Objects with Broad Boundaries

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Definition
Objects with broad boundaries are spatial objects, whose crisp boundaries are replaced by an area expressing the boundary’s uncertainty. There are two main interpretations for broad boundaries: (1) for positional uncertainty, the broad boundary represents the set of all possible positions among which the unknown boundary position is hidden; (2) for “fuzzy” boundaries, that is, boundaries that are by nature not crisp, the broad boundary represents their minimum and maximum extent. The main motivation for objects with broad boundaries is to record information about uncertainty together with the data. In this way, they represent a new geometric model that overcomes the limits of current spatial database models, which are a collection of lines (points, polylines and polygons). The geometric model of objects with broad boundaries takes into account a 3-valued indeterminacy of location (false, maybe, true), where “false” means that the point is not in the location, “true” means that the point is in the location and “maybe” means either that the point is with some probability in the location or that the point belongs, up to a certain membership value, to the location. Regions, lines and points with broad boundaries can be distinguished. In the case of lines, the broad interior can also be defined: a line with a broad boundary and broad interior is called an uncertain line.

Historical Background
To represent uncertainty in spatial data, many models suggested the introduction of broad boundaries replacing crisp ones in the case of regions [2,5,7,10,14] and lines [1]. The advantage of objects with broad boundaries is that they can be implemented on existing database systems at reasonable cost, being a direct extension of existing geometric models. Objects with broad boundaries corresponding to a 3-valued indeterminacy of a region’s location do not support any further hypothesis on the internal structure of the broad boundary. Other approaches utilize fuzzy sets [15] or probability theory [16], which describe the internal structure of the uncertain geometry with membership functions or probability distributions, respectively. These other
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Scientific Fundamentals

A region with a broad boundary is an extension of a region with a crisp boundary (for the definition of the latter, refer to simple regions with holes [3]). The following definitions are based on point-set topology:

Definition 1. A region with broad boundary $A$ is made up of two regions $A_1$ and $A_2$, with $A_1 \subseteq A_2$, where $\partial A_1$ is the inner boundary of $A$ and $\partial A_2$ is the outer boundary of $A$.

Definition 2. The broad boundary $\Delta A$ of a region with broad boundary $A$ is the closed subset comprised between the inner boundary and the outer boundary of $A$, i.e., $\Delta A = \overline{A_2} - \overline{A_1}$, or equivalently $\Delta A = A_2 - A_1^\circ$.

Definition 3. Interior, closure, and exterior of a region with broad boundary $A$ are defined as $A^\circ = A_2 - \Delta A$, $\overline{A} = A^\circ \cup \Delta A$, and $A^- = IR^2 - \overline{A}$, respectively.

Examples of regions with broad boundaries are illustrated in Fig. 1. If simple regions are substituted by composite regions, the most general case of composite regions with broad boundaries is obtained (Fig. 2).

In the case of lines, it is necessary to take into account the uncertainty related to the endpoints of the line (broad interior, Fig. 3b). These two independent aspects define the concept of uncertain line (Fig. 3c). They are defined as follows:

Definition 4. Given a simple line $L$, whose exact position in $IR^2$ is unknown but can be delimited by a bounded point set, the broad boundary of $L$ is the union of two point sets $BB_1(L)$ and $BB_2(L)$ that contain the two endpoints of $L$.

Definition 5. Given a simple line $L$, whose exact position in is unknown but can be delimited by a bounded point set, the broad interior of $L$ is a point set $BI(L)$ that contains the interior of $L$.

Definition 6. Given a simple line $L'$, an uncertain line $L$ is made up of a broad boundary $BB_1(L')$ and $BB_2(L')$ and a broad interior $BI(L')$. The boundary of $L$, indicated with $\Delta L$, is the union of $BB_1(L')$ and $BB_2(L')$. The interior of an uncertain line $L$, indicated by $L'$, is given by the difference $L' = L - \Delta L$.

