ranking limits this particular method, but the underlying logic can recognize interrelationships not treated by an arithmetical procedure.

A generalized set of rules provide a way to fill in the complex multidimensional interactions of a complete overlay (as in the factor combination or integrated terrain unit approach) with a bit more clarity. There seem to be few published examples of such an approach, however.

### Summary of Rules

This presentation of overlay combination distinguishes methods based on the amount of information used. In all cases, a number of map layers have been combined using overlay. Each location on the map has an attribute on each of the input layers. The enumeration rules preserve all this detail for later consideration. The dominance rules pick one of the values as the result; the exclusionary screening rule is used quite frequently in applying regulations because of its simplicity. The contributory rules use all the attributes available to create some kind of composite attribute value. The limitation is that each layer contributes its value without regard for the others. These methods are relatively easy to implement but full of assumptions. Interaction rules try to provide a method to treat the complexities of the environment. The result depends on the specific combination of attribute values for some layers taken together. It is not surprising that these methods are underdeveloped in practical cases. Truly defensible applications of GIS will require continued development of the procedures for map combination. Many models of environmental interactions exist, but they are not always implemented in their full complexity.

## SUMMARY

Map overlay had its origins in a simpler world of physical maps drafted on transparent material and examined on a light table. In a GIS, overlay constructs the linkage between different sources of information using the geometry as a key. Attributes attached to the sources can then be combined using four general classes of rules: enumeration, dominance, contributory, and interaction. Chosen with care, the composite information forms a strong base for geographic analysis because it can integrate diverse sources. By itself, overlay provides direct answers to certain analytical needs such as change detection. However, it only addresses phenomena that are collocated. The next step is to broaden the analysis to larger neighborhoods.

CHAPTER 6

# DISTANCE RELATIONSHIPS

## CHAPTER OVERVIEW

- Construct vector buffers around isolated objects.
- Perform distance measurements and construct distance fields for rasters.
- Introduce extended Voronoi representations of distance relationships.

Chapter 5 concentrated on the overlay method, a technique to integrate different sources. As with any tool kit, there is a risk of seeing the world through the viewpoint of that one method. To the hammer salesperson, the whole world is full of nails (that need hammers). With geographic information, there is a similar risk. Regulations and specifications are usually written to reflect what seems technically feasible. Scientists, naturally, tend to use the techniques with which they are most familiar, sometimes missing important insights. There are many tools beyond overlay. This chapter will introduce one such tool in some depth that will lead to a more general set of neighborhood tools in the next chapter.

The next step in expanding the range of tools from the strict locality of overlay is adding tools that discover distance relationships implicit in a spatial representation. These operations can construct a new representation using distance measurements from some existing representation, thus qualifying as a limited form of transformation. The nature of these transformations depends on the assumptions implicit in the measurement framework. Chapter 7 will continue in the same direction with more generalized methods that operate on neighborhoods.

## EXAMPLES OF DISTANCE SPECIFICATIONS

Before considering the procedures used to implement distance measurement, it is useful to consider some of the motivations for using distance in geographical analysis. Distance can be a positive or a negative factor in location. This section presents examples of distance zones that occur in many application fields under somewhat different labels and with different scientific authority.

## Exclusionary Zones around Features: Buffers and Setbacks

Separation between objects implies a relationship that can be measured as a distance. Distance serves as the very prototype of a continuous measurement scale used by analogy in all other measurement situations. Yet, all forms of human society try to simplify the continuous variation of distance into categories of inside and outside, near and far, us and them.

The exclusionary logic introduced for map overlay applies to distance measurement under a number of terms. The word **buffer** is commonly used in environmental regulation, and it has been adopted by a number of GIS packages. Buffers are usually constructed outward to protect some element. In development regulations such as zoning ordinances, the word *setback* appears. **Setbacks,** however, tend to move inward within an area by constructing lines parallel to the boundaries. Both buffer and setback imply a simple zone: inside and outside the critical distance (Figure 6-1).

Land regulation often converts continuous distance into a category. Setbacks, for example, have a long history. In colonial America as early as 1703, there were regulations for a minimum front yard in Williamsburg, Virginia. Certainly the concept of such regulation was imported from European models. As town planning became more universal in the early twentieth century, the setback became an integral part of suburbia. Eventually, other environmental regulations imposed outward distance criteria (buffers). Changes in local ordinances require notice to adjoining property owners, usually specified as everyone within some given distance. Automated parcel records provide the database of property owners who must be notified concerning a land use action (Figure 6-2). To extract the property owners who should be notified, one must construct a new geometric object (the buffer) and then decide what is inside that object. In effect, this operation works in the reverse direction of the geocoding operation described in Chapter 3. Here a geometric relationship is used to extract text addresses.

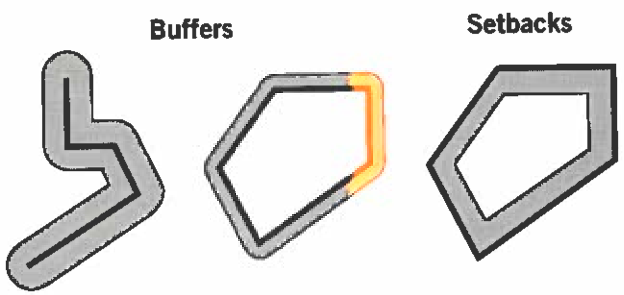


**Figure 6-1** Diagram of simple buffers and a setback. Note that buffers go outward from lines or areas, but setbacks run inward in areas, but not lines.

