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Grandchamp Enguerran

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Fuzzy-Vector Structures for Transient-Phenomenon Representation

Enguerran Grandchamp

Abstract This paper deals with data structures within GIS. Continuous phenomena are usually represented by raster structures for simplicity reasons. With such structures, spatial repartitions of the data are not easily interpretable. Moreover, in an overlapping/clustering context, these structures remove the links between the data and the algorithms. We propose a vector representation of such data based on non-regular multi-ring polygons. The structure requires multi-part nested polygons and new set operations. We present the formalism based on belief theory and uncertainty reasoning. We also detail the implementation of the structures and the set operations. The structures and the set operations are illustrated in the context of forest classification having diffuse transitions.

Keywords Data structures · Transient phenomenon · Forest classification · Fuzzy

1 Introduction

The content of paper lies at the crossroads of knowledge representation [16], fuzzy modeling [1, 6] and geographic information systems. Indeed, we propose a new way to represent uncertain knowledge within a GIS [2, 7, 8].

The fuzzy concept is used to represent uncertainty [3, 5]. A fuzzy set is based on a belief function f (see Fig. 1) [10–13], which gives for each point P of the space a confidence coefficient ($C \in [0, 1]$) regarding the membership of P to a given hypothesis or characteristics.

Within a GIS there are two ways to represent data [15]: a vector layer [4] or a raster one. Without loss of generality, let us consider spatial data in the rest of the article [i.e., two dimensions $P(x, y)$]. Spatial data can be classified in two categories: discrete and continuous. Discrete data—such as buildings, roads, or administrative

E. Grandchamp (✉)

LAMIA, Université des Antilles, Campus de Fouillole, 97157 Pointe-à-Pitre, Guadeloupe, France

e-mail: enguerran.grandchamp@univ-antilles.fr

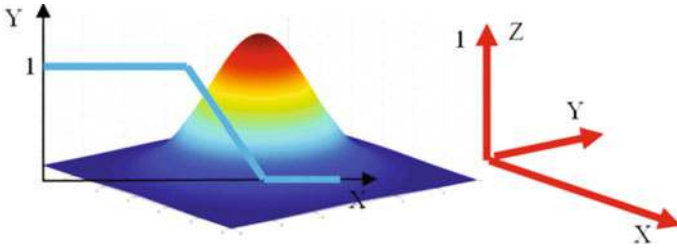


Fig. 1 One-dimensional (confidence along the y-axis) and 2D (confidence along the z-axis) Belief function

limits—naturally find a representation with the vector formalism because they have, by definition, a well-defined and localized border. In