For a point-like spatial phenomenon, the main source of uncertainty is related to the indetermination of its position in space:

Definition 7. Given a point $P'$, whose exact position in is unknown but can be delimited by a bounded point set, an uncertain point is a point set $P$ that contains $P'$. The boundary of an uncertain point is empty, while the interior of an uncertain point is equal to the uncertain point.

The models for expressing the topological relations between spatial objects with uncertainty are defined starting from the main models that apply to crisp objects, namely, the 9-intersection [9] and the CBM [6].
The 9-intersection model applied to objects with a broad boundary is expressed by the following matrix:

\[ M = \begin{pmatrix}
A^o \cap B^o & A^o \cap B & A^o \cap B^- \\
\Delta A \cap B^o & \Delta A \cap B & \Delta A \cap B^- \\
A^- \cap B^o & A^- \cap B & A^- \cap B^-
\end{pmatrix}. \]

An illustration of the 44 topological relations between regions with a broad boundary is given in Fig. 4 and the additional 14 relations for composite regions with a broad boundary in Fig. 5.

The topological relations of the CBM for objects with a broad boundary are defined as follows:

**Definition 8.** The relation \( \text{touch}(A, B) \) is true, if and only if:

\((A^o \cap B^o = \emptyset) \land (A \cap B \neq \emptyset)\)

**Definition 9.** The relation \( \text{in}(A, B) \) is true if and only if
\( (A^o \cap B^o \neq \emptyset) \land (A \cap B = A) \).

**Definition 10.** The relation \( \text{cross}(A, B) \) is true if and only if:

\[(\dim(A^o \cap B^o) < \max(\dim(A^o), \dim(B^o))) \land (A \cap B \neq A) \land (A \cap B \neq B).\]

**Definition 11.** The relation \( \text{overlap}(A, B) \) is true if and only if:

\[(\dim(A^o) = \dim(B^o) = \dim(A^o \cap B^o)) \land (A \cap B \neq A) \land (A \cap B \neq B).\]

**Definition 12.** The relation \( \text{disjoint}(A, B) \) is true if and only if \( A \cap B = \emptyset. \)
Spatial relations of the 9-intersection can be organized in a graph having a node for each relation and an arc for each pair of matrices at minimum topological distance [8], also called the conceptual neighborhood in [12]. The correspondence between the CBM relations and the 58 relations of the 9-intersection can be shown over the graph (Fig. 6) with a partition into four clusters.

The number of possible topological relations between uncertain lines is 146. In Fig. 7, they are listed by using a linear notation by rows for the values of the 9-intersection matrix.

**Key Applications**

A representation of a spatial phenomenon as an object with a broad boundary can have several semantic interpretations [17] and can be therefore used in a variety of applications.

**Incomplete Representation of a Feature**

In vector databases, if there are missing sides of a polygon or a line, due to omissions in digitization or imperfect data conversion, broad boundaries can be introduced to represent the possible location of the missing segments.

**Conflicting Representations of a Feature**

In the case of cadastral data, or representations of political boundaries (in general, the case of existing data that provide approximations to some real objects), broad boundaries can result from the merging of different representation of the same region.

**Changing Representations of a Dynamic Spatial Phenomenon**

If there are different observations of the same geographic phenomenon taken at different times, the core region may be interpreted as being the collection of locations that are in the region at all times, while the broad boundary may be interpreted as the collection of locations that are in the region at some, but not all, times.

**Imprecise Observation of a Spatial Phenomenon**

At a certain resolution (i.e., a partition of the space in which locations indiscernible from the observation are grouped into the same elementary unit of the space), the elementary units impose a granularity of the underlying space. A region with a broad boundary can represent an imprecise observation of a region at a certain resolution.

