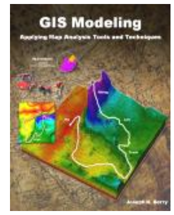
Beyond Mapping IV

Topic 2 – Extending Effective Distance Procedures



GIS Modeling book

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Advancing the Concept of Effective Distance

(GeoWorld, February 2011)

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The previous section described several advanced distance procedures. This and the next section expand on those discussions by describing the algorithms used in implementing the advanced grid-based techniques.

The top portion of figure 1 shows the base maps and procedure used in deriving Static Effective Distance. The “Starter” map identifies the locations from which distance will be measured, and their row, column coordinates are entered into a data stack for processing. The “Friction,” or discrete cost map, notes conditions that impede movement within a project area—“absolute” barriers prohibit, while “relative” barriers restrict movement.

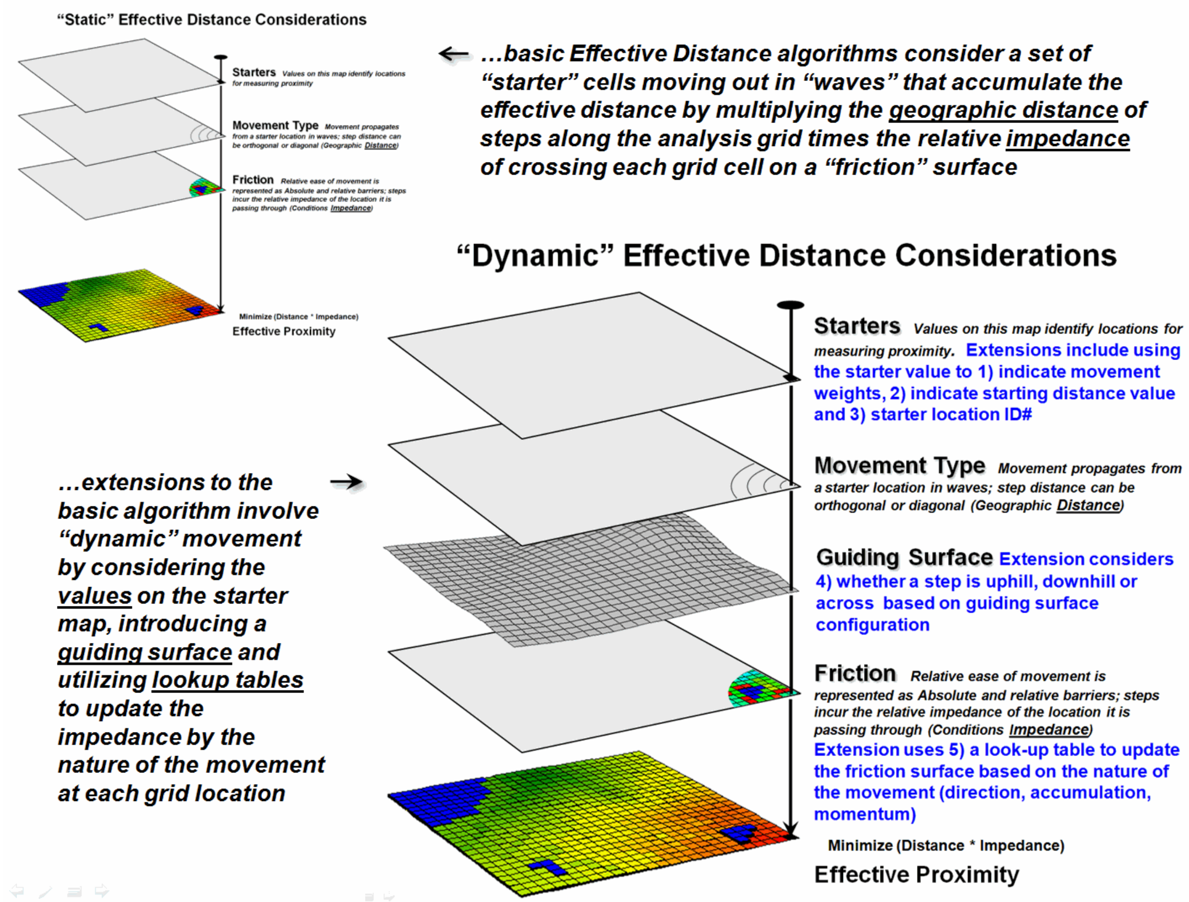

Figure 1. The five most common Dynamic Effective Distance extensions to traditional "cost distance" calculations.

Briefly stated, the basic algorithm pops a location off the Starter stack, then notes the nature of the geographic movement to adjacent cells— orthogonal= 1.000 and diagonal= 1.414. It then checks the impedance/cost for moving into each of the surrounding cells. If an absolute barrier exists, the effective distance for that location is set to infinity. Otherwise, the geographic movement type is multiplied by the impedance/cost on the friction map to calculate the accumulated cost. The procedure is repeated as the movement "wave" continues to propagate like tossing a rock into a still pond. If a location can be accessed by a shorter wave-front path from the Starter cell, or from a different Starter cell, the minimum effective distance is retained.

The "*minimize (distance * impedance)*" wave propagation repeats until the Starter stack is exhausted. The result is a map surface of the accumulated cost to access anywhere within a project area from its closest Starter location. The solution is expressed in friction/cost units (e.g., minutes are used to derive a travel-time map).

The bottom portion of figure 1 identifies the additional considerations involved in extending the algorithm for Dynamic Effective Distance. Three of the advanced techniques involve special handling of the values associated with the Starter locations—1) weighted distance, 2) stepped accumulation and 3) back-link to closest Starter location. Other extensions utilize 4) a guiding surface to direct movement and 5) look-up tables to update relative impedance based on the nature of the movement.

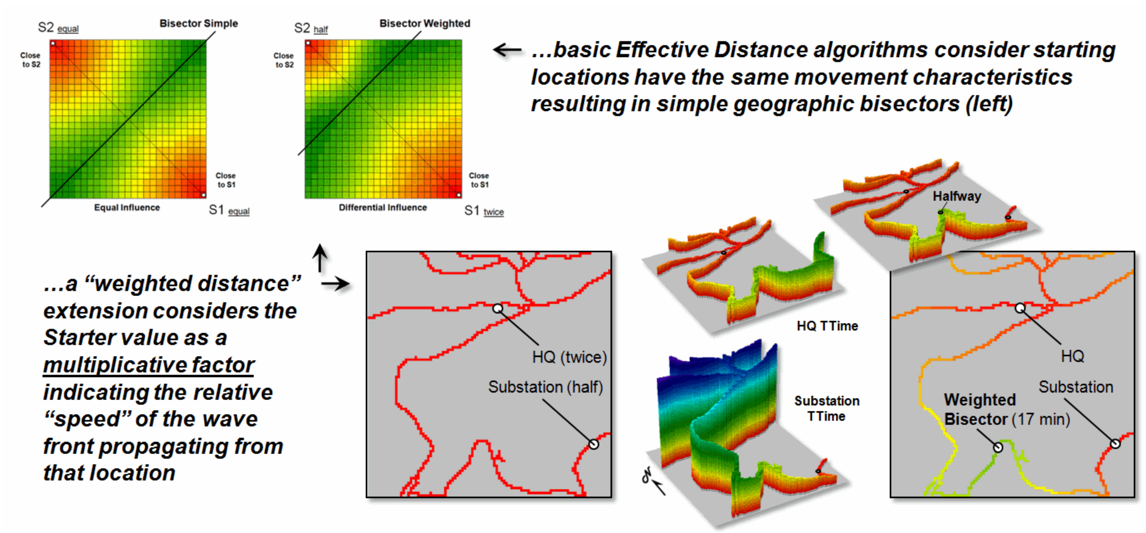

Figure 2. Weighted distance takes into account differences in the relative movement (e.g., speeds) away from different Starter locations.

Figure 2 shows the results of "weighted distance" that considers differences in *movement characteristics*. Most distance algorithms assume that the character of movement is the same for all Starter locations and that the solution space between two Starter locations will be a true halfway point (perpendicular bisector). For example, if there were two helicopters flying toward each other, where one is twice as fast as the other, the "effective halfway" meeting is shifted to an off-center, weighted bisector (upper left). Similarly, two emergency vehicles traveling at different speeds will not meet at the geographic midpoint along a road network (lower right).