**Buffer:** A zone constructed outward from an isolated object (point or line) to a specific distance.

**Setback:** A zone inside a polygon constructed by a fixed distance from the edge of the polygon; typically used to restrict building or activities too close to the edge of a property parcel.



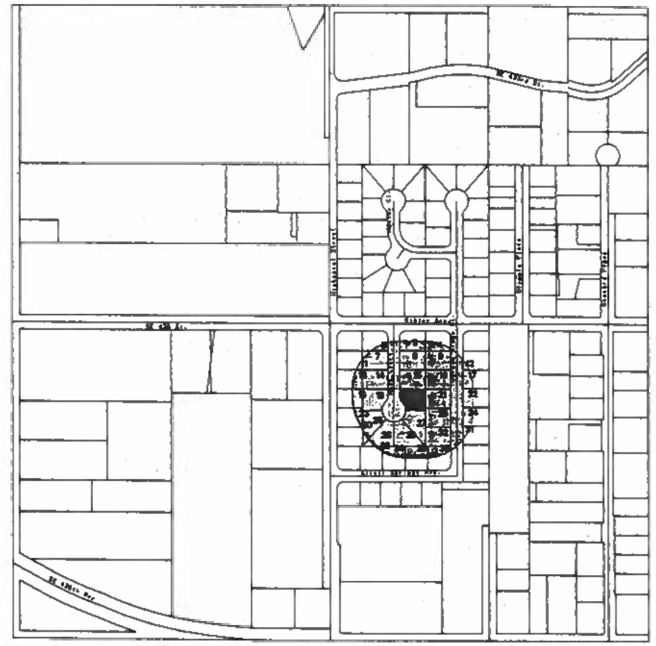

**Figure 6-2** Buffer constructed around a parcel. Zoning regulations require mailing notices to all owners within 225 feet of the applicant's property when an owner applies for certain changes in land use. (Source: Metro King County, Washington)

Perhaps the most common application for buffers comes from the difficulties of environmental management for linear features within larger landscapes. Ecologists have long recognized the value of edges as habitat and as a locus for flows of all kinds. This scientific recognition spurred regulations based on buffers. For example, streams present a problem in forest management, and much of the current dispute about environmental regulation in the Pacific Northwest of the United States involves arguments about buffer definitions and widths. Thus, the State of Washington Forest Practice Rules and Regulations (1988) will serve to introduce the concept of buffers.

At the societal level, the Pacific Northwest region of the United States has a conflict between two environmental property regimes. On the one hand, land can be purchased, and the property owner can extract the economic benefits of the land by cutting trees. On the other hand, fish swim freely in the waters of the state and belong to whoever catches them, subject to state regulations and treaty obligations to Native Americans. The terrestrial and aquatic arenas create quite different attitudes about public and private rights, but they would not conflict if the two regimes remained distinct. However, the environment is not divided into two neatly separated zones. Many of the fish in question return from the ocean to fresh water to spawn. The reproduction of fish depends on cold water temperatures and gravel stream bottoms. Both characteristics can be influenced by logging. Removing trees can open the stream to direct sunlight, raising the water temperature to a level where the fish fry cannot thrive. Furthermore, removing vegetation can increase sediment flow into the stream, covering the gravel.

Thus, there is an environmental interaction where the activities of one group can influence another. Under the simplified rules of exclusive ownership (pure capitalism), the timber owner would have the right to remove any trees, thus causing a reduction in fish survival. As with many such interactions, the consequences would not be immediately detected, particularly when the fish resource is diffuse and under collective ownership. The economic benefit of logging the trees can be seen immediately, but the reduction in salmon stocks is much harder to attach to a specific logging operation. This situation characterized the logging practices during the first century of European development in the region. Eventually, the rights of the fisheries became more apparent. Through the procedures of state regulation of forest practices, forest landowners were required to change their practices. The nature of these regulations is strongly contested between the various parties, and the political power of the various interests can be seen in the width of buffers.

The Timber/Fish/Wildlife Agreement (Washington State 1987) represents one recent compromise, created before the federal interest in protection of the spotted owl habitat created a further set of negotiations. Timber owners are restricted in their activities near streams, in a carefully arranged geometric framework. The goal is to ensure that the fish habitat remains shaded and free of sediment, while permitting some economic benefit from the timber on these lands. Trees within a certain distance of the stream contribute to the shade that maintains the cool water habitat. In addition, logging triggers erosion. Undisturbed vegetation can trap sediment before it reaches a stream channel. The clean geometry of exclusive landownership thus has been modified by a geometric construct—a buffer called the riparian management zone (RMZ). The regulation (Table 6-1) changes streams from essentially linear features into areas. Different buffer widths protect each different class of streams, based on expected fish habitat and political compromise. Unfortunately, the widths of the RMZ buffers may not be large enough to reduce sedimentation sufficiently (Castelle et al. 1992). The more recent federal forest plan adopted riparian buffers of 300 feet as a further attempt to preserve habitat.

Protection of fisheries was not motivated by a cartographic model of the world. The shade on the streams clearly comes from nearby trees. The RMZ concept includes many field-based determinations about the temperature sensitivity of the water, the streambed materials, and other concerns that influence the regulation. But then, to ease implementation, the regulation is converted into the simple cartographic format of an exclusive buffer zone, encapsulating the political tension between competing forces. The buffer concept can become a major regulatory element as a surrogate for understanding the actual interactions.



