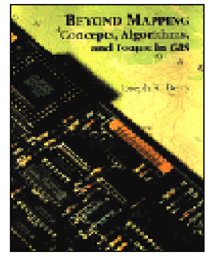
Beyond Mapping I

Topic 3 – *Assessing Neighborhood Characteristics using Roving Windows*



***Beyond Mapping* book**

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Imagination is more Important than Information (Einstein)

(GIS World, June/July 1990)

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...but directed imagination needs the best information it can get.

When viewing a map, the human mind nearly explodes with ideas about the landscape. Although the ideas are limitless, our ability to process the detailed spatial data is limited. When the computer 'views' a map, it sees an organized set of spatial data ripe for processing, but has no idea of its significance. Think about it, when was the last time you took your computer for a walk in the woods?

That's the beauty of the man/machine bonding in GIS. The imagination of the user is magnified many-fold by the machine's ability to assemble detail as directed. Ian McHarg vividly makes this point in his lectures on GIS-- 'it is a tool that extends the mind.' We easily conceptualize scenarios for a landscape, but lack the facility to effectively evaluate their relative merits. That's why we need our little silicon subordinate... to take care of the details. From this perspective GIS is less computer mapping and spatial data base management, than it is a Decision Support System (DSS) for modeling and evaluating alternative land uses.

The foundation of this 'thinking with maps' is rooted in the analytic capabilities of GIS. The last series of articles described how our simple concept of distance has been extended by the computer's ability to calculate proximity, movement and connectivity. This is the first of a few articles investigating a related set of analytic tools concerned with vicinity. Or, more technically stated, the analysis of spatially defined neighborhoods by considering a map location within the context of its neighboring locations. As with all GIS processing, new values are computed as a function of the values on another map. In neighborhood analysis two steps are involved. First, establish the neighborhood and its values, then summarize the values.

Determination of neighborhood membership is like a 'roving window' moving about a map. Picture a window with nine window panes looking straight down onto a piece of the landscape (sort of makes you feel all powerful, doesn't it). Now, like a nosey neighbor, systematically move it around to check out the action. Suppose your concern was surface configuration. You would note the nine elevation values within the window, then summarize the 3-dimensional surface they form. If all of the values were the same, say 100 feet elevation, you would say it was a boring flat area and move your window slightly to one side. Some larger values appear on the side window panes. Move it another couple of notches and the window is full of different elevation values.

Imagine the nine values become balls floating at their respective elevation. Drape a sheet over them like the magician places a sheet over his suspended assistant (who says GIS isn't at least part magic). There it is-- surface configuration... now numerically summarize the lumps and bumps formed by the ghostly sheet. That means reducing the nine values to a single value characterizing the surface. How about its general steepness? You could compute the eight individual slopes formed by the center value and its eight neighbors (change in elevation divided by the change in horizontal distance expressed as a percent). Then average them for an average slope. You could, but how about choosing the maximum slope? That's what water does. Or the minimum slope? That's what a weary hiker does. In special cases you would choose one of these statistics.

Most often you are interested in the best overall slope value. This is determined by the 'best fitted plane' to the data. Replay your vision of the nine floating balls. Now insert a glass panel (plane) in such a way that the balls appear balanced about it (minimizing the deviations from the plane to the balls). If you're a 'techy', you will recognize this is simple 'linear regression', except in 3-dimensional space. But, if you value your computer's friendship, don't use a 'least-squares fit' algorithm. Use vector algebra, its much faster.

As the window progresses about the map, slope values are assigned to the center window pane (cell) until all locations have received a value... abra-ca-da-bra, a slope map. Locations with larger values indicate steep terrain; smaller values for gently sloped terrain. But what is the terrain's orientation? That's an aspect map. Move the same window and best fitted plane about the map, but this time use its 'direction cosines' to indicate the orientation of the plane. Is it facing south? Or north? Or 47 degrees azimuth? It could make a big difference. If you're trying to grow trees in a moisture limited region those south facing slopes are only good for rattlesnakes. However, if there is ample water, they get the most sunlight and tend to grow your best trees. If you're a land planner, the southern slopes tend to grow the best houses, or at least lowest heating bills.

