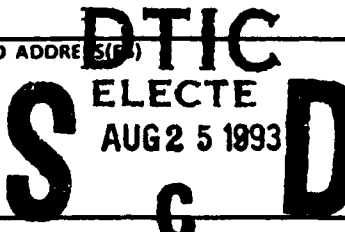


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DIRECTIONAL REGIONS IN GEOGRAPHIC INFORMATION SYSTEMS (GIS)

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ABSTRACT

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While direction is fundamental to geography, the implementation of directional functions in Geographic Information Systems (GIS) is limited. The focus of this paper is the extension of direction-related concepts through the definition of directional regions, such as "the area north of Washington, DC." Directional regions are constructed from combinations of six elements: the feature, the reference, an orientation, a viewspan, a viewfield and a region of interest. This approach allows users to create new area features which can be incorporated in a GIS. These features are a valuable tool for geographical analysis, since they further constrain reasoning on a data set.

INTRODUCTION

Geographic Information Systems (GIS) have long functioned using data models, terminology and concepts created by system developers rather than users. Potential users of GIS technology are often unwilling to adopt GIS because of the mismatch between their mental concepts of space and the limited data models and functions implemented within a GIS. This situation has slowed the transition of GIS applications to a wider audience.

One area of potential improvement to GIS is the handling of directional information. Direction is one of three basic spatial concepts, along with distance and connectivity, identified by Kolars and Nystuen. (Kolars and Nystuen, 1974, p. 16) According to Cromley, 'Direction is the orientation with the line of sight from a point. Directional relationships are important because they give a frame of reference between objects.' (Cromley, 1992, p. 10)

Direction is most commonly used to describe the relative relationship of two points, such as "point a is northeast of point b" or "point a is 45 degrees from point b." Routines to calculate the direction between two points or between a point and the nearest point on another feature are sometimes included in GIS software. In addition, some research has been directed at the determination of directional relationships among polygons (Peuquet and Zhan, 1987). However, functions to comprehensively determine directional relationships among objects (such as lines or polygons) or to create directional regions relative to a single object (point, line, or area) are not found in commercial products.

This paper focuses on the development of directional regions, such as "the area north of x." Examples of the military use of directional regions are illustrated in the following excerpt from the Army's FM-100-5, Operations.

After 6 months of fruitless fighting *north of Vicksburg*, Grant moved his army *south of the fortress* and crossed to the *eastern bank of the Mississippi* early in May, masking the move with demonstrations and raids. [Italics added]
(Department of Army, 1986, FM 100-5 Operations, p. 91)

METHODOLOGY FOR DIRECTIONAL REGION CREATION

One problem with the use of directional regions in a GIS is that multiple definitions are possible. "North of x" may mean "north of all points in feature x," "north of at least one location in feature x," "north of the centroid of feature x," "north of the northern boundary (however this is defined) of feature x," or any of a host of other possible definitions.

To circumvent this difficulty, an approach has been developed to specify directional regions using qualifying elements. The elements constrain the ambiguous description "area north of x" and allow the directional region concept to be implemented. No attempt is made to determine which of the many possible resulting directional regions is most appropriate for a given application, since that judgement is application-dependent.

Combinations of six elements are required to define a directional region: the feature, the reference, an orientation, a viewspan, a viewfield and a region of interest (Figure 1). These elements are described in greater detail below.

Feature. Directional regions are created for geographic features. These features may be represented by points, lines, areas, or combinations of these objects.

Reference. The reference is the portion of the feature representation, which is used in conjunction with the orientation, to define the directional region. The reference can be a point or line, but need not be the same as the feature. For points, however, a point is the only valid reference. A line or polygon could have either a point or line as a reference.

The reference must be fully described prior to creating a directional region. This can be seen by the example of a point reference for a polygon feature. There are an infinite number of possible points which could be selected for any polygon, of which three would be the most commonly used. These would be the extreme points or the centroid. For example, if the directional region "north" is "north of at least one point in a polygon" the reference would be the southernmost point in the polygon. If the directional region "north" is "north of all points in a polygon," the reference would be the northernmost point in the polygon. If the directional region "north" is "north of the polygon centroid," the reference would be the polygon centroid.

