organizing Geographic Space for Effective Analysis; To Boldly Go Where No Map Has Gone Before; Beware the Slippery Surfaces of GIS Modeling ; Explore Data Space; The Universal Key for Unlocking GIS's Full Potential; Thinking Outside the Box

– *Slide* 5 **A Mathematical Structure for Map Analysis/Modeling –** Moving Mapping to Map Analysis; Use Map-ematical Framework for GIS Modeling; Getting the Numbers Right

– *Slide 6*, **Spatial Analysis Operations (Geographic Context)** – Simultaneously Trivializing and Complicating GIS; SpatialSTEM Has Deep Mathematical Roots; Understanding Grid-based Data; Suitability Modeling

– *Slide 7*, **Spatial Analysis Operations (Math Examples) –** Map-ematically Messing with Mapped Data; Characterizing Micro-terrain Features; Reclassifying and Overlaying Maps ; Use Map-*ematical* Framework for GIS Modeling

– *Slide 8*, **Spatial Analysis Operations (Distance Examples) –** Bending Our Understanding of Distance; Calculating Effective Distance and Connectivity; E911 for the Backcountry; Routing and Optimal Paths; Deriving and Using Travel-Time Maps; Applying Surface Analysis; Deriving and Using Visual Exposure Maps; Creating Variable-Width Buffers

– *Slide 9*, **Spatial Statistics Operations (Numeric Context) –** Infusing Spatial Character into Statistics; Paint by Numbers Outside the Traditional Statistics Box; Use Spatial Statistics to Map Abnormal Averages

– *Slide 10*, **Spatial Statistics Operations (Linking Data Space with Geographic Space) –** Spatial Interpolation Procedures and Assessment; Linking Data Space and Geographic Space; Babies and Bath Water; Making Space for Mapped Data

– *Slide 11*, **Spatial Statistics Operations (Data Mining Examples) –** Characterizing Patterns and Relationships; Analyzing Map Similarity and Zoning; Discover the "Miracle" in Mapping Data Clusters

– *Slide 12*, **Spatial Statistics Operations (Data Mining Examples) –** Spatially Evaluating the T-test; Depending on Where is What; Recasting Map Analysis Operations

– *Slide 13*, **Techniques for Assessing Multi-layered Data–** Finding Common Ground in Paper and Digital Worlds; Maps Are Numbers First, Pictures Later; Multiple Methods Help Organize Raster Data; VtoR and Back! (Pronounced "V-tore")

– *Slide 14*, **Techniques for Assessing Multi-layered Data–** Finding Common Ground in Paper and Digital Worlds; Maps Are Numbers First, Pictures Later; Multiple Methods Help Organize Raster Data; VtoR and Back! (Pronounced "V-tore")

– *Slide 15*, **So What's the Point? –** Is GIS Technology Ahead of Science?; GIS Evolution and Future Trends; Spatial Modeling in Natural Resources; Lumpers and Splitters Propel GIS; The Softer Side of GIS