Weighted distance is fairly easy to implement. When a Starter location is popped off the stack, its value is used to set an additional weighting factor in the effective distance algorithm—*minimize ((distance * impedance) * <u>Starter weight</u>)*. The weight stays in effect throughout a Starter location's evaluation and then updated for the next Starter location.

Figure 3 shows the results of "stepped accumulation" distance that considers a series of sequenced *movement steps* (see Author's Note). In the example, on-road travel-time is first calculated along the road network from the headquarters Starter location with off-road travel treated as an absolute barrier. The next step assumes starting anywhere along the roads and proceeding off-road by ATV with relative barriers determined by terrain steepness and absolute barriers set to locations exceeding ATV operating limits (<40% slope). The final step propagates the distance wave into the very steep areas assuming hiking travel.

Stepped distance is a bit more complicated to implement. It involves a series of calls to the effective distance algorithm with the sequenced Starter maps values used to set the accumulation distance counter— *minimize [Starter value + (distance * impedance)]*. The Starter value for the first call to calculate effective distance by truck from the headquarters is set to one (or a slightly larger value to indicate "scramble time" to get to the truck). As the wave front propagates each road location is assigned a travel-time value.

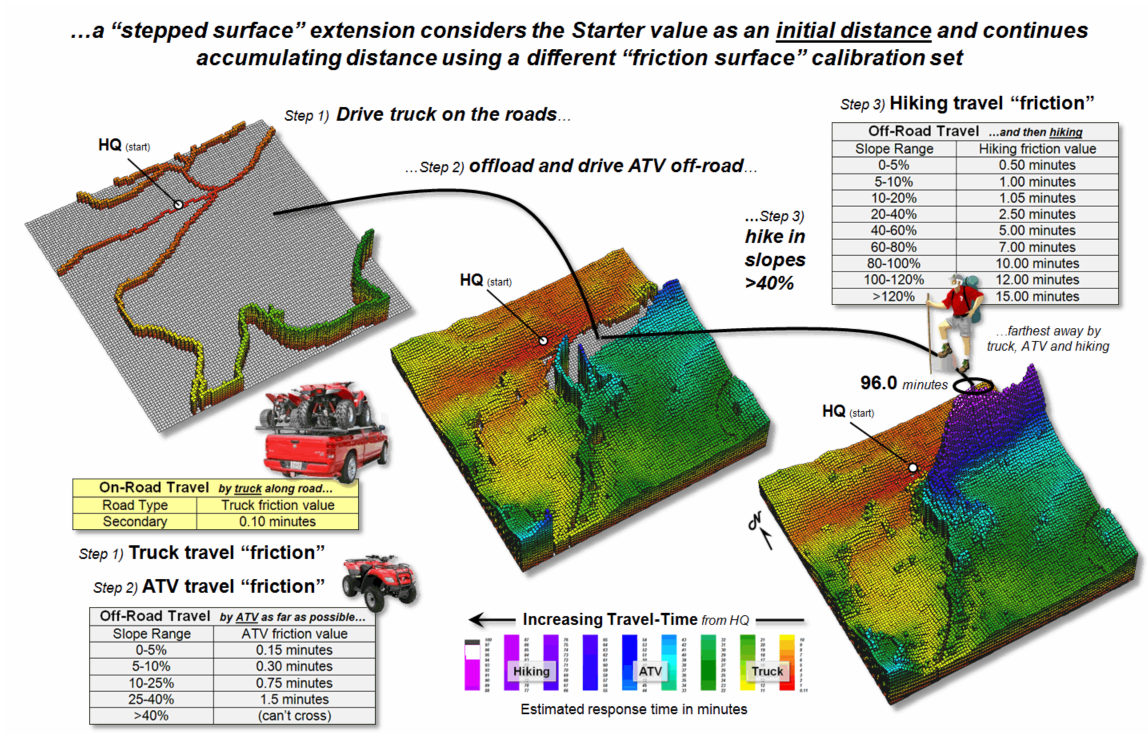

Figure 3. A stepped accumulation surface changes the relative/absolute barriers calibrations for different modes of travel.

The second stage uses the accumulated travel-time at each road location to begin off-road ATV movement. In essence the algorithm picks up the wave propagation where it left off and a different friction map is utilized to reflect the relative and absolute barriers associated with ATV travel. Similarly, the third step picks up where ATV travel left off and distance wave continues into the very steep slopes using the hiking friction map calibrations. The final result is a complete travel-time surface identifying the minimum time to reach any grid location assuming the best mix of truck, ATV and hiking movement.

A third way that Starter value can be used is as an ID number to identify the Starter location with the minimum travel-time. In this extension, as the wave front propagates the unique Starter ID is assigned to the corresponding grid cell for every location that "beats" (minimizes) all of the preceding paths that have been evaluated. The result is a new map that identifies the effectively closest Starter location to any accessible grid location within a project area. This new map is commonly referred to a "*back-link*" map.

In summary, the value on the Starter map can be used to model weighted effective distance, stepped movement and back-linked to the closest starting location. The next section considers the introduction of a *guiding surface* to direct movement and use of look-up tables to change the friction "on-the-fly" based on the *nature of the movement* (direction, accumulation and momentum).

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Author's Note: *For more information on backcountry emergency response, see Topic 8, GIS Modeling in Natural Resources.*

A Dynamic Tune-up for Distance Calculations

(GeoWorld, March 2011)

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Last section described three ways that a "Starter value" can be used to extend traditional effective distance calculations—by indicating movement weights (*gravity model*), indicating a starting/continuing distance value (*stepped-accumulation*) and starter ID# for identifying which starter location is the closest (*back-link*). All three of these extensions dealt with differences in the nature of the movement itself as it emanates from a location.

The other two extensions for dynamic effective distance involve differences in the nature of the intervening conditions—*guiding surface* redirection and *dynamic impedance* based on accumulation, momentum and direction. Figure 1 identifies a "guiding surface" responding to whether a movement step is uphill, downhill or across based on the surface's configuration.

Inset a) on the left-side of the figure shows a constrained proximity surface that identifies locations that are up to 200 meters "downhill" from roads. The result forms a "variable-width buffer" around the roads that excludes uphill locations. The downhill locations within the buffer are assigned proximity values indicating how close each location is to the nearest road cell above it. Also note that the buffer is "clipped" by the ocean so only on-island buffer distances are shown.

Inset b) uses a different kind of guiding surface— a tilted plane characterizing current flow from the southwest. In this case, downhill movement corresponds to "down-current" flows from the two adjacent watersheds. While a simple tilted plane ignores the subtle twists and turns caused by winds and bathometry differences, it serves as a first order current movement characterization.

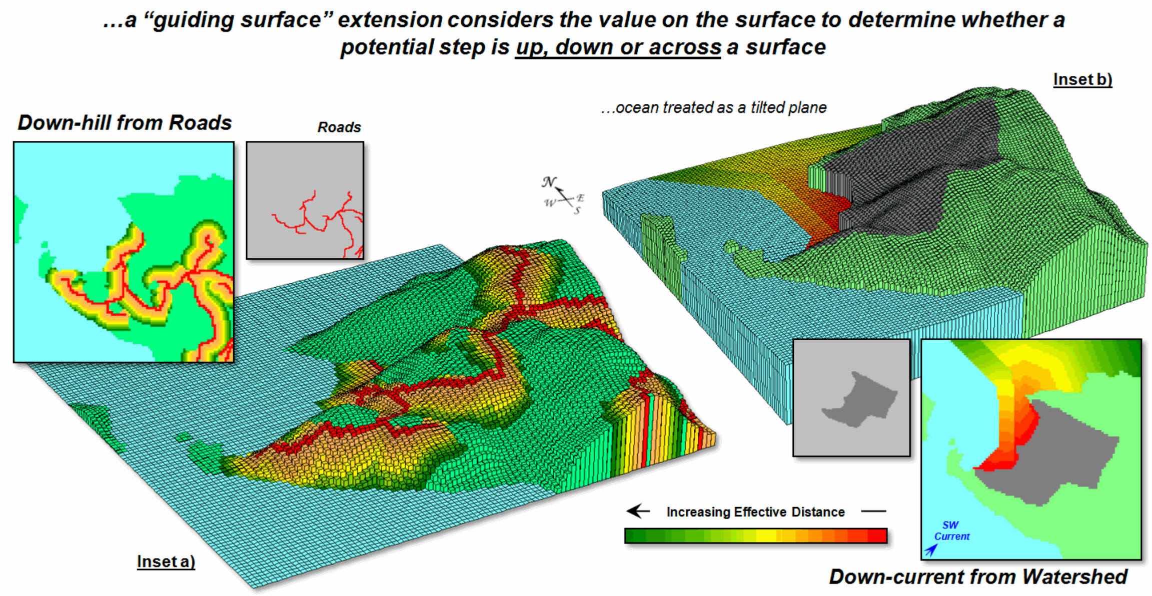


Figure 1. A Guiding Surface can be used to direct or constrain movement within a project area.