**TABLE 6-1 Riparian Management Zone (RMZ) Requirements**

| *Water Type and Width (Feet)* | *Maximum RMZ Width (Feet)* |
|---|---|
| Type 1 and 2 >75 | 100 |
| Type 1 and 2 <75 | 75 |
| Type 3 > 5 | 50 |
| Type 3 < 5 | 25 |
| Type 4 and 5 (all widths) | 25 |

*Source: Washington Administrative Code (WAC) 222-30-020 (4c).*

*Definitions of Water Classes*

Type 1: All water inventoried as "shorelines of the state" (an explicit list of objects)

Type 2
- Water diverted for use by 100 residences
- Within a campground of 30 units and within 100 feet
- Used by substantial numbers of significant fish (channel >20 feet and gradient <4% OR lakes >1 acre)

Type 3
- Water diverted for use by 10 residences
- Used by significant numbers of anadromous fish (channel >5 feet and gradient <12% and not upstream waterfall >10 feet OR lakes <1 acre connected to anadromous streams)
- Used by significant numbers of resident game fish (channel >10 feet and gradient <12% and summer flow >0.3 cfs OR lakes >0.5 acre)
- Protect downstream water quality (>20% of flow in Type 1 or 2)

Type 4: Not Type 1, 2, 3 and channel >2 feet

Type 5: Not Type 1, 2, 3, 4; intermittent or seasonal flow

*Source: WAC 222-16-030.*

## Beyond Buffers and Setbacks

Buffers can be used to protect some features, to push activities away. Other situations may use proximity as a positive factor and may seek to minimize distance. For these purposes, it makes more sense to use the continuous measure of distance, not a buffer.

A substantial body of location theory addresses the use of distance as a factor in various kinds of decisions. Often the simpler location theories are based on an analogy to a model from physics. Various physical laws specify different relationships over distance: sound pressure diminishes with the inverse cube of distance, and gravity diminishes with the inverse square of distance. Simple transportation cost would seem to increase as a linear function, but usually terminal costs and economies of scale make it rise more slowly than a linear function. Each of these numerical relationships must be considered in converting from strict distance to the purposes of a given project. Geographic reality is often much more complicated than the simplified worlds of a physical model. Careful construction of geographical relationships can provide much greater realism. The tools for such models will be introduced in later chapters.

## DISTANCE MEASUREMENT

Distance is a relationship between two points in space. Because measurement frameworks constrain relationships, each data model treats distance differently. Given these differences, the methods connected to a system of representation adopt different tactics. Yet, there is some unity of purpose hidden behind the differences.

### Distance Relationships

Although distance is a relationship between two points, it is often simplified and considered to be an attribute. Distance is an appropriate attribute for a line segment because the segment embodies the same relationship. Distance can be totaled for aggregations of line segments as long as this aggregate distance is understood to be distance along some network, and not the distance as the crow flies. These distance measurements do not require complex logic because the distances can be computed from the coordinates of endpoints. In practical application, however, the concept of *river mile* or *highway distance markers* runs into difficulties as the networks change. If you shorten the road near the beginning, do you move all the markers and change everything in the database? Mark Twain's *Life on the Mississippi* measures the passage up the river in a flexible sequence of old mile markers, cut-offs, and new channels before the Corps of Engineers tamed the fluvial processes.

In much of the site selection literature, distance is mentioned as a criterion measured from a linear or areal object, but the geometry is far from simple. The distance required is usually the minimum distance to any point or line along the description of the object—essentially a dominance operation on a set of simple distance calculations.

As with operations such as exclusionary screening, the use of distances often begins with an isolation operation that extracts some element from a more complex coverage (see Chapter 4). Internal complexities are simplified into a binary distinction, and distances are measured from these isolated objects outward into the void. Starting with this simplified conception, elaborations like variable widths (as required for the RMZ regulation) can be added. In any case, the process still starts by creating an isolated object view.

Construction of distances varies depending on the underlying representation model of the GIS software. In the vector environment, there are so many possible point pairs for constructing distances that distance relationships are usually simplified into buffers. In the raster environment, the process is less tied to a specific threshold. Moving outward from the objects of interest, each cell can measure the specific distance to the nearest feature. Despite these capabilities, however, users of raster software tend to construct buffers using binary thresholds of the continuous results. This section will discuss both vector and raster separately and then discuss similarities. In both cases, the distance processors construct a map layer to be used with others in an overlay application.



### Constructing Buffers with Vector Data

As the examples above demonstrate, the external context of the application often provides specific widths for a buffer. In some cases, these values come from clearly established science, though other distances are fairly arbitrary. Most vector software constructs buffers of a specified width. Some software can vary the distance according to other attributes, so that the RMZ buffers in Table 6-1 could be computed in a single operation.

To review the measurement process, a buffer is just a particular case of an isolated object, a contour line drawn at a specified distance from the selected feature. The location of the contour line can be calculated from the coordinates of the relevant portions of the original feature. There are a number of methods to obtain this measurement. The simple method treats each chain in isolation; the generalized Voronoi network, discussed below, offers an alternative.

Buffer construction in its vector form is usually performed in a series of steps hidden from the user. Each boundary chain is converted into a sausage, a locus of parallel lines and circles that stake out the contour of the chosen distance away from that particular line (Figure 6-3). Then all these sausages are passed through an overlay processor or some other geometric process to discard zones of overlap. The process creates an isolated object, a contour of the chosen distance. The area inside the buffer is undifferentiated, considered homogeneous, due to using the distance attribute as control.