There is one final surface configuration factor to consider-- profile. Imagine a loaf of bread, fresh from the oven. It's sort of like an elevation surface. At least mine has deep depressions and high ridges. Now start slicing the loaf and pull away an individual slice. Look at it in profile concentrating on the line the top crust portion traces. From left to right, the line goes up and down in accordance with the valleys and ridges it sliced through. Use your arms to mimic the shapes along the line. A 'V' with both arms up for a valley. An inverted 'V' with both arms down for a ridge. Actually there are only nine fundamental profile classes (distinct positions for your two arms). Values one through nine will serve as our numerical summary of profile.

However, a new window is needed. This time as you look down onto the landscape, move a window with just three panes along a series of parallel lines. At an instant in time, you have defined three elevation values. Compare the left side value to the center. Is it higher or lower? Put your left arm in that position. Now do the same for the right side and center values. Note the fundamental profile shape you have formed and assign its value to the center location. Move the window over one pane and repeat until you have assigned a profile value to every map location. The result of all this arm waving is a profile map-- the continuous distribution profiles viewed from some direction. Provided your elevation data is at the proper resolution, it's a big help in finding ridges and valleys running in a certain direction. That's where the gold might be. Or, if you look from two opposing directions (orthogonal) and put the two profile maps together, a location with an inverted 'V' in both directions is likely a peak.

There is a lot more to neighborhood analysis than just characterizing the lumps and bumps of the terrain. What would happen if you created a slope map of a slope map? Or a slope map of a barometric pressure map? Or of a cost surface? What would happen if the window wasn't a fixed geometric shape? Say a ten minute drive window. I wonder what the average age and income is for the population within such a bazaar window?... See you next issue.

It's Like the New Math… I am just too old

(GIS World, August/September 1990)

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Earlier discussions have established 'maps as data'. The fact that maps are numbers in a GIS is what allows us to go beyond mapping. It extends pens, symbols and colors to spatial statistics, mathematics and modeling. But in doing so, does it leave the typical user in the dust?

Your initial response is likely, "You bet. Its like new math, I'm just too old." We have our established procedures for dealing with maps and data, built up through years of study at the School of Hardknocks. Maps are colorful graphics you hang on the wall, and data are colorless numbers you align in a column. The thought that they are one of the same is unsettling. Well, let's return to that Land of Oz, featuring neighborhood characterization.

When last we saw our hero, the 'roving window,' he was about to crash into a lumpy, bumpy terrain surface. If that is all that he is good for, he was going to end it all. Let's review the facts. The procedure for assessing surface configuration was described as a window with nine panes moving about a map of elevation values. At an instant in time, the nine values in the window are summarized for the slope and aspect of the three-dimensional surface they form (see last issue for algorithms). The results are assigned to the location at the center of the window, then the window advances to the next position. This procedure is repeated until a slope or aspect value is assigned to all locations in a project area. Useful information, but is that all there is?

Of course not, this is the Land of Oz. A slope map is actually the first derivative of the elevation surface. You remember the derivative; that blood-sucking calculus teacher threatened you with it. In simple terms, a derivative indicates the 'rate of change' in one variable with respect to another. In the terrain slope example, it is the rate of change in elevation per geographic step-- "rise is to run." If elevation doesn't change, the terrain is flat. If it changes a lot over a short distance, it's steep. Slope (derivative) indicates how rapidly things are changing throughout your map. Aspect indicates the direction of this change. "I can handle that."

OK. Then what is the second derivative of an elevation map? The slope of a slope map? Let's see, the first derivative is the rate of change in elevation per geographic step. Then the second derivative must be the rate of change in the rate of change in elevation per geographic step. What? That doesn't make sense. Maps are maps and math is math, and you shouldn't confuse them. No, the result is called a surface 'roughness' map. It shows you where those little brown contour lines are close together, then far apart, then close together again, then far apart-- heart break terrain for tired hikers. Close your eyes and envision a steep mountain side you have to climb. It could be worse.

Suppose the slope isn't constant (a tilted, straight line in profile), but variable (a tilted, wiggly line in profile). To get to the same point, you would hike up, then down, then up, then down... at each rise, your hopes (and elevation advantage earned) would be lost. Neither man nor machine likes to run around in this sort of terrain. If you're a forester, a roughness map could help you in harvest planning. If you're a regional planner, it could help you assess likely corridors for a proposed highway. If you're a hydrologist, it could help in modeling surface runoff.