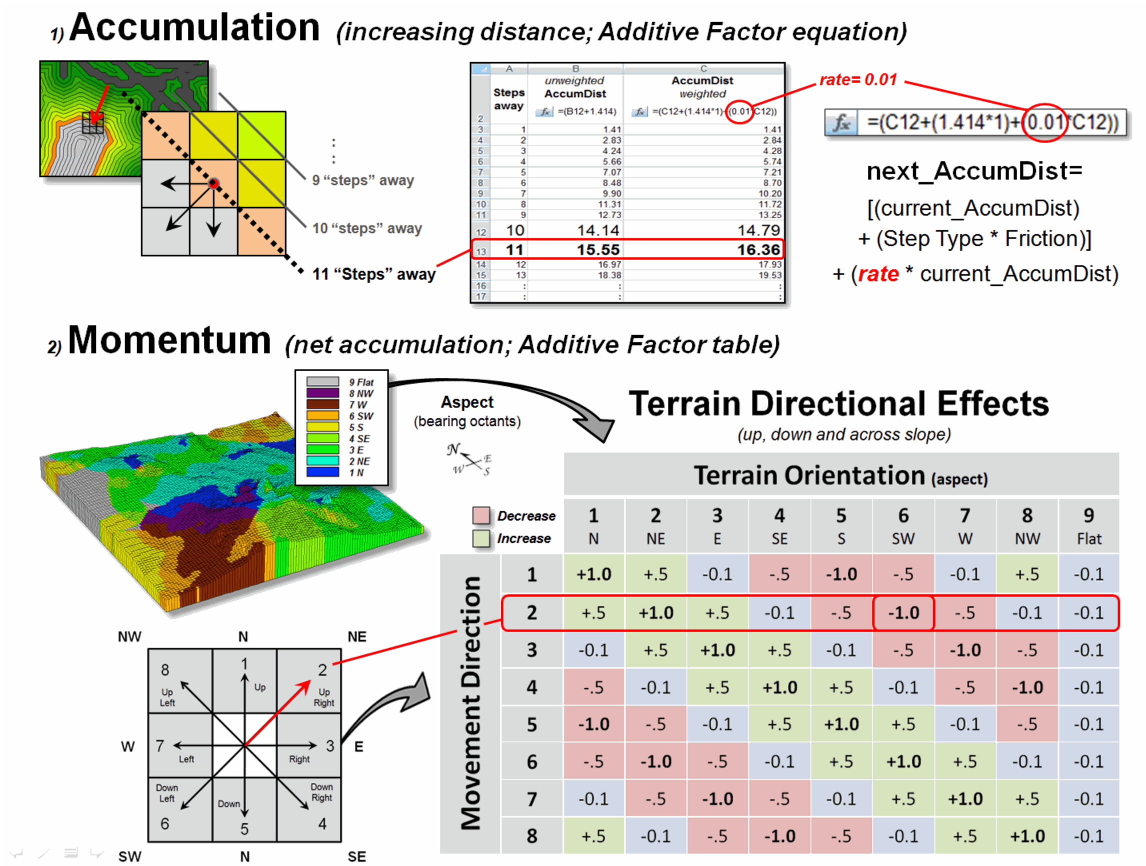
A similar, yet more detailed guiding surface, is a barometric map derived from weather station data. A "down-wind" map tracks the down surface (barometric gradient) movement from each project location to areas of lower atmospheric pressure. Similarly, "up-surface" movement from any location on a pollution concentration surface can help identify the probable pathway flow from a pollution source (highest concentration).

"Dynamic impedance" involves changes with respect to increasing distance (accumulation), net movement force (momentum) and interactions between a movement path and its intervening conditions (direction). The top portion of figure 2 outlines the use of an "additive factor equation" to dynamically slow down movement in a manner analogous to compound interest of a savings account. As a distance wave propagates from a Starting location, the effective distance of each successive step is slightly more impeded, like a tired hiker's pace decreasing with increasing distance—the last mile of a 20 mile trek seems a lot farther.

The example shows the calculations for the 11^{th} step of a SW moving wave front (orthogonal step type= 1.414) with a constant impedance (friction= 1) and a 1% compounding impedance (rate= .01). The result is an accumulated hindrance effectively farther by about 25 meters (16.36

– 15.55=.81 * 30m cell size).

The bottom portion of figure 2 shows the approach for assessing the net accumulation of movement (momentum). This brings back a very old repressed memory of a lab exercise in a math/programming course I attempted over 30 years ago. We were given a terrain-like surface and coefficients of movement (acceleration and deceleration) of a ball under various uphill and downhill situations. Our challenge was to determine the location to drop the ball so it would roll the farthest …the only thing I really got was "dropping the ball." In looking back, I now realize that an "additive factor table" could have been a key to the solution.

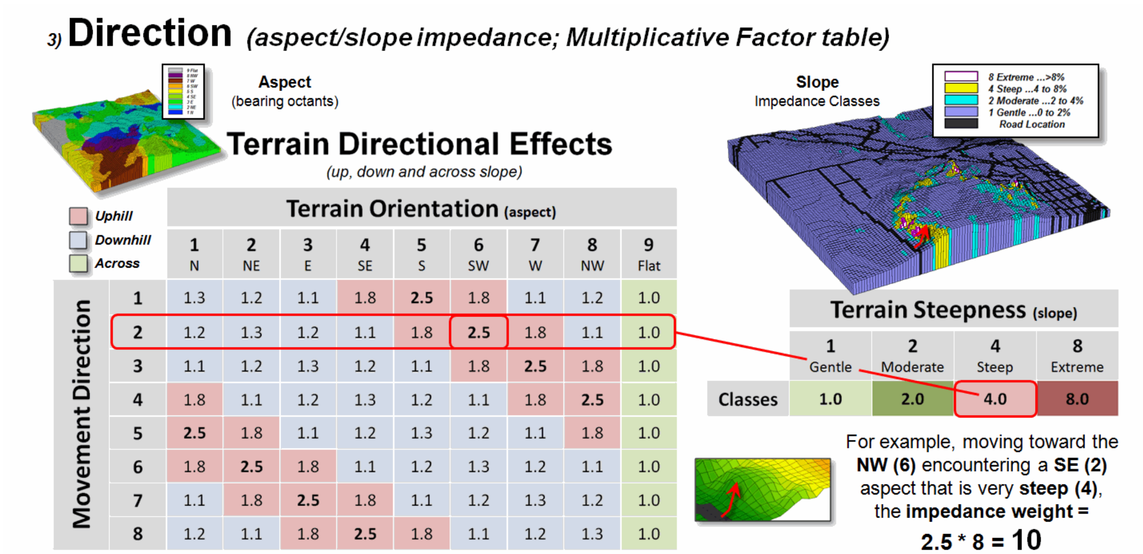


Movement Direction	1 N	2 NE	3 E	4 SE	5 S	6 SW	7 W	8 NW	9 Flat
1	+1.0	+.5	-0.1	-.5	-1.0	-.5	-0.1	+.5	-0.1
2	+.5	+1.0	+.5	-0.1	-.5	-1.0	-.5	-0.1	-0.1
3	-0.1	+.5	+1.0	+.5	-0.1	-.5	-1.0	-.5	-0.1
4	-.5	-0.1	+.5	+1.0	+.5	-0.1	-.5	-1.0	-0.1
5	-1.0	-.5	-0.1	+.5	+1.0	+.5	-0.1	-.5	-0.1
6	-.5	-1.0	-.5	-0.1	+.5	+1.0	+.5	-0.1	-0.1
7	-0.1	-.5	-1.0	-.5	-0.1	+.5	+1.0	+.5	-0.1
8	+.5	-0.1	-.5	-1.0	-.5	-0.1	+.5	+1.0	-0.1

Figure 2. Accumulation and Momentum can be used to account for dynamic changes in the nature of intervening conditions and assumptions about movement in geographic space.