### Measuring Distance in a Raster

The measurement process changes in the raster environment. Because space is controlled, the distance from the selected cells to other cells can be measured directly without slicing the distance into a contour form. The process usually begins with a selection operation to isolate the starting cells and to define the void in which distances will be measured. By definition, cells in the selected object have a distance of zero. Exact distances from cell center to cell center can be calculated using the Pythagorean formula. If there is more than one starting cell, the desired result is the minimum of all the distances. There are some shortcuts to avoid creating many distance measurements that will not be used. One algorithm for distance construction operates iteratively. Each cell with a value propagates that value plus the cell width to its neighbors. Hence it has been called `spread` in some implementations, an apt sense of how it works. Figure 6-4 shows the sequence of operations for a few cells. The result is a continuous field surrounding the original selected objects.

At short distances, the granularity of the pixels only permits certain integer multiples of the pixel width. This can be difficult if a particular threshold cannot be rep-

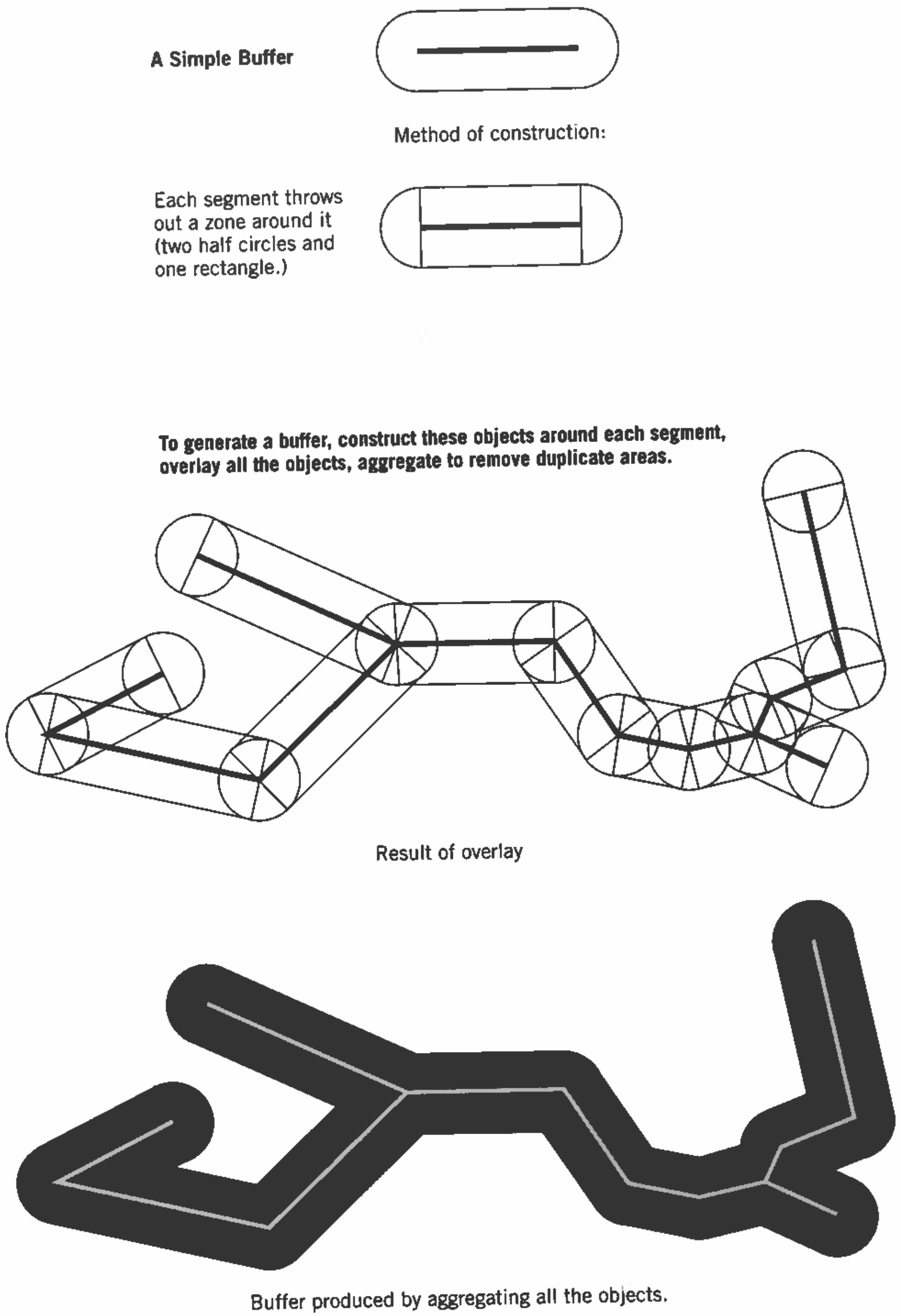


**Figure 6-3** Construction method for buffers in a vector representation.



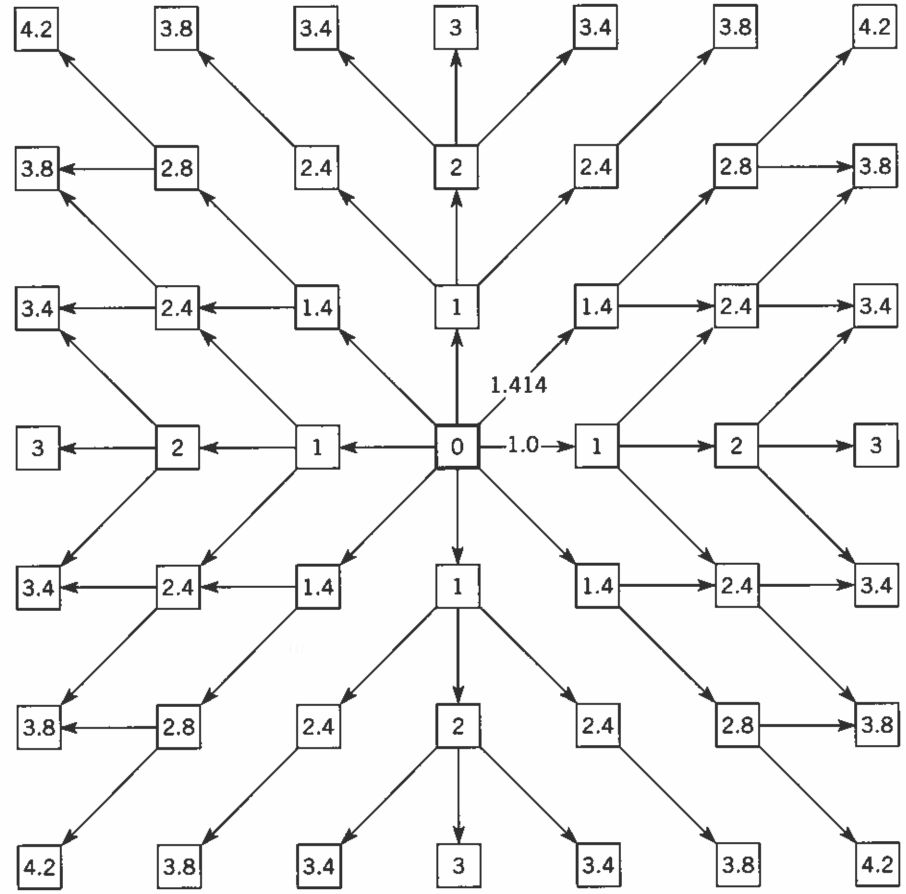


**Figure 6-4** Measuring distances by adding distances to cell neighbors.

resented in whole cell widths. In addition, diagonal distances can be a bit troublesome, depending on the implementation. Early software stored distances only as integer counts of pixels, which did not permit the diagonal neighbors to have the correct distance of $\sqrt{2}$ times cell width. Even using 1.414 for diagonal neighbors will assign values off the major axes that are a bit higher than if calculated directly (for example, the cells shown as 2.4 in Figure 6-4 are more accurately 2.234 – the square root of 5). For a given buffer distance, finer pixels lead to better results at a cost in greater storage and computation.

This iterative approach can be propagated as far as required. It takes longer to fill the whole matrix than it does to detect the nearest neighbors, but the process is not beyond reason for databases of practical size. The spreading algorithm produces a continuous distance surface outward from the starting cells. A threshold can convert these measurements into a simple category inside or outside a tolerance (a classification operation). This approximates the result of a vector buffer operation. More interestingly, distance from the selected feature becomes a value for the pixel that can be compared to the