Weatherpersons have used map derivatives for years. They collect barometric pressure readings at weather stations, then interpolate these data into pressure gradient maps. To a casual observer, these maps look just like a terrain surface... peaks, valleys and a host of varying slopes connecting them. Winds blow from high to low pressure; or stated another way, from the peaks to the valleys along the pressure gradient. The steeper the slope between peaks and valleys, the stronger the wind will be. Therefore, a 'slope' map of the pressure gradient surface indicates wind speed at each location. The aspect of the same map indicates wind direction at each location. So that's how they get tomorrow's 'gusty' prediction. Or how about a cooling pond's 'thermal gradient'? ...a mountain of high temperature at the point of discharge that dissipates at different rates and directions as a function of depth, bottom conditions, streams and springs. Slope and aspect of this thermal gradient maps these complex interactions.

Let's recapitulate before we go on. The familiar concepts of terrain slope and aspect are down-to-earth examples of that elusive mathematical concept of the derivative. It gives a firm footing in the real world to one of the most powerful mathematical tools in numerical space. A slope map indicates the spatial distribution of the rate of change in any map variable. An aspect map indicates the direction of that change. Since slope and aspect have a more general meaning than giving direction to raindrops, what else can they do?

Consider an accumulation surface. Remember that bizarre map discussed a few issues ago in connection with weighted distance measurement. An example is a 'travel-time' map indicating how long it would take to travel from one location to all other locations in a project area. If you move in straight lines in all directions, a perfect bowl of constantly increasing distance is formed. However, if you are a realistic hiker your movement throughout the area will bend and twist around both absolute and relative barriers, as defined by terrain and land cover features. The result is a travel-time map that is bowl-like, but wrinkled with ridges and valleys. That's weird, but still a map surface that is not unlike a terrain surface. Its slope indicates the ease of optimal movement across any location in the project area. Its aspect indicates the direction of optimal movement. So what?

Think about it. This is a map of the pattern of optimal movement throughout an area. Such information is invaluable whether you are launching a crew of fire fighters or a cruise missile. But why stop at a travel-time map. Why not a 'cost surface,' in which its derivative produces a marginal cost map-- the cost to go an additional step in space. Or a 'marginal revenue' map. Such is the decision fodder that fuels the salaries of most MBA's-- except expressed as an entire map, instead of a single number.

At least two things should be apparent from the above discussion. First, that map analysis in a GIS is based on mathematics. Maps are large groups of numbers and most of the traditional analysis techniques are applicable. Certainly the derivative is a switch hitter that propels GIS beyond mapping. How about the integral? Sure, why not? Envision a single, huge window that covers the entire map and sum all the values. How about the mean? Just divide the integrated sum by the number of locations. How about the standard deviation? And the coefficient of variation? Sure, but that's for the next issue. The other thing that should be apparent is that you don't want to have a thing to do with this map-ematics …maybe, maybe not. By reading this far, a seed has been set. At minimum, the thought of a map derivative will haunt you in your shower; like that innocent bather who checked in at the Bates Motel.

Torture Numbers, They'll Tell you Anything

(GIS World, October/November 1990)

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The last two sections introduced the idea of 'roving' a small window throughout a map summarizing the surface configuration detected at each location. Slope, aspect and profile of an elevation surface made sense. You have dug in your fingernails on steep, southerly slopes and pitched your tent on flat ones. But the extension of the concept to abstract maps, such as travel-time and cost surfaces, may have been a bit uncomfortable. Relating it to math's derivative made it down right inhospitable. Hopefully you saw through all that academic hyperbole to visualize its application potential. Surface configuration tells you how and where a 'mapped variable' is changing-- important information to tell you how and where you should change your management action.

There is another fundamental way to summarize a roving window-- statistically. For example, "How many houses are there within a quarter mile radius?". Or, "What is the average lead concentration in the soil within a hundred meters?" In these instances, the numbers defining a map are 'windowed', then statistically summarized, with the summary value assigned to the center location of the window. The window repeats this process as it moves about the map. The list of data summary techniques is large indeed-- total, average, standard deviation, coefficient of variation, maximum, minimum, median, mode, diversity, deviation, and many others. In fact, any of the traditional mathematical and statistical operations can be used to summarize the data in the window.