The table in the figure shows the "costs/payments" of downhill, across and uphill movements. For this simplified example, imagine a money exchange booth at each grid location—the toll or payout is dependent on the direction of the wave front with respect to the orientation of the surface. If you started somewhere with a $10 bag of money, depending on your movement path and surface configuration, you would collect a dollar for going straight downhill (+1.0) but lose a dollar for going straight uphill (-1.0).

The table summarizes the cost/payout for all of the movement directions under various terrain conditions. For example, a NE step is highlighted (direction= 2) that corresponds to a SW terrain orientation (aspect= 6) so your movement would be straight uphill and cost you a dollar. The effective net accumulation from a given Starter cell to every other location is the arithmetic sum of costs/payments encountered—the current amount in the bag at location is your net accumulation; stop when your bag is empty ($0). In the real-world, the costs/payments would be coefficients of exacting equations to determine the depletions/additions at each step.



Movement Direction	1 N	2 NE	3 E	4 SE	5 S	6 SW	7 W	8 NW	9 Flat
1	1.3	1.2	1.1	1.8	2.5	1.8	1.1	1.2	1.0
2	1.2	1.3	1.2	1.1	1.8	2.5	1.8	1.1	1.0
3	1.1	1.2	1.3	1.2	1.1	1.8	2.5	1.8	1.0
4	1.8	1.1	1.2	1.3	1.2	1.1	1.8	2.5	1.0
5	2.5	1.8	1.1	1.2	1.3	1.2	1.1	1.8	1.0
6	1.8	2.5	1.8	1.1	1.2	1.3	1.2	1.1	1.0
7	1.1	1.8	2.5	1.8	1.1	1.2	1.3	1.2	1.0
8	1.2	1.1	1.8	2.5	1.8	1.1	1.2	1.3	1.0

	1 Gentle	2 Moderate	4 Steep	8 Extreme
Classes	1.0	2.0	4.0	8.0

Figure 3. Directional effects of movement with respect to slope/aspect variations can be accounted for "on-the-fly."

Figure 3 extends the consideration of dynamic movement through the use of a "multiplicative factor table" based on two criteria—terrain aspect and steepness. All trekkers know that hiking up, down or across slope are radically different endeavors, especially on steep slopes. Most hiking time solutions, however, simply assign a "typical cost" (friction) that assumes "the steeper the terrain, the slower one goes" regardless of the direction of travel. But that is not always true, as it is about as easy to negotiate across a steep slope as it is to traverse a gentle uphill slope.

The table in figure 3 identifies the multiplicative weights for each uphill, downhill or across movement based on terrain aspect. For example, as a wave front considers stepping into a new location it checks its movement direction (NE= 2) and the aspect of the cell (SW= 6), identifies the appropriate multiplicative weight in the table (2,6 position= 2.5), then checks the "typical" steepness impedance (steep= 4.0) and multiplies them together for an overall friction value (2.5*4.0= 10.0); if movement was NE on a gentle slope the overall friction value would be just

1.1.

In effect, moving uphill on steep slopes is considered nearly 10 times more difficult than traversing across a gentle slope …that makes a lot of sense. But very few map analysis packages handle any of the "dynamic movement" considerations (gravity model, stepped-accumulation, back-link, guiding surface and dynamic impedance) …that doesn't make sense.

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Author's Note: *For more information on effective distance procedures, instructors see readings, lecture and exercise for Week 4, "Calculating Effective Distance" online course materials at www.innovativegis.com/basis/Courses/GMcourse10/.*

Contiguity Ties Things Together

(GeoWorld, March 2008)

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One of the most interesting, yet often overlooked operations involves "clumping" map features—more formally termed *Contiguity*, the state of being in contact or close proximity. Our brain easily assesses this condition when viewing a map but the process for a computer is a bit more convoluted. For example, consider the two spatial patterns in top portion of figure 1 (inset 1A). While both maps have the same number and size of scattered forest parcels, the distribution pattern on the left appears more dispersed than the relatively clumped pattern on the right.

Since vector-based systems store features as a loose set of discrete entities in a spatial table, the computer is unable to "see" the entire spatial pattern and intervening geographic space. Grid-based systems, on the other hand, store an entire project area as an analysis frame including the spaces. Inset 1B represents the individual features as a collection of grid cells. Adjacent grid cells have the same stored value to uniquely identify each of the individual features (1 through 9 in this case). Note that both patterns in the figure have nine distinct grid features—it's the arrangement of the features in geographic space that establishes the Dispersed and Clumped patterns.

Proximity establishes effective connections among distinct features and translates these connections into patterns. For example, assume that a creature isn't constrained to the edges of a single feature, but can move away for a short distance—say one grid space for a slithering salamander outside its confining habitat. Trekking any farther would result in an exhausted and dried-out salamander, akin to a raisin. Now further assume that the venturesome salamander's unit is either too small to support the current population or that he yearns for foreign beauties. The Dispersed pattern will leave him wanting, while the Clumped pattern triples the possibilities.

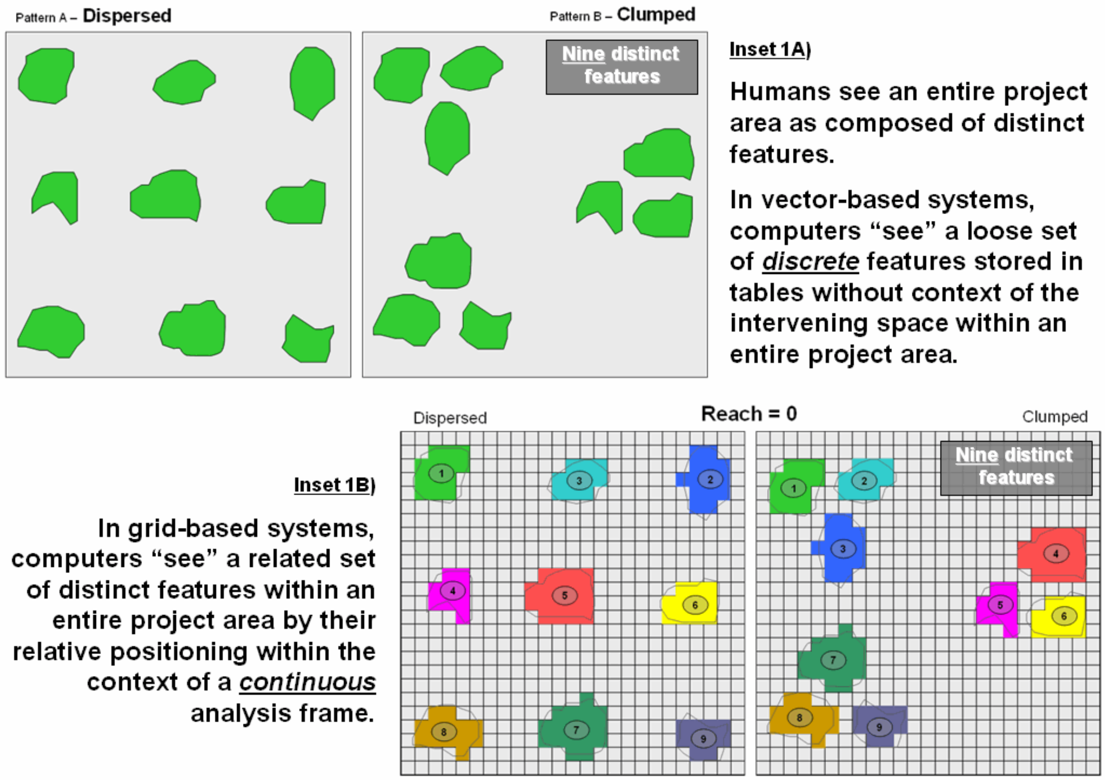

Figure 1. Humans see complete spatial patterns sets, while computers "see" individual features that have to be related through data storage and analysis approaches imposing topological structure.

The top portion of figure 2 (inset 2A) depicts how reaching out one grid space from each of the distinct features can identify effective groupings of individual habitat units. The result is that the nine defacto "islands" are grouped into three effective habitat units in the Clumped pattern. In practice, contiguity can help wildlife planners consider the pattern of habitat management units, as well as simply their number, shape and size. Arrangement can be as important (more?) as quantity and aerial extent.