**Inherently Vague Representations of Real World Spatial Objects**

Most geographical objects that are not manmade artifacts or conventions fall in this category. They may be represented by fuzzy sets, if a reasonable method of quantifying the membership function for the fuzzy set is available. A region with a broad boundary is interpreted as an approximation in which the broad boundary of the region represents the part of the object where the membership function gradually decreases from 1 to 0. There are two special cases:

**Resulting from Scale Change** These are spatial objects that only exist at coarser resolutions (small scale), but are
constructed from more finely grained real world objects (large scale). Such objects may be obtained by semantic generalization, aggregating other objects of a different nature that exist at a larger scale. This is the case of urban settlements that are seen as an aggregation of other objects (such as houses, streets, subways, and bridges), or woods that are made up of trees. The broad boundary of such objects represents a peripheral zone where the density of the elements composing the aggregate has an intermediate value.

**Resulting from Variation of Context** These correspond to linguistic propositions made up of a geographic location plus a qualitative modifier. The boundary of a region “the south of England” is dependent on the context in which the linguistic proposition is placed and its intended use. It might be a different region if the proposition is placed in a historic, architectural, or biological context; finally, it might even depend on different opinions of individuals. Also, the qualitative modifier, like all qualitative spatial terms, has a different meaning depending on the granularity with which it is defined. For example, in the two domains for qualitative modifiers (south, center, north) and (south, north), the proposition “the south of England” would subsume a rather different underlying region.

**Future Directions**
Current spatial database systems do not contemplate any explicit mechanism to handle uncertainty, with the exception of some metadata information, such as the resolution used to capture the data. The main problem about spa-
tial objects that are stored in spatial databases is that it is impossible to reason about the degree of indetermina-
tion of a result, since data have lost the information about all the sources of uncertainty resulting from various transformations that data have undertaken. An adequate modeling of geometric uncertainty in spatial data is essential for the assessment of data quality, and, consequently, for helping any process related to dataset acquisition and integration [11,13].

Broad boundaries record the information about uncertainty together with the data in order to be able to deal with it during any kind of spatial analysis. Future research directions are the definitions of extended spatial operators for objects with broad boundaries to support a spatial database implementation.

**Cross References**
- Approximation
- Dimensionally Extended Nine-Intersection Model (DE-9IM)
- Imprecision and Spatial Uncertainty
- Moving Object Uncertainty
- Representing Regions with Indeterminate Boundaries
- Spatial Data, Indexing Techniques
- Uncertainty, Modeling with Spatial and Temporal
- Vague Spatial Data Types

**Recommended Reading**
OGC Web Services

MARKUS LUPP
lat/lon GmbH, Bonn, Germany

Synonyms

OWS

Definition

Open Geospatial Consortium (OGC) Web Services (OWS) are services defined by the OGC, allowing all kinds of geospatial functionality. They include services for data access, data display and data processing. OWS requests are defined using the Hyper Text Transfer Protocol (HTTP) protocol and are encoded using key-value-pairs (KVP) structures or Extensible Markup Language (XML). The most widely known OWS is the Web Map Service (WMS).

Main Text

The currently most important distributed computing platform supported by the OGC is the web, or to be more precise the HTTP. HTTP defines two ways for passing information between clients and services, one of them being HTTP GET, most commonly associated with the KVP encoding and HTTP POST, usually used in conjunction with XML-encoded requests.

They can be classified into application services, portrayal services, data services, registry services and processing services [1]. Application services define interfaces for human interaction. Humans use application services to access portrayal, data, registry and processing services.

Portrayal (or visualization) services allow the display of geospatial data. Examples for such services are the Web Map Service (WMS) for display of maps and the Web Terrain Services (Web Perspective View Service) for display of three-dimensional data such as digital building or terrain models.

Data (access) services can be used for accessing the original geospatial data. Examples for such services are the Web Feature Service (WFS) for access of geospatial features encoded in GML and Web Coverage Service (WCS) for access to geospatial data describing space-varying phenomena such as satellite imagery, digital elevation models or triangulated irregular networks (TIN). There are also more specialized data access services, for example the Sensor Observation Service (SOS) for managing deployed sensors and retrieving sensor and specifically “observation” data.

Registry (or catalog) services define mechanisms to classify, register, describe, search, maintain and access information about geospatial resources available in a network. The