But that's not all. Because of the spatial nature of mapped data, new operations arise, such as Fourier two-dimensional digital filtering-- a real trek on the quantitative side that is beyond the scope of this article. Yet the basic concept imbedded in these seemingly complex procedures actually is quite simple. Consider the housing density map noted above. The number of houses within a quarter mile of any location is an indicator of human activity. More houses means more activity. Yet suppose your concern is a noisy neighborhood. It's not just the total number of houses in the vicinity of a location, but their juxta-positioning. If the woofers and tweeters are concentrated close to you, you'll be rock'n through the night. If most are at the edge of your neighborhood 'window', no problem. Physics describes this condition as the 'dissipation of sound as a non-linear function of distance.' You probably describe it as relief. That means a house twice as far away sounds a whole lot quieter than the one next door.

To our GIS, that means a 'distance weighted' window capability. Weights are calculated as an inverse function of the distance for each window position. The result is a matrix of numbers analogous to writing a weighting factor on each pane of glass forming the entire window. When you look though this window at the landscape, multiply the data you see times its respective weight, then statistically summarize these data and assign the summary value to the center location of the window. In this instance, the noise emanating from each house is adjusted for its positioning in the window and the total noise computed by summing all of the adjusted values.

The concept of weighted windows is fairly easy to grasp. The procedure used to derive the weights is what separates the manager from the mathematician. For now, let's stick to the easy stuff-- for example, weighted nearest neighbor interpolation. It uses an 'inverse distance squared' window similar to the one described above. Instead of noisy data, field collected measurements of well pollution levels, or barometric pressure, or animal activity can be used.

Consider figure 1, but please excuse the PC EGA color graphics slide of the screen. It's not as pretty as a workstation rendering, but I did it on my lap at 30,000 feet. Inset (a) shows a geographic plot of animal activity recorded during a twenty-four hour period at sixteen sample sites for a 625 hectare project area. Note the higher measurements are concentrated in the northeast, while the lower measurements are in the northwest. The highest activity level is 87, while the lowest is 0-- forming a rather large data range of 87. The computed average activity is 22.56, with a standard deviation of $\pm$ 26.2. On the whole, the area is fairly active but not too bad.

Inset (b) shows the result of moving the inverse distance squared window over the data map. At each stop the activity data is multiplied by its weighting factor, and the weighted average of all the adjusted measurements is assigned to the center of the window. This provides an estimate (interpolated value) of activity which is primarily influenced by those sampled points closer to it. It's common sense... if there is a lot of activity immediately around a location; chances are there is a lot of activity at that location. This is often the case, but not always (that's why we need the mathematician's complex weighting schemes).

"Whoa! You mean tabular data can be translated into maps?" In many instances, the answer is yes. The 22.56 average animal activity actually implies a map. It's just that it is a perfectly flat surface that estimates a 22.56 activity level is everywhere... plus or minus the standard deviation of 26.2, of course. But it doesn't indicate where you would expect more activity (plus), or where to expect less (minus). That's what the interpolated map does. If higher activity is measured all around a location, such as in the northeastern portion, then why not estimate more than the average? Not a bad assumption in this case, but 'it depends on the data' is the correct answer. As with all map analysis operations, you aren't just coloring maps, you're processing numbers with all the rights, privileges and responsibilities of math and stat. Be careful.