Orientation. The orientation is the user-specified angle from a reference line or base line which defines the direction of the region. The reference line is usually north; either true north, magnetic north, or grid north. The angle is measured clockwise from the reference line and may either be named, such as north, northeast, north by northeast, etc. or specified in degrees, such as 0 degrees, 45 degrees, or 22.5 degrees.

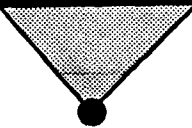
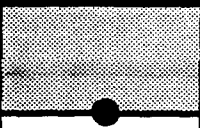
Feature	 Point	 Line	 Area
Reference	 Point	 Line	
Orientation	 0 Degrees	 45 Degrees	 90 Degrees
Viewspan	 0 Degrees	 90 Degrees	 180 Degrees
Viewfield	 Zonal	 Planar	 45 Degrees
Region of Interest	 Excluded	 Included	 Partial

Figure 1. Elements of a Directional Region

Viewspan. Directional regions are constrained by either a viewspan or viewfield. The viewspan describes the angular field of view from the reference. For example, if the reference is a point and the orientation is 45 degrees with a viewspan of 10 degrees, points falling within a fan defined by the reference point, lines extending from the reference point at 40 degrees to 50 degrees to the boundary of the data set, and the portion of the boundary closing the area, would be considered to be contained in the 45 degree directional region.

While the viewspan is most commonly used with point references, it may be used with a line reference as well. In the case of a line, the fan is applied to all locations along the line.

Viewfield. The viewfield is an alternate way of constraining the directional region. This concept applies only to regions generated from line references. The viewfield defines an area bounded by the reference, lines extending from the endpoints of the reference to the boundary of the data set, and the section of the data set boundary closing the area.

For an area, the critical points on the line reference would likely be the points which are the extremes perpendicular to the orientation. If the orientation were north, these would be the easternmost and westernmost points.

If the viewfield is zonal, the directional region is defined as the enclosed area bounded by the line reference, lines which are parallel to the orientation and extend from the endpoints of the line reference to the boundary of the data set, and a line connecting the points intersecting the boundary of the data set. If the viewfield is planar, the directional region is defined as the enclosed area bounded by the line reference, lines which are perpendicular to the orientation and extend from each endpoint of the line reference, and a line connecting the points intersecting the boundary of the data set. An azimuth may also be given, which will define lines extending from the endpoints. In the example of a "north" region with a 45 degree viewfield, the line extending from the westernmost endpoint would extend to the boundary at -45 degrees and the easternmost endpoint would extend to the boundary at 45 degrees. Zonal and planar viewfields are special cases of the more general azimuth viewfield specification.

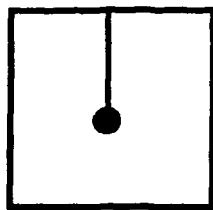
Region of Interest. The region of interest controls whether or not the feature is included, excluded, or partially included in the directional region. This applies only to area features.

As an example, a directional region north may be defined for an area as all locations north of the polygon centroid with a viewspan of 180 degrees. If the value of the region of interest is "included," the complete feature is part of the directional region. If the value of the region of interest is "excluded," the feature is not part of the directional region. If the value of the region of interest is "partial," the portion of the feature within the viewspan is included within the directional region.

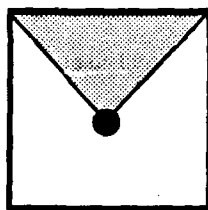
DIRECTIONAL REGIONS FOR POINTS, LINES, AND AREAS

Directional regions for points, lines and areas all have a reference, an orientation, and either a viewspan or viewfield. The viewspans and viewfields can later be combined in different ways to further define the region. In addition, directional regions defined for area features include a region of interest.

