Recasting Map Analysis Operations for General Consumption

(GeoWorld, February 2013; www.innovativegis.com/basis/BeyondMappingSeries/Beyondmapping_IV/Topic9/FurtherReading9.htm#Section4)

Earlier discussions have suggested that there is "*a fundamental mathematical structure underlying grid-based map analysis and modeling that aligns with traditional non-spatial quantitative data analysis*" (see Author's Note 1). This conceptual framework provides a common foothold for understanding, communicating and teaching basic concepts, procedures and considerations in spatial reasoning and analysis resonating with both GIS and non-GIS communities—a **SpatialSTEM** schema—that can be applied to any grid-based map analysis system (see Author's Note 2).

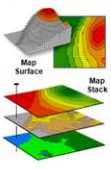
Spatial Analyst has 170 Tools in 22 **Toolsets** for supporting spatial analysis and modeling

Toolset	Description	Toolset	Description
Conditional	Controls the output values based on the conditions placed on the input values as either queries on the attributes or a condition based on the position	Math Bitwise	Computes the binary representation of the input values
Density	Calculates the density of input features within a neighborhood around each output raster cell	Math Logical	Evaluates the values of the inputs and determines the output values based on Boolean logic
Distance	Calculates distance, paths and corridors as Euclidean (straight-line) or cost-weighted distance	Math Trigonometric	Performs various trigonometric calculations on the values in an input raster layer
Extraction	Extracts a subset of cells from a raster layer by either the cells' attributes or their spatial location	Multivariate	Analyzes relationships among many raster layers through Classification (both Supervised and Unsupervised) and Principal Component Analysis (PCA)
Generalization	Cleans up or generalizes the data in a raster layer for a more general analysis	Neighborhood	Creates output values for each cell location based on the location value and the values identified in a specified neighborhood
Groundwater	Performs rudimentary advection-dispersion modeling of constituents in groundwater flow	Overlay	Applies weights to several input raster layers and combines them into a single output layer
Hydrology	Models the flow of water across a surface	Raster Creation	Generates new raster layers in which the output values are based on a constant or a statistical distribution
Interpolation	Creates a continuous (or prediction) surface from sampled point values	Reclass	Provides a variety of methods for reclassifying or changing input cell values to alternative values
Local	Creates a value at each cell location based on the values from a set of input raster layers at that same location (point-by-point)	Solar Radiation	Maps and analyzes the effects of the sun over a terrain surface for specific time periods
Map Algebra	Performs spatial analysis by creating expressions in algebraic form (equations)	Surface	Quantifies and visualizes terrain landform configuration
Math General	Applies a basic or advanced mathematical function to an input raster layer	Zonal	Output is a result of computations performed on all cells that belong to each input zone (region)

…all of the 117 analytical tools can be reorganized into traditional math/stat groupings

Mathematical Perspective:

- **Basic GridMath & Map Algebra** (+ - * /)
- **Advanced GridMath** (Math, Trig, Logical Functions)
- **Map Calculus** (Spatial Derivative, Spatial Integral)
- **Map Geometry** (Euclidian Proximity, Narrowness, Effective Proximity)
- **Plane Geometry Connectivity** (Optimal Path, Optimal Path Density)
- **Solid Geometry Connectivity** (Viewshed, Visual Exposure)
- **Unique Map Analytics** (Contiguity, Size/Shape/Integrity, Masking, Profile)



Statistical Perspective:

- **Basic Descriptive Statistics** (Min, Max, Median, Mean, StDev)
- **Basic Classification** (Reclassify, Contour, Normalize)
- **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)

Figure 1. Grid-based map analysis operations in any GIS system, such as Spatial Analyst, can be reorganized into commonly understood classes of traditional quantitative data analysis.

For example, the top portion of figure 1 identifies the 22 map analysis "toolsets" containing over 170 individual "tools" in the *Spatial Analyst* module (ArcGIS by Esri). The organization of the classes of operations involves a mixture of—

- Traditional math/stat procedures (*Conditional, Map Algebra, Math General, Math Bitwise, Math Logical, Math Trigonometric, Multivariate, Reclass*);
- Extensions of traditional math/stat procedures (*Distance, Interpolation, Surface*);
- Unique map analysis procedures (*Density, Local, Neighborhood, Overlay, Zonal*);
- Application-specific procedures (*Groundwater, Hydrology, Solar Radiation*); and
- Housekeeping tasks (*Extraction, Generalization, Raster Creation*).

In large part, this toolset structuring is the result of the module's development over-time responding to "business case" demands by clients instead of a comprehensive conceptual organization. In contrast, Tomlin's "Local, Focal, Zonal and Global" classes characterize the analytical operations on how the input data is obtained for processing, while my early groupings of "Reclassify, Overlay, Distance, Neighbors and Statistical" reflect the characteristics of the mapped data generated by the processing.

However, all three of these GIS-based schemas are foreign and confusing to the vast majority of potential map analysis users (all STEM disciplines) as they do not align with their traditional quantitative data analysis experiences. This conceptual disconnect keeps GIS on the sidelines of the much larger quantitative analysis community and reinforces the idea that GIS is a "technical tool" (mapping and geoquery) not a full-fledged "analytical tool" (spatial analysis and statistics).