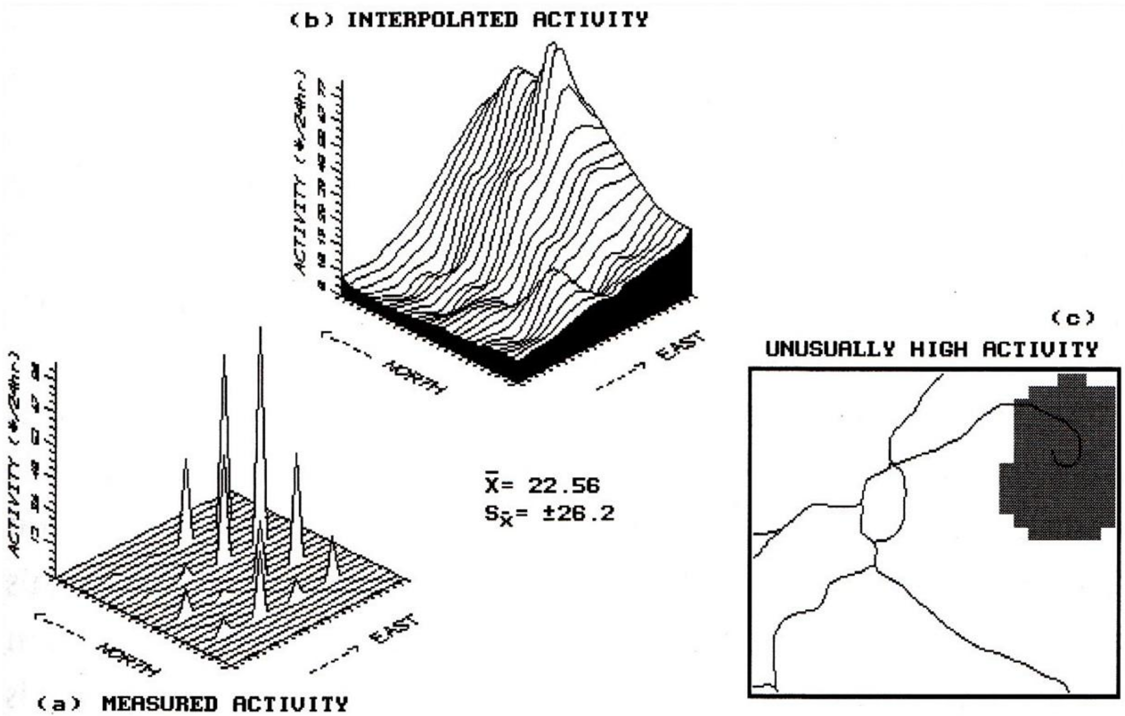

Figure 1. Spatial interpolation of discrete point samples generates a continuous map surface that in turn, identifies areas of unusually high activity.

You might be asking yourself, "If the interpolated surface predicts a different animal activity at each location, I wonder where there are areas of unusual activity." That's a 'standard normal variable (SNV)' map. It's this simple... SNV=((x-average)/standard deviation)*100, where x is an interpolated value. It's not as bad as you might think. If the interpolated value (x) is exactly the same as average, then it computes to 0... exactly what you would expect. Positive SNV values indicate areas above the average (more than you would expect); negative values indicate areas below the average (less than you would expect). A +100 or larger value indicates areas that are 100%, or more, of a standard deviation above the average... very unusually high activity. Inset (c) of the accompanying figure locates this area as easily accessible by the woods road in the northeast. Now get in your pickup truck and check it out. For the techy-types, the SNV map is the geographic plot of the standard normal curve and the map in inset (c) is the plot of the upper tail of the curve. For the rest of us, it's just a darn useful technique that provides a new way of looking at our old data. It brings statistics down to earth.

So, spatial interpolation is a neighborhood operation involving; at least conceptually, a roving window; a weighted one at that. Actually, it's an operation fairly similar to the familiar concepts of slope and aspect calculation. In the next issue, we will finish our brush with neighbors by considering 'dynamic' windows. Once you have tasted weighted windows, you will love dynamic ones. See you then.

I Don't Do Windows

(GIS World, December 1990)

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The previous sections have discussed 'neighborhood' operations as moving a window about map. We found that the data within a window at an instant in time could be used to characterize the surface configuration (e.g., slope or aspect) or generate a summary statistic (e.g., total or average). The value representing the entire neighborhood is assigned to the focus of the window, then the window shifts to the next location.

It is a simple, straight forward process, except for two counts. One involves understanding the wealth of mathematical and statistical processes involved. Most traditional math/stat operations are possible (those termed 'commutative' operations for the techy types). That leads to the other complicating count-- why would I want to do these unnatural, numerical things to a map? And what would I do with the bazaar results, such as a marginal cost map (slope of a cost surface)? Hopefully, the preceding articles provided enough examples to stimulate your thinking beyond traditional mapping, to maps as data, and finally to map analysis.

Intellectual stimulation, however, can quickly turn to conceptual overload. Risking this, let's return to spatial interpolation. Recall that interpolation involves moving window about a map, identifying the sampled values within the window, summarizing these samples and finally assigning the summary to the focus of the window. The summary could be a simple arithmetic average or a weighted average (most commonly 'the inverse distance squared' weighted average).