The lower portion of figure 2 (inset 2b) illustrates a similar analysis assuming a creature that can slither, crawl, scurry or fly up to three grid spaces. The result is three effective habitat groupings—two on the left comprised of six individual units and one on the right comprised of three individual units.

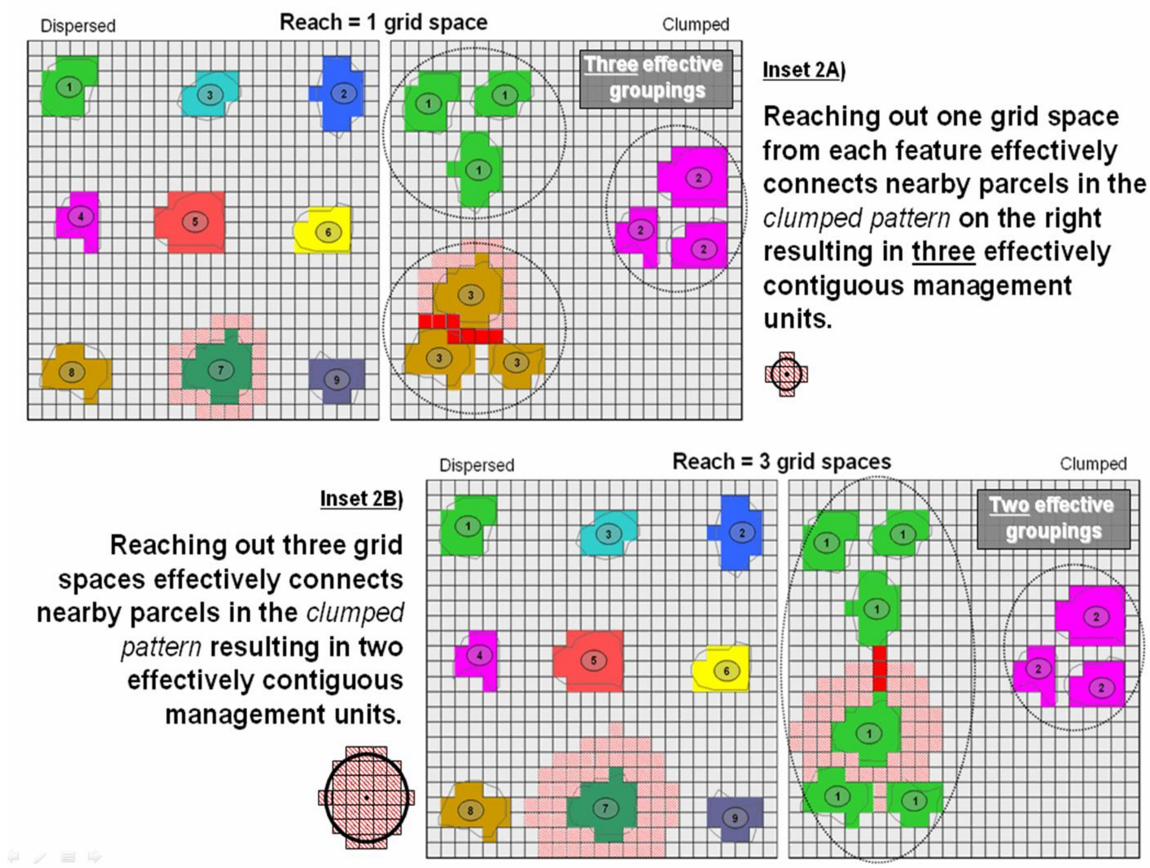

Figure 2. Contiguity uses relative proximity to determine groups of nearby features that serve as extended management units.

Contiguity, therefore, is in the mind of the practitioner—how far of a reach that connects individual features is a user-defined parameter to the spatial analysis operation. However, as is the rule in most things analytical, how the tool works is rarely how we conceptualize the process, or its mathematical expression. Spatial algorithms often are radically different animals from manual procedures or simply evaluating static equations.

The "CLUMP" operation works by employing a moving filter like you read a book but looking back and up at the grid cells previously considered. For the 1-grid space reach example, a 3x5 filter (figure 3) starts in the upper-left corner of the analysis frame and moves across the row from left to right. The first grid cell containing a forest parcel is assigned the value 1. If it encounters another forest cell while an earlier clump is in the filter, the same clump number is assigned—within the specified proximity that establishes effective contiguity. If it encounters a forest cell with no previous clump numbers in the filter, then a new sequential clump number is assigned. Successive rows are evaluated and if the filter contains two or more clump numbers, the lowest clump number is assigned to the entire candidate grouping—merging the sides of any

U-shaped or other upward pointing shape.

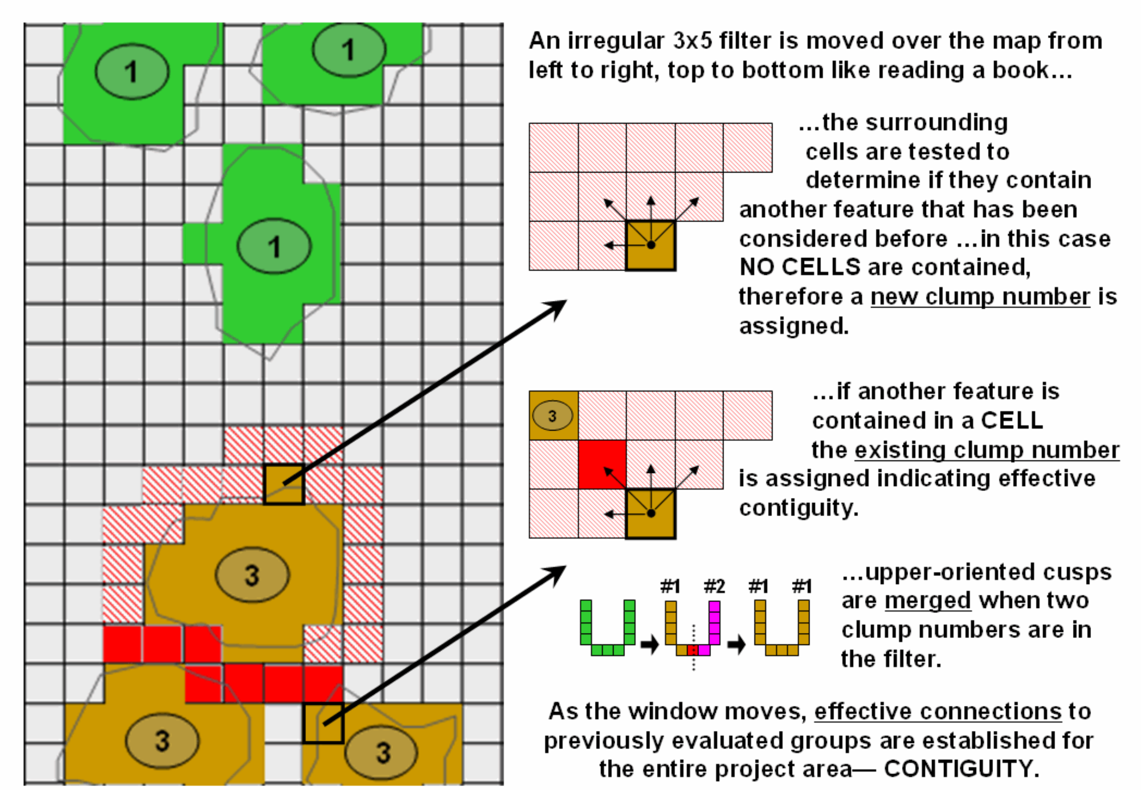

Figure 3. An irregular filter is used to establish effective connections among neighboring features.

While the clumping algorithm involves a "roving window" that that solves for the "effective proximity" of nearby groupings of similar characteristics the operation is usually classified as a Reclassifying operation because its result simply assigns a clump number to neighboring clumps without altering their shape or pattern.

The bottom line isn't that you fully understand contiguity and its GIS analytic expression. Rather the big picture has two main points— 1) that there are a lot of useful map analysis tools in the GIS quiver that aren't part of your paper map experience, and 2) that the algorithms used in these tools require different perspective than traditional conceptual and mathematical approaches. It is a contemporary blend of geography, math and programming skills that move us beyond mapping.

However, it is the blinders of disciplinary stovepipes in companies and on campuses that often hold us back. Hopefully a GIS user community asking the hard questions that can't be answered unilaterally will be the catalyst that transcends the human barriers—sort of intellectual contiguity.