distances computed from some other feature. By subtracting one value from the other, the zone closer to one than the other will be the positive or negative values in the result. For example, the archaeological sites in a region of New Mexico include two periods called Mesilla and El Paso. The relationship between these two periods can be studied by constructing a distance surface around each. The difference of these two surfaces shows those areas closer to one or the other (Figure 6-5), providing some measure of resource base for each settlement. Analysis of the nearest facility is central to cellular telephone applications, industrial location, and allocation of service areas for all kinds of services.

## Distance Analysis for La Selva Project

As described in the sequence of boxes in earlier chapters, the La Selva project sought an explanation for the spatial pattern of selective harvest that had altered the ecological character of the primary forest. In the last chapter, the soil factor had one high accuracy association, but with a low completeness. More interesting explanations required a distance analysis. After examining a set of alternatives, the distance to roads held the greatest value. However, there was not a specific threshold for a sharp buffer edge, the determinacy analysis provided a way to tell what the distance relationship had been. All of the forested area (100%) within 10 m of the road had been selectively cut, but this only accounted for 5% of the selectively cut area. Moving out to 30 m only dropped the accuracy to 99%, and increased completeness to 28%. Moving to 50 m only reduced accuracy to 97% and increased completeness to 45%. At 100 m, the accuracy and completeness were both at 79%. If the distance was taken out to 500 m, it would capture 98% completeness, but only at a 43% accuracy. Using this information, the distance from roads works as an explanation of selective cutting with a distance range somewhere between 50 and 100 m. A bit more experimentation could select the appropriate trade-off between accuracy and completeness. When combined with interactions with soils and other factors, a succinct explanation can be developed.

The iterative approach to distance measurement permits some additional controls not found in the vector case. The search process can be constrained to respect a barrier or to move only downhill on a topographic surface. More important, the iterative process, since it works cell by cell, could weight the distance based on some impedance to travel through the cell. Both enhancements move away from the pure Pythagorean distance to some interaction with a surface. These operations will be considered in Chapter 7, which deals with surfaces and more advanced neighborhood operations.