How about another conceptual step? Instead of making the weights a simple function of distance, incorporate a 'bias' based on the trend in the sampled data. This is what that mysterious interpolator 'kriging' does. It's based on common sense-- the accuracy of an estimated value is best at a sampled location and becomes less reliable as interpolated points get further away. Simple and straight forward. But the direction to a sampled value often makes a difference. For example, consider the change in ecological conditions as you climb from Death Valley to the top of Mount Whitney. As elevation rapidly increases you quickly pass through several ecological communities. If you move along an elevation contour, things don't change as quickly. For years, ecologists have used elevation in their mapping.

Now envision a map of this area (or refer to a map of southeastern California). Major changes in elevation primarily occur along the East/West axis. Most of the contours (constant elevation) run along the North/South axis. If our understanding of ecology holds, an estimated location should be influenced more by samples in a North/South direction from it. Samples to the East/West should have less influence. That's what kriging does. It first analyzes the sample data set for directional bias, then adjusts the weighting factors it uses in summarizing the samples in the window. In this case, it would uncover the directional bias in the sample data (induced by elevation gradient, provided theory holds), then sets the window weighting factors.

Another way to conceptualize the direction-biased window is as an ellipse instead of a circle. Inverse distance squared weighting forms concentric halos of equal weights-- a circular window. Kriging windows form football-shaped halos reaching out the farthest in the direction of trend in the data-- an elliptical window. For the techy few, this is similar to the 'Mahalanobis' distance in multivariate analysis. For the rest of us, it demonstrates the first consideration in roving window design-- direction. Why do widows have to form simple geometric shapes, like circles and squares, in which all directions are symmetrically considered? Well they don't.

For example, consider secondary source air pollution and health risk mapping. If you have a map of the concentration of lead in soils you might identify as 'risky' those areas with high concentrations within five hundred meters. To produce this map you could move a window with a radius of 500 meters throughout the lead map, assigning the average concentration as you go. But this process ignores the prevailing winds. An area might have a high concentration to the north, with low concentrations elsewhere. Its average might be within the guidelines, but as the wind blows from the north, the real effect would be disastrous for a home built at this location. In this case, a wedge-shaped window oriented to the north (up wind) would be more appropriate.

Actually there is more to windows than just direction. There is distance. For example, consider a big wind from the north. Under these conditions relatively distant locations of high concentrations could affect you. Under light winds they wouldn't. Considering both wind direction and strength, results in a dynamic window that adjusts itself each time it defines a neighborhood. To accomplish this, you need a wind map (often referred to as a 'wind rose') as well as the lead concentration map. The wind map develops the window configuration and the lead map provides the data for summary. In reality, 'cumulative effects' and 'particulate mixing' should be considered, but that's another story... even more complicated. But in the end, it just results in better definition of window weights.

Let's try another dynamic window example. Suppose you were looking for a good place for a fast food restaurant. It should be on an existing road (the automobile is king). It should be close to those most prone to a 'Mac attack' (wealthy families with young children). Armed with these criteria, you begin your analysis. First you need to build a data base containing information on roads and demographic information. With any luck, the necessary data are in the 'Tiger Files' available for your area (see the several previous GIS World articles on this data source).

Now all you need is a procedure that relates movement along roads from a location to the people data-- a 'travel-time window'. Based on the type of roads around a location, move the reach out ten minutes in all directions. The result is a spider-web-like window that reaches farther along fast roads than along slow roads. A bit odd-shaped, but it's a window no less. Now lay the window over the demographic data to calculate the average income and number of children per household. Assign your summary value then move to the next location along the road. When all locations have been considered, the ones with the highest 'yuppie indexes' are where candidate restaurant locations.

All this may sound simple (ha!), but it's a different story when you attempt to implement the theory.

Several GIS software packages will allow you to create 'dynamic weighted window 'maps. It's not a simple keystroke, but a complex command 'macro.' Such concepts are pushing at the frontier GIS. It's currently the turf of the researcher. Then again, GIS as you know it was just a glint in the researcher's eye not so long ago. I bet you will 'do windows' in your lifetime. It'll be fun.

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