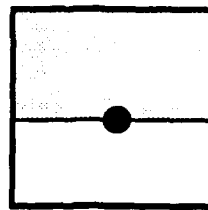
Point Features. Directional regions generated for point features are the simplest form of all directional regions. This is because the point is both the region of interest and the reference. With the addition of an orientation and a viewspan, the directional region is fully described (Figure 2).



Feature: Point
Reference : Point
Orientation: 0 Degrees
Viewspan: 0 Degrees



Feature: Point
Reference : Point
Orientation: 0 Degrees
Viewspan: 90 Degrees



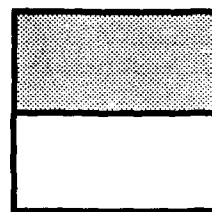
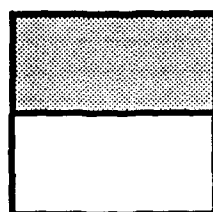
Feature: Point
Reference : Point
Orientation: 0 Degrees
Viewspan: 180 Degrees

Figure 2. Directional Regions for Point Features

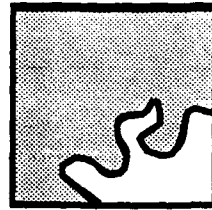
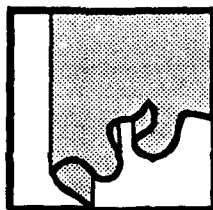
Line Features. Directional regions for line features are considerably more complicated than the regions for point features. The reference may be a point on the line, a line segment, or the entire line. This reference needs to be fully described and defined by the user prior to creating the region. An orientation and viewspan or viewfield is also required.

The concept of a directional region for a line requires some clarification because of differences between the viewspan and viewfield (Figure 3). In simple cases, both are equivalent. However, in more complicated cases they differ significantly. The viewspan is taken from all points along the reference line and the viewfield bounds the region by one side of the reference. Depending on the selection of the line reference, both may result in areas on both sides of the line reference being included. Despite this problem, the viewfield, rather than viewspan, is often more appropriate for a line reference.

Simple
Case



Complex
Case



Feature: Line
Reference: Line
Orientation: 0 Degrees
Viewspan: 0 Degrees

Feature: Line
Reference: Line
Orientation: 0 Degrees
Viewfield: Planar

Figure 3. Directional Regions for Line Features

Area Features. Area features are the source of more variations of directional regions than either points or lines (Figure 4, Figure 5). The reference can be either a point, a line segment, or a line. In addition to viewspan or viewfield specifiers, the directional region is also defined by the region of interest.

The reference for an area is a key factor in the appearance of the resulting directional region. Common point references are the polygon's extreme locations (relative to the orientation) or the area's centroid. If the orientation was north, the maximum extreme would be the northernmost point and the minimum extreme would be the southernmost point.

If the viewspan was 180 degrees, the region created with reference to the northernmost point would be "north," as defined by the area north of all points of a line perpendicular to the orientation and passing through the northernmost point and the boundaries of the data set.

The region created with reference to the southernmost point would be "north," as defined by the area north of all points of a line perpendicular to the orientation and passing through the southernmost point and the boundaries of the data set.

A line reference is another logical choice. It makes sense to define a line with endpoints at the extreme locations perpendicular to the orientation. Using the example above, where the orientation is north, the line reference would include the easternmost and westernmost locations as endpoints.

If there were multiple points at the easternmost extreme of the reference, then a rule could be adopted, such as selecting the northernmost point on the easternmost extreme.

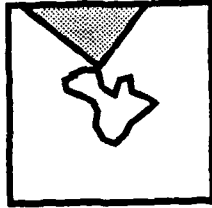
APPLICATION OF DIRECTIONAL REGIONS

The entire purpose for creating directional regions is to support higher level reasoning with geographic data. Just as the descriptions of generic landforms, like mounts (Graff, 1993), is a higher conceptual level than the points in a matrix of elevation data, directional regions represent a higher conceptual level than the coordinates of vector data or pixels of raster data.