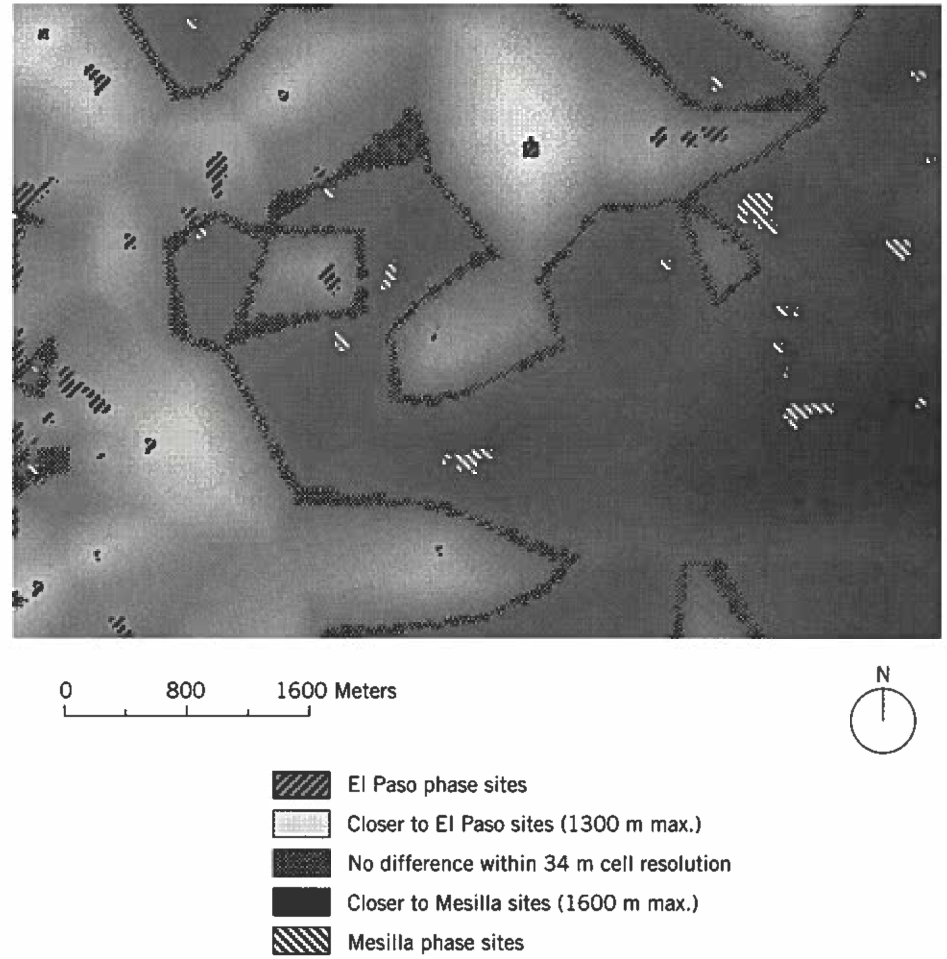


**Figure 6-5** Subtracting two distances. Difference between distance to archaeological sites from two different periods, Mogollan Plateau, New Mexico. (Source: Linse 1993)

## Comparison

To compare the two approaches, the vector method permits the analyst to select a buffer width and to construct that buffer contour directly. Current computation methods are fairly crude but effective. In the raster implementation, the representation is more approximate. The features have been simplified into the cellular representation, thus losing perhaps a half-cell width of spatial resolution, particularly for linear networks. In addition, distances are constrained by the grid. For buffer widths of three cell widths or more, the raster method provides a reasonable approximation.

The raster method permits a more continuous approach to the distance measurement than the fixed-threshold calculation now performed by most vector software. A continuous approach allows numerical comparisons between distance relationships. This is not an inherent property of the raster method, however, because some experimental vector methods calculate a similar result. These experimental methods use the generalized Voronoi diagram.

## EXTENDED VORONOI NETWORKS

Vector and raster methods are locked in the classical opposition between control by attribute and control by space. Buffers in the vector view must be isolated contours because some form of attribute control seems necessary. Similarly, the raster can estimate distances but only inside the discrete steps of the gridded space. In most GIS packages, these are the only alternatives provided.

Recently, a thread of research has taken a fresh approach. Much as the triangulated irregular network (TIN) structure (introduced in Chapter 2) does not fit the opposition between raster and vector, the alternative works by a form of control through relationships. The roots of this approach run rather deep in a number of fields, particularly climatology and mathematics. Consider the set of polygons that assign a space that is closest to each of a cloud of points (Figure 6-6). In geography, these polygons have been called "Thiessen polygons" after a climatologist who used them to perform a transformation from point climate stations to watersheds (see Chapter 9). In mathematics and computer science, the same construction is called the **Voronoi network** after earlier and more precise work by a Russian mathematician. This book will use the term Voronoi network for this construction. Whatever the name, the polygons control for the relationship of being nearest to a particular point. Each side of a polygon is a perpendicular bisector of the line between two neighboring points. Construction is easier when approached as a triangulation connecting the neighboring points (gray lines in Figure 6-6). Construction of **Delaunay triangulations** (named after another Russian writing under a pseudonym) and Voronoi networks is well established (Preparata and Shamos 1985).

For broader utility, the concept of proximal zones must be extended from points to handle lines as well. The "extended" Voronoi network captures the *relationships* of

**Voronoi network:** A set of lines that divides a plane into the area closest to each of a set of points. The lines are perpendicular bisectors of the lines connecting nearest points (Delaunay triangulation).

**Delaunay triangulation:** A network that connects each point in a set of points to its nearest neighbors; topological "dual" of the Voronoi network.



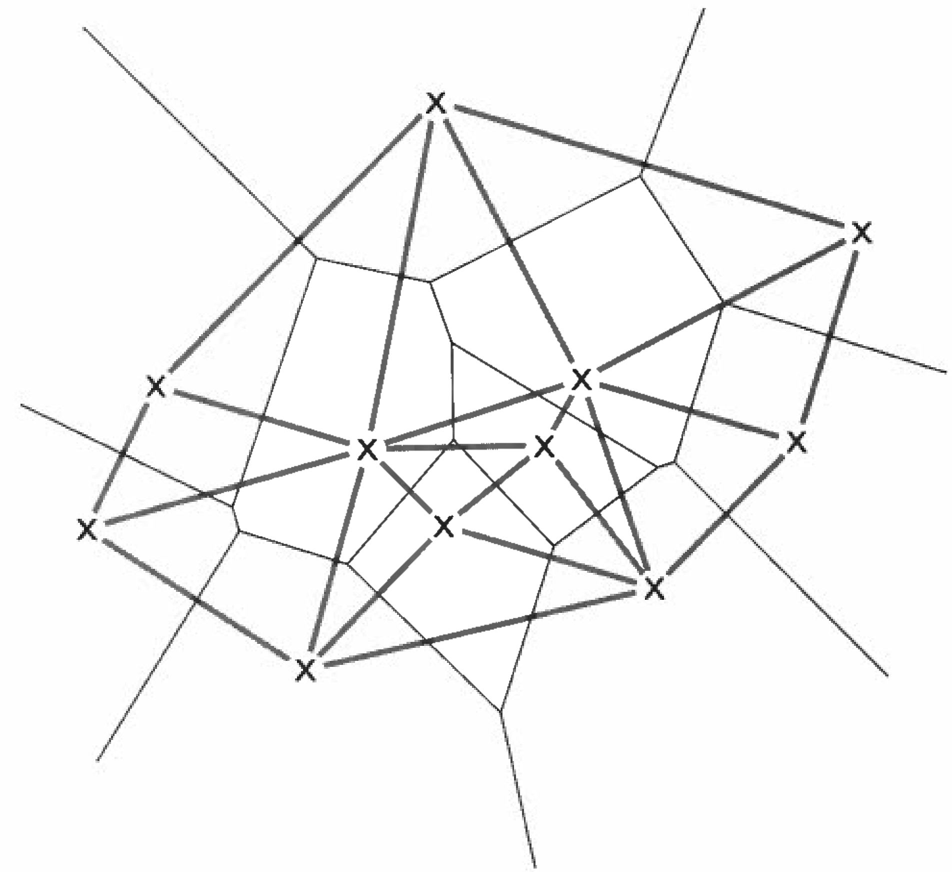

**Figure 6-6** Zones for nearest neighbors of points: Voronoi network is shown in thicker lines and Delaunay triangulation connecting neighboring points in lighter gray.

nearest objects that may seem intuitive for the human vision system but are not recognized by the established representation schemes. Each zone represents the part of the plane that is closer to one particular object (a point or a line) than any other. The edges of this network (boundaries between areas closer to one particular object, traced along the locus of equidistance) include three geometric primitives (Figure 6-7): the perpendicular bisectors used by the basic Voronoi network for point–point situations, angle bisectors for line–line relationships, and parabolic sections for line–point relationships. The extended network encapsulates a model of distance because inside each zone of the network only one object needs to be examined. Any vector buffer can be produced from this diagram by contouring the network at the desired distance. There will be no overlay or geometric postprocessing required. A team at Laval University has implemented a practical solution to calcu-

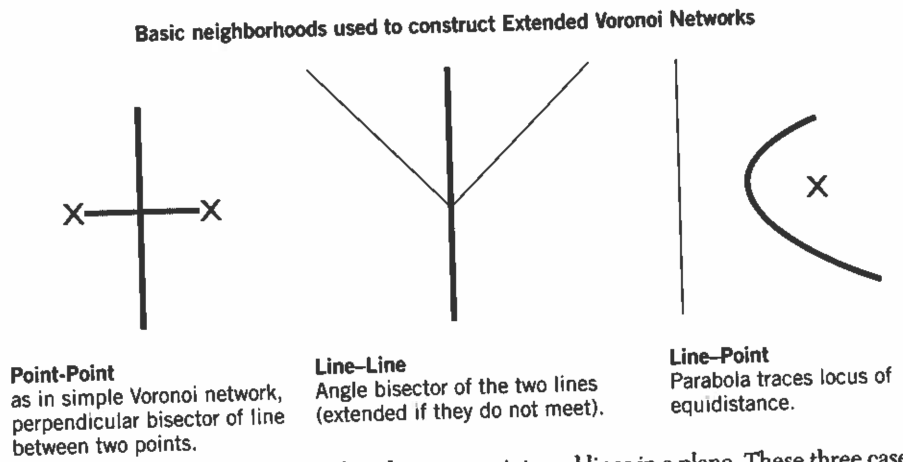


**Figure 6-7** Basic distance relationships between points and lines in a plane. These three cases divide a space into the area closer to one or the other. Point–point neighbors are separated by perpendicular bisector; line–line by the angle bisector; point–line by a section of a parabola.

lating these extended Voronoi networks (Gold 1992) (Figure 6-8). It may take some time for these innovations to move from the research community into commercial software packages.