A Narrow-minded Approach

(GeoWorld, June 2009)

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In the previous sections, advanced and sometimes unfamiliar concepts of distance have been discussed. The traditional definition of “shortest straight line between two points” for *Distance* was extended to the concept of *Proximity* by relaxing the “two points” requirement; and then to the concept of *Movement* that respects absolute and relative barriers by relaxing the “straight line” requirement.

The concept of *Connectivity* is the final step in this expansion referring to how locations are connected in geographic space. In the case of effective distance, it identifies the serpentine route around absolute and through relative barriers moving from one location to another by the “shortest” effective path—shortest, the only remaining requirement in the modern definition of distance. A related concept involves straight rays in 3-dimensional space (line-of-sight) to determine visual connectivity among locations considering the intervening terrain and vegetative cover.

However, there is yet another concept of connectivity— *Narrowness* defined as the “shortest cord through a location connecting opposing edges.” As with all distance-related operations, the computer first generates a series of concentric rings of increasing distance from an interior point (grid cell). This information is used to assign distance to all edge locations. Then the computer moves around the edge totaling the distances for opposing edges until it determines the minimum—the shortest cord. The process is repeated for all map locations to derive a continuous map of narrowness.

For a boxer, a map of the boxing ring would have values at every location indicating how far it is to the ropes with the corners being the narrowest (minimum cord distance). Small values indicate poor boxing habitat where one might get trapped and ruthlessly bludgeoned without escape. For a military strategist, narrow locations like the Khyber Pass can prove to be inhospitable habitat as well.

Bambi and Mama Bam can have a similar dread of the narrow portions of an irregularly shaped meadow (see figure 1, insets *a* and *b*). Traditional analysis suggests that the meadow's acreage times the biomass per acre determines the herd size that can be supported. However, the spatial arrangement of these acres might be just as important to survival as the caloric loading calculations. The entire meadow could be sort of a Cordon Bleu of deer fodder with preference for the more open portions, an ample distance away from the narrow forest edge where danger may lurk. But much of the meadow has narrow places where patient puma prowl and pounce, imperiling baby Bambi. How can new age wildlife managers explain that to their kids—survival is just a simple calculation of acres times biomass that is independent of spatial arrangement, right?

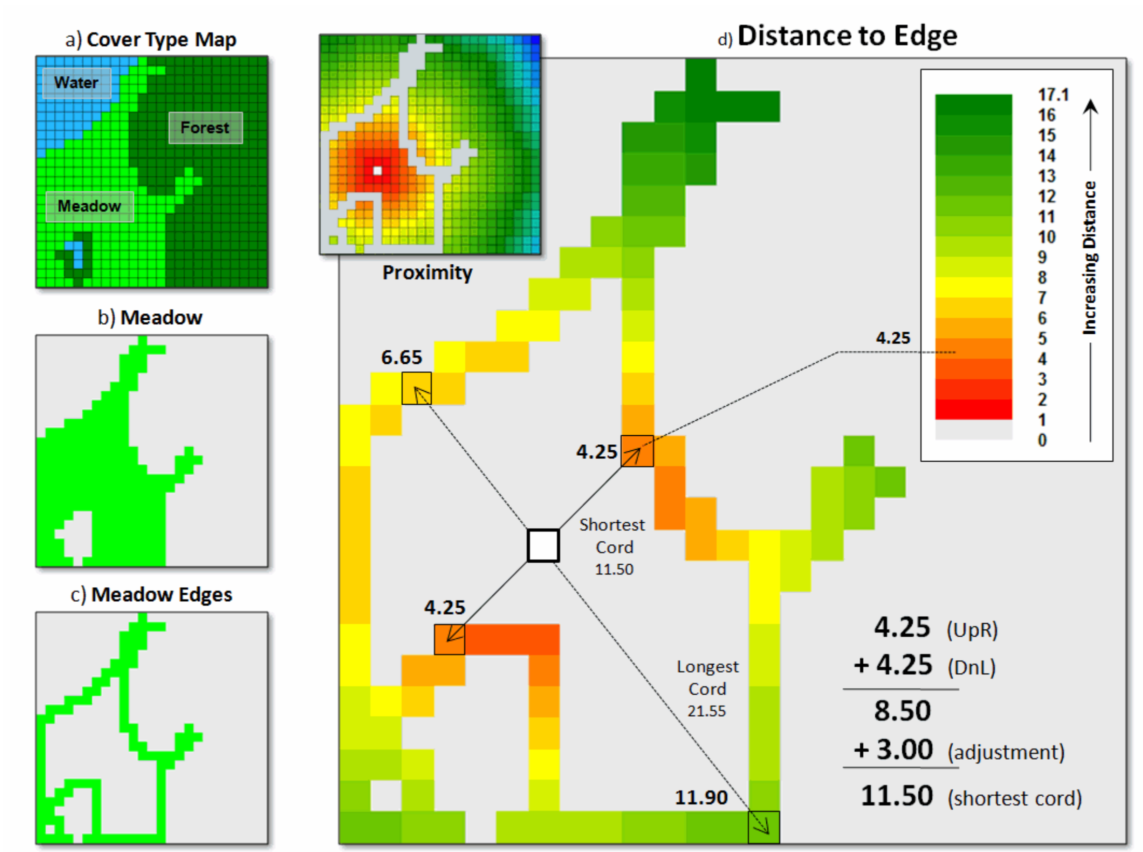

Figure 1. Narrowness determines constrictions within a map feature as the shortest cord connecting opposing edges.

Many GIS applications involve more than simple inventory mastication—extent (spatial table) times characteristic/condition (attribute table). So what is involved in deriving a narrowness map? …how can it be summarized? …how might one use a narrowness map and its summary metrics?

The first step is to establish a simple proximity map from a location and then transfer this information to the edge cells of the parcel containing the location (figure 1, insets *c* and *d*). The algorithm then begins at an edge cell, determines its opposing edge cell along a line passing through the location, sums the distances and applies an adjustment factor to account for the center cell and edge cell lengths. In the example, the shortest cord is the sum of the upper-right distance and its lower-left opposing distance plus the adjustment factor (4.25 + 4.25 + 3.00= 8.50). All other cords passing through the location are longer (e.g., 6.65 + 11.90 + 3.00= 21.55 for the longest cord). Actually, the calculations are a bit dicier as they need to adjust for off-orthogonal configurations …a nuance for the programmers among you to consider.

Once the minimum cord is determined the algorithm stores the value and moves to the next location to evaluate; this is repeated until the narrowness of all of the desired locations have been derived (figure 2 inset *e* for just the meadow and *f* for the entire area). Notice that there are two dominant kidney-shaped open areas (green tones)—one in the meadow and one in the forest. Keep in mind that the effect of the "artificial edges" of the map extent in this constrained example would be minimal in a landscape level application.