The bottom portion of figure 1 identifies the two broad categories of traditional data analysis—Mathematics and Statistics—broken into seven major groupings that resonate with non-GIS communities. All of Spatial Analysts' 117 analytical operations (the other 53 are "reporting/housekeeping") can be reorganized into the commonly recognized quantitative analysis categories.

Figures 2 and 3 at the end of this section show my initial attempts at the reorganization (see Author's Note 3).

The bottom line is that the SpatialSTEM framework recasts map analysis concepts and procedures into a more generally understood organization. Within this general schema, map analysis is recognized as a set of natural extensions to familiar non-spatial math/stat operations. For example—

- A high school **math teacher** might follow a discussion of the Pythagorean Theorem with "…but what if there is an impassible barrier between the two points? The distance is no longer a straight line but some sort of a 'bendy-twisty' route around the barrier. How would you calculate the not-necessarily-straight distance? The 'Splash Algorithm' does that by…" (you know the rest of the story).
- Or a **statistics instructor** might follow a lecture on the derivation of the Standard Normal Curve for characterizing the 'numerical distribution' of a data set with "…but what about the 'spatial distribution' of the data? Is data always uniform or randomly distributed in geographic space?

How could you characterize/visualize the spatial distribution? 'Spatial Interpolation' does that by…" (you know the rest of the story).

- Or an **environmental science teacher** might follow a lecture on the use of riparian buffers with "…but are all 'buffer-feet the same'? What about the slope of the surrounding terrain? …and the type of soil? …and the density of vegetation? Wouldn't an area along a stream that is steep with an unstable soil and minimal vegetation require a much larger setback than an area that is flat with stable soils and dense vegetation? How could you create a variable-width buffer around streams that considers the intervening erosion conditions? A simple 'sediment loading model does that by…" (you know the rest of the story).
- Or a **crop scientist** who historically calculated the increase (decrease) in yield over a previous year for a new genetic variety as the percent change in the total "weigh-wagon" records for an entire trial field. But with GPS-enabled yield maps that automatically collect on-the-fly yield measurements as a harvester moves through a field, a detailed map of the percent change can be generated by spatially evaluating the standard algebraic equation by… (you know the rest of the story).
- Or a **sales manager** can use 'address geo-coding' to sprinkle sales data onto a grid map and then compute 'roving window' totals to generate a sales density surface showing where sales are high (or low) throughout each of several sales territories. The map analysis can be extended to calculate areas of unusually high (or low) sales by identifying locations that are more than one standard deviation above (or below) the average sales density… (you know the rest of the story).

Dovetailing map analysis with traditional quantitative analysis thinking moves GIS from a "specialty discipline down the hall and to the right" for mapping and geoquery, to an integrated and active role in the spatial reasoning needed by tomorrow's scientists, technologists, decision-makers and other professionals in solving increasing complex and knurly real-world problems. From this perspective, "thinking with maps" becomes a true fabric of society thus fulfilling GIS's mega-technology promise.

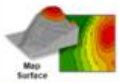
…the two listings at the end of this paper cross-reference Spatial Analysis tools in ArcGIS software by Esri to commonly recognized quantitative math/stat analysis categories.

For more in depth discussion of the grid-based map analysis and modeling framework supporting SpatialSTEM, see—

Topic 9 – Math/Stat Framework for Map Analysis
in book IV of the Beyond Mapping Compilation Series posted at…

http://www.innovativegis.com/basis/BeyondMappingSeries/Beyondmapping_IV/

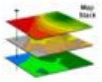
***Author's Notes**: 1) see the Chronological Listing of Beyond Mapping columns posted at www.innovativegis.com/basis/MapAnalysis/ChronList/ChronologicalListing.htm; 2) for numerous links to papers, PowerPoint slide sets and other materials describing the SpatialSTEM framework, see www.innovativegis.com/Basis/Courses/SpatialSTEM/; 3) at the same SpatialSTEM posting, see the white paper entitled "Math/Stat Classification of Spatial Analysis and Spatial Statistics Tools (Spatial Analyst by Esri)" more detailed description of the recasting of Spatial Analyst's operations by traditional non-spatial mathematics and statistics categories.*



Spatial Analysis Operations — Mathematical Perspective

Raster-based Map Analysis and Modeling Operations

*...for Esri **Spatial Analyst** Software*



Mathematical Concepts	Spatial Analyst Toolsets and Tools
Basic GridMath & Map Algebra *(+ - * /):*	
General Math Toolset, *Basic Arithmetic tools:*	Plus, Minus, Times, Divide
General Math Toolset, *Power tools:*	Square, Square Root, Power
Map Algebra Toolset:	Raster Calculator
Advanced GridMath *(Math, Trig, Logical Functions):*	
General Math Toolset, *Conversion tools:*	Abs, Negate, Float, Int, Round Down, Round Up, Mod
General Math Toolset, *Exponential and Logarithmic tools:*	Exp, Exp2, Exp10, Ln, Log2, Log10
Trigonometric Math Toolset:	Cos, Sin, Tan, ACos, ASin, ATan, ATan2, CosH, SinH, TanH, ACosH, ASinH, ATanH
Logical Math Toolset, *Relational tools:*	Equal To, Not Equal, Greater Than, Greater Than Equal, Less Than, Less Than Equal
Logical Math Toolset, *Boolean tools:*	Boolean And, Boolean Or, Boolean Xor, Boolean Not
Logical Math Toolset, *Combinatorial tools:*	Combinatorial And, Combinatorial Or, Combinatorial XOr
Logical Math Toolset, *Logical tools:*	Diff, InList, Is Null, Over, Test
Conditional Toolset:	Con
Bitwise Toolset:	Bitwise XOr, And, Or, Bitwise Not
Map Calculus *(Spatial Derivative, Spatial Integral):*	
Surface Toolset, *Surface Configuration tools:*	Slope, Aspect, Curvature
Zonal Toolset, *Zonal Statistics tools:*	Zonal Statistics
Map Geometry *(Euclidian Proximity, Effective Proximity):*	
Distance Toolset, *Euclidean Distance tools:*	Euclidean Distance, Euclidean Direction, Euclidean Allocation
Distance Toolset, *Effective Distance tools:*	Cost Distance, Cost Allocation, Cost Back Link
Plane Geometry Connectivity *(Optimal Path, Optimal Path Density, Surface Configuration):*	
Distance Toolset, *Effective Distance tools:*	Cost Path, Path Distance, Corridor, Path Distance, Path Distance Allocation, Back Link
Hydrology Toolset, *Flow Density tools:*	Flow Accumulation
Hydrology Toolset, *Surface Configuration tools:*	Flow Length, Flow Direction, Sink, Fill, Watershed, Basin, Focal Flow
Solid Geometry Connectivity *(Visual Exposure):*	
Surface Toolset, *Visual Connectivity tools:*	Viewshed, Observer Points
Unique Map Analytics *(Reclassify, Contiguity, Shape):*	
Reclass Toolset, *Reclassification tools:*	Reclass, Slice
Local Toolset, *Combinatorial tool:*	Combine
Generalization Toolset, *Contiguity tool:*	Region Group, Nibble, Majority Filter
Surface Toolset, *Surface Configuration tool:*	Cut Fill
Zonal Toolset, *Zonal Geometry:*	Zonal Geometry

Figure 2. Reorganization of Spatial Analyst's analytical "tools" into traditional mathematical categories.

Spatial Statistics Operations — Statistical Perspective

Raster-based Map Analysis and Modeling Operations

...for Esri ***Spatial Analyst Software***

Statistical Concepts	Spatial Analyst Toolsets and Tools
Basic Descriptive Statistics *(Min, Max, Median, Mean, StDev, etc.)*	
Local Toolset, ***Cell Statistics tools:*** Cell Statistics	
Local Toolset, ***Frequency tools:*** Equal To Frequency, Greater Than Frequency, Less than Frequency	
Local Toolset, ***Ranking tools:*** Rank, Lowest Position, Highest Position, Popularity	
Overlay Toolset: Weighted Overlay, Weighted Sum	
Basic Classification *(Reclassify, Contour, Normalization):*	
Reclass Toolset, ***Reclassification tools:*** Reclass, Slice	
General Math Toolset, ***Basic Arithmetic tools:*** Plus, Minus, Times, Divide	
Map Comparison *(Joint Coincidence, Difference):*	
Local Toolset, ***Combinatorial tool:*** Combine	
General Math Toolset, ***Basic Arithmetic tools:*** Plus, Minus, Times, Divide	
Unique Map Statistics *(Zonal, Roving Window, Block Summaries):*	
Zonal Toolset, ***Zonal Statistics tools:*** Zonal Statistics	
Neighborhood Toolset, ***Focal (roving window) tools:*** Focal Statistics, Filter	
Neighborhood Toolset, ***Block tool:*** Block Statistics	
Raster Creation Toolset: Create Constant Raster, Create Normal Raster, Create Random Raster	
Surface Modeling *(Density Analysis, Spatial Interpolation, Trend):*	
Neighborhood Toolset, ***Focal (roving window) tool:*** Focal Statistics (sum)	
Interpolation Toolset: IDW, Kriging, Spline, Spline with Barriers, Natural Neighbor, Trend	
Advanced Classification *(Maximum Likelihood, Clustering):*	
Multivariate Toolset, ***Classification tools:*** Maximum Likelihood Classification, Iso Cluster Unsupervised Classification	
Correlation and Regression: *no direct tools in Spatial Analyst (dropped from AML Grid module; in Spatial Statistics toolbox)*	
Multivariate Toolset, ***Classification tools:*** Maximum Likelihood Classification, Iso Cluster Unsupervised Classification	
Correlation and Regression: *no direct tools (dropped from earlier AML Grid module)*	

Figure 3. Reorganization of Spatial Analyst's analytical "tools" into traditional statistical categories.