## DATA QUALITY ASPECTS OF DISTANCE RELATIONSHIPS

The distance operations discussed in this chapter work on a single representation, so they do not provide a method to test one source against another. However, by combining with the overlay testing method discussed in Chapter 5, buffers can serve a role in data quality tests. More important, the distance relationships can serve as a model of certain kinds of error.

The construction of buffers applies meticulous geometric rules to information that may be nowhere near as precise as it seems. A buffer tool can also be interpreted as a statement about uncertainty in the representation. In the place of the exact model, the measurement of boundary lines should be considered from a statistical point of view. The linework obtained could be modeled as a true location, perturbed by some amount of measurement error. Many cartographic processes introduce error in positioning a line, and each error may have a distinct form. A band around the line provides a first approximation of the likely position of the true line.

As a statistical model, this would imply a set of contours for the probability of finding the true line at a given distance from the measurement obtained. The width of this zone may be uncomfortably large. For example, in considering just the line width error, the digitizing process, and roundoff for the U.S. Geological Survey GIRAS data, the standard deviation of the error might be 20 meters on the ground. Constructing a buffer of this width may indicate the potential variation in the area calculations due to measurement error in the linework. The area in a 20-meter buffer can range up to 10% of the area in a GIRAS coverage, depending on the density of linework (Chrisman 1982b).



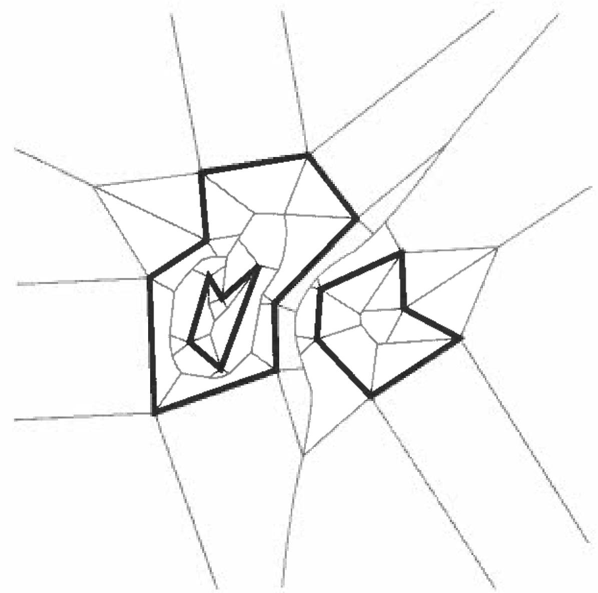

**Figure 6-8** Extended Voronoi network creates zones nearest to a collection of points and lines.

The appropriate statistical procedures to handle boundary imprecision have not been developed, though it remains a key issue of research concern (Goodchild and Gopal 1989; Chrisman and Lester 1991; Burrough and Frank 1996). It is particularly difficult to distinguish the various forms of error in boundaries of categorical coverages. Some models deal simply with measurement error, while others focus on the lack of sharp transitions between the categories (Burrough 1989; Wang et al. 1990; Leung et al. 1992). Each kind of error will occur in different amounts, and thus different models and tools must be used to approximate the behavior of the error distribution. A fixed width buffer is not the only model for error, but it can help visualize the potential influence of uncertain boundaries.

## SUMMARY

Distance transformations construct a new geographic representation based on distance relationships implicit in some original coverage. Just as raster and vector offer two distinct approaches to controlling space or attribute, the construction of distance transformations varies between these basic approaches to spatial representation. Current vector methods permit the exact construction of a buffer (a contour for a specific distance from a selected object). Raster methods permit the storage of the distance measurements, sampled at discrete points. Raster results can treat distance in a more continuous manner, not just the sharp edges of a buffer. Despite these differences, regulations are usually written with specific thresholds. The output from a distance transformation can be considered a new coverage for use with the other tools, such as overlay. Alternatively, a new measurement framework, the extended Voronoi diagram, can represent the distance relationships without the compromises inherent in the vector or raster techniques.

CHAPTER 7

# SURFACES AND NEAR NEIGHBORS

## CHAPTER OVERVIEW

- Describe properties of surfaces and how they are calculated.
- Examine geometric component of neighborhood construction.
- Present rules for combining attributes discovered inside a neighborhood.

The previous chapter introduced a set of operations to handle distance relationships. These operations belong to a larger set that deal with neighborhoods—the spatial context around each value. To extend to a more general treatment of neighborhoods, the surface provides a clearer model than the discrete objects that formed the major focus of the previous chapters. Thus, this chapter begins with a review of surfaces and then presents a system to understand neighborhood operations for all kinds of geographic distributions, not just surfaces. This chapter deals with near neighborhoods, leaving more complicated operations to the next chapter.

## SURFACES

The concept of a surface implies a distribution of a continuous attribute over a two-dimensional region. A number of distinct measurement frameworks share this conceptual model. Surfaces have only one value at any point. Thus, from a topological perspective, a surface is simply a plane deformed into the third dimension. Some call surfaces "two-and-a-half" dimensional. Surfaces are two dimensional in topological form and are measured in three dimensions. There is no reason to assign the value of one half to this combination. Fractional values of "dimension" are used to quantify the space-filling properties of lines and surfaces using fractal theory (Mandelbrot 1982; Goodchild and Mark, 1987).