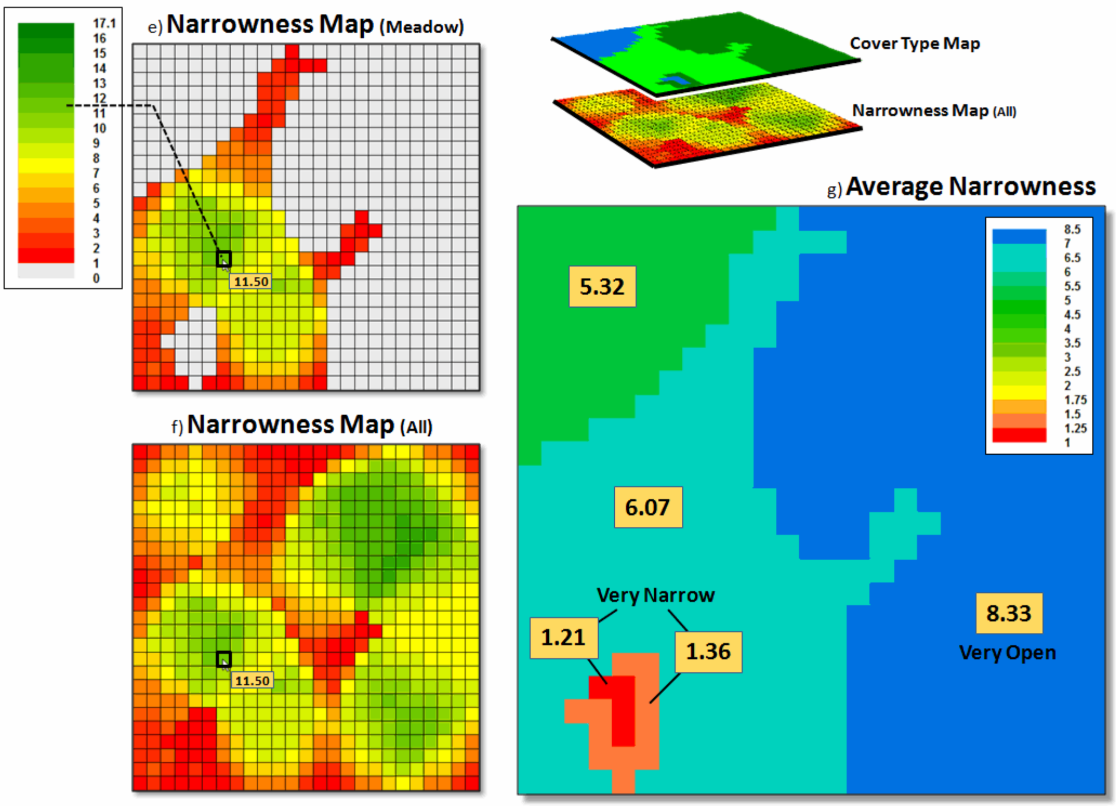

Figure 2. Summarizing average narrowness for individual parcels.

The right side of figure 2 (inset *g*) illustrates the calculation of the average narrowness for each of the cover type parcel Narrowness determines constrictions within a map feature (polygon) as the shortest cord connecting opposing edges, such as a forest opening. It uses a region-wide overlay technique that computes the average of the narrowness values coinciding with each parcel. A better metric of relative narrowness would be the ratio of the number of narrow cells (red-tones) to the total number of cells defining a parcel. For a large perfectly circular parcel the ratio would be zero with increasing ratios to 1.0 for very narrow shapes, such as very small or ameba-shaped polygons.

Narrowing-In on Absurd Gerrymanders

(GeoWorld, July 2012)

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In light of the current political circus, I thought a bit of reflection is in order on how GIS has impacted the geographic stage for the spectacle—literally drawing the lines in the sand. Since the 1990 census, GIS has been used extensively to "redistrict" electoral territories in light of population changes, thereby fueling the decennary turf wars between the Democrats and Republicans.

Redistricting involves redrawing of U.S. congressional district boundaries every ten years in response to population changes. In developing the subdivisions, four major considerations come into play—

1) equalizing the population of districts,
2) keeping existing political units and communities within a single district,
3) creating geographically compact, contiguous districts, and
4) avoiding the drafting of boundaries that create partisan advantage or incumbent protection.

Gerrymandering, on the other hand, is the deliberate manipulation of political boundaries for electoral advantage with minimal regard for the last three guidelines. The goal of both sides is to draw district boundaries that achieve the most political gain.

Three strategies for gerrymandering are applied—

1) attempt to concentrate the voting power of the opposition into just a few districts, to dilute the power of the opposition party outside of those districts (termed "excess vote"),
2) diffuse the voting power of the opposition across many districts, preventing it from having a majority vote in as many districts as possible ("wasted vote"), and
3) link distant areas into specific, party-in-power districts forming spindly tentacles and ameba-line pseudopods ("stacked").

For example, the 4th Congressional District of Illinois is one of the most strangely drawn and gerrymandered congressional districts in the country (figure 1). Its bent barbell shape is the poster-child of "stacked" gerrymandering, but Georgia's flying pig, Louisiana's stacked scorpions and North Carolina's praying mantis districts have equally bizarre boundaries.

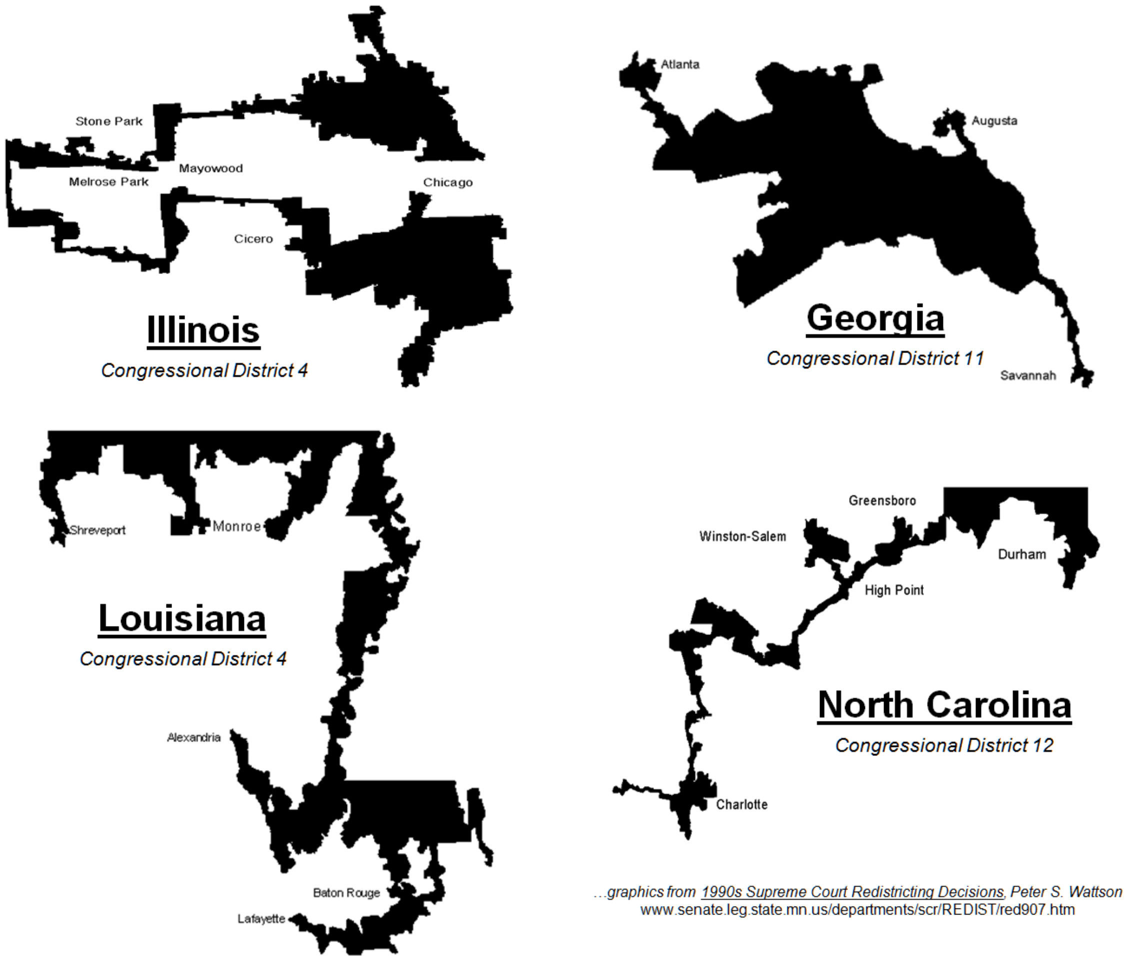


Figure 1. Examples of gerrymandered congressional districts with minimal compactness.

Coupled with census and party affiliation data, GIS is used routinely to gerrymander congressional districts. But from another perspective, it can be used to assess a district's shape and through legislative regulation could impose indices that encourage compactness. A "convexity index" (CI) and a "narrowness index" (NI) are a couple of possibilities that could rein-in bazaar gerrymanders.

The boundary configuration of any feature can be identified as the ratio of its perimeter to its area (see author's notes 1 and 2). In planimetric space, the circle has the least amount of perimeter per unit area. Any other shape has more perimeter (see figure 2), and as a result, a different Convexity Index.

In the few GIS software packages having this capability, the index uses a "fudge factor" (k) to account for mixed units (e.g., m for P and m^2 for A) to produce a normalized range of values from 1 (very irregularly shaped) to 100 (very regularly shaped). A theoretical index of zero indicates an infinitely large perimeter around an infinitesimally small area (e.g., a line without perimeter or area, just length). At the other end, an index of 100 is interpreted as being 100 percent similar to a perfect circle. Values in between define a continuum of boundary regularity that could be used to identify a cutoff of minimal irregularity that would be allowed in redistricting.