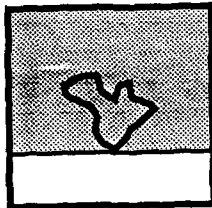
Directional regions can be used to further constrain the search space for spatial queries. It is possible to imagine use of this capability for a variety of applications, including military planning, disaster preparedness, or search and rescue.

For example, a lost hiker in the wilderness may have last been spotted at a particular cabin, have been heading in a certain direction and be likely to set up camp near a spring. Using this information, park rangers could narrow their search space by doing the following: 1) identifying the cabin, 2) creating a directional region using the cabin as a point feature, 3) identifying all springs in the area and 4) performing a point in polygon operation to locate all springs in the directional region "north" of the cabin.

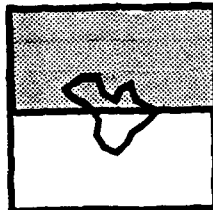
Point Reference



Feature: Area
Reference: Northernmost Point
Orientation: 0 Degrees
Viewspan: 90 Degrees
Region Constraint: Excluded

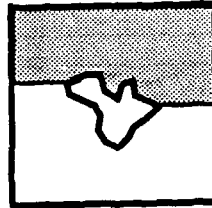


Feature: Area
Reference: Southernmost Point
Orientation: 0 Degrees
Viewspan: 180 Degrees
Region of Interest: Included

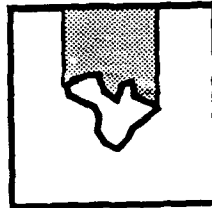


Feature: Area
Reference: Centroid
Orientation: 0 Degrees
Viewspan: 180 Degrees
Region of Interest: Partial

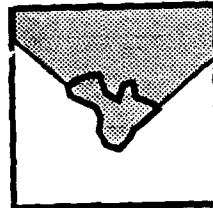
Line Reference



Feature: Area
Reference: Northern Boundary
Orientation: 0 Degrees
Viewfield: Planar
Region of Interest: Excluded

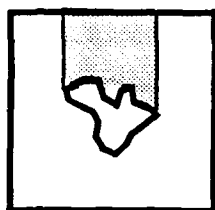


Feature: Area
Reference: Northern Boundary
Orientation: 0 Degrees
Viewfield: Zonal
Region of Interest: Excluded

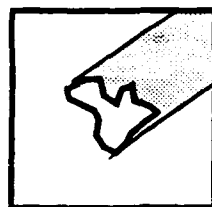


Feature: Area
Reference: Northern Boundary
Orientation: 0 Degrees
Viewfield: 45 Degrees
Region of Interest: Included

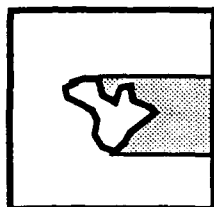
Figure 4. Directional Regions for Area Features



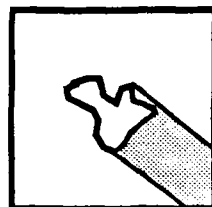
Feature: Area
Reference: Northern Boundary
Orientation: 0 Degrees
Viewfield: Zonal
Region of Interest: Excluded



Feature: Area
Reference: Northeastern Boundary
Orientation: 45 Degrees
Viewfield: Zonal
Region of Interest: Excluded



Feature: Area
Reference: Eastern Boundary
Orientation: 90 Degrees
Viewfield: Zonal
Region of Interest: Excluded



Feature: Area
Reference: Southeastern Boundary
Orientation: 135 Degrees
Viewfield: Zonal
Region of Interest: Excluded

Figure 5. Regions of Varying Orientation

SUMMARY

Direction is a fundamental spatial concept and this paper extends its application through the definition of directional regions. Directional regions may be useful in a GIS to create areas which can be used to constrain spatial queries.

The proposed method defines directional regions in terms of six elements: the feature, the reference, an orientation, a viewspan, a viewfield and the region of interest. These elements can be used to create a number of different directional regions for a single orientation. The selection of the most appropriate definition of a directional region for a particular application is left to the user.

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