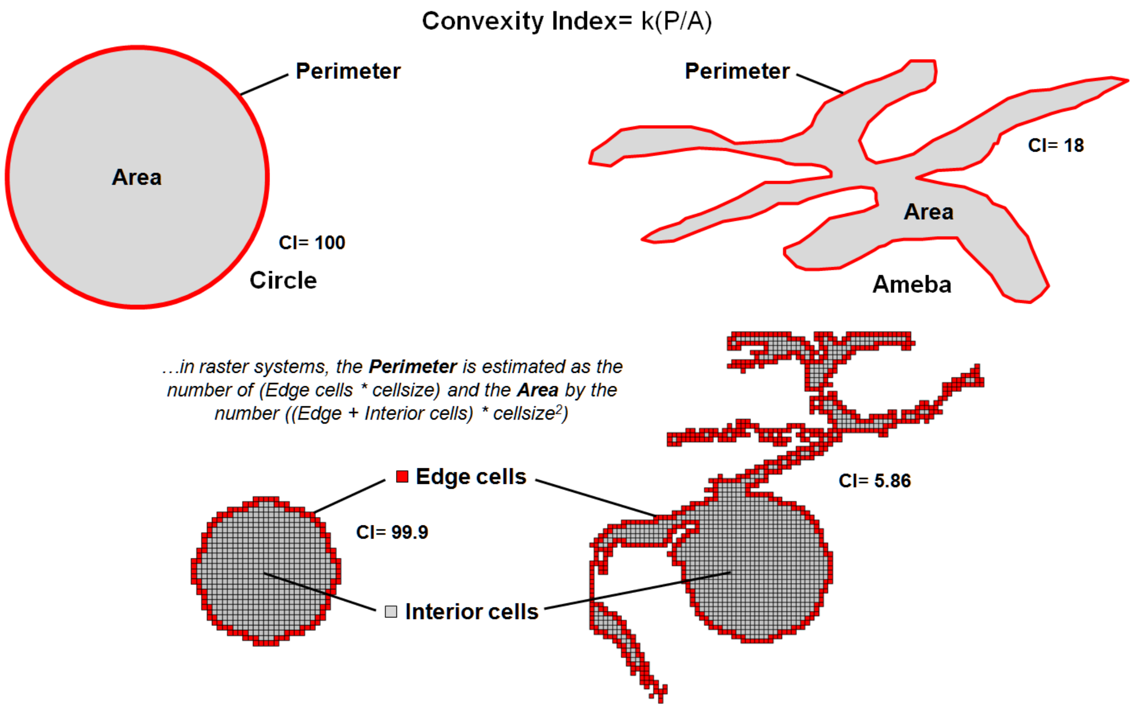
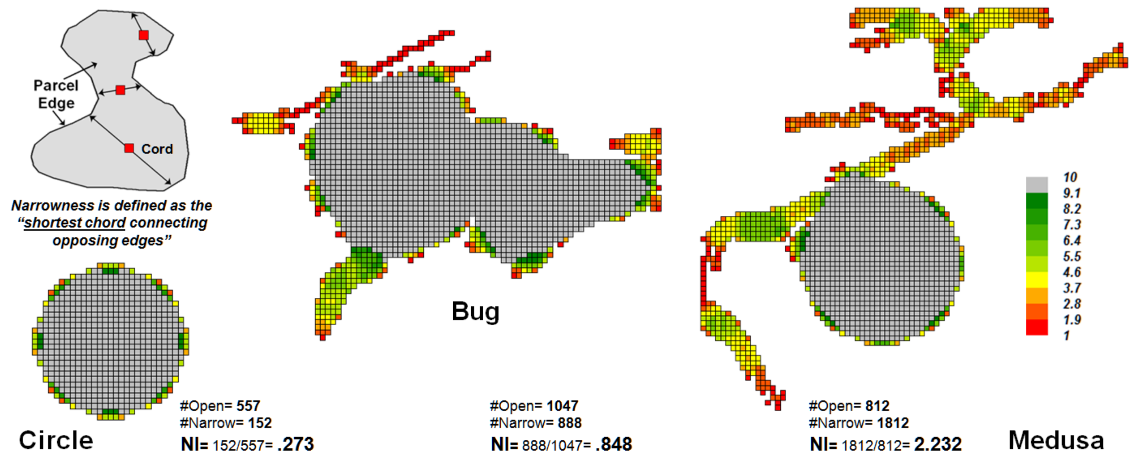


Figure 2. Convexity is characterized as the normalized ratio of a feature's perimeter to its area.

Another metric for assessing shape involves calculating "narrowness" within a map feature. Narrowness can be defined as the "shortest cord passing through a location that connects opposing edges" (see author's note 3). In practice, narrowness is calculated to a specified maximum distance. Locations with cords exceeding this distance are simply identified as "open areas."

In figure 3, the narrow locations are shown as a color gradient from the most narrow locations (red=1 cell length= 30m) to minimally narrow (green= 9.9999 *30m= 299.9m) to open areas (grey= $\geq$300m). Note the increasing number of narrow locations as the map features become increasingly less compact.

A Narrowness Index can be calculated as the ratio of the number of narrow cells to the number of open cells. For the circle in the figure, NI= 152/557= .273 with nearly four times as many open cells than narrow cells. The bug shape ratio is .848 and the spindly Medusa shape with a ratio of 2.232 has more than twice as many narrow cells as open cells.



Min [>=]	Max [<]	Count		% Gridded Area	Color
9.1	10	557		88	
8.2	9.1	12		1.9	
7.3	8.2	8		1.3	
6.4	7.3	8		1.3	
5.5	6.4	0		0	
4.6	5.5	24	152	3.8	
3.7	4.6	8		1.3	
2.8	3.7	8		1.3	
1.9	2.8	8		1.3	
1	1.9	0		0	

Min [>=]	Max [<]	Count		% Gridded Area	Color
9.1	10	1470		77	
8.2	9.1	25		1.3	
7.3	8.2	13		0.68	
6.4	7.3	34		1.8	
5.5	6.4	48		2.5	
4.6	5.5	81	888	4.2	
3.7	4.6	69		3.6	
2.8	3.7	41		2.1	
1.9	2.8	58		3	
1	1.9	75		3.9	

Min [>=]	Max [<]	Count		% Gridded Area	Color
9.1	10	812		47	
8.2	9.1	13		0.76	
7.3	8.2	4		0.23	
6.4	7.3	26		1.5	
5.5	6.4	82		4.8	
4.6	5.5	132	1812	7.7	
3.7	4.6	200		12	
2.8	3.7	177		10	
1.9	2.8	170		9.9	
1	1.9	102		5.9	

Figure 3. Narrowness is characterized as the shortest cord connecting opposing edges.

Both the convexity index and the narrowness index quantify the degree of irregularity in the configuration of a map feature. However, they provide dramatically different assessments. CI is a non-spatial index as it summarizes the overall boundary configuration as an aggregate ratio focusing on a feature's edge and can be solved through either vector or raster processing. NI on the other hand, is a spatial index as it characterizes the degree and proportion of narrowness throughout a feature's interior and only can be solved through raster processing. Also, the resulting narrowness map indicates where narrow locations occur, that is useful in refining alternative shapes.

To date, the analytical power of GIS has been instrumental in gerrymandering congressional districts that forge political advantage for whichever political party is in control after a census. In engineering an optimal partisan solution the compactness criterion often is disregarded.

On the other side of the coin, the convexity and narrowness indices provide a foothold for objective, unbiased and quantitative measures that assess proposed district compactness. Including acceptable CI and NI measures into redistricting criteria would insure that compactness is addressed— gentlemen (and ladies), start your GIS analytic engines.

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Author's Notes: *1) See Beyond Mapping Compilation Series Book I, Topic 5, "You can't See the Forest for the Trees," September 1991, for additional discussion on Feature Shape Indices. 2) PowerPoint on Gerrymandering and Legislative Efficiency by John Mackenzie, Director of Spatial Analysis Lab, University of Delaware posted at www.udel.edu/johnmack/research/gerrymandering.ppt.*

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Further Online Reading: *(Chronological listing posted at* ***www.innovativegis.com/basis/BeyondMappingSeries/****)*

Just How Crooked Are Things? — *discusses distance-related metrics for assessing crookedness (November 2012)*

Extending Information into No-Data Areas — *describes a technique for "filling-in" information from surrounding data into no-data locations (July 2011)*

In Search of the Elusive Image — *describes extended geo-query techniques for accessing images containing a location of interest (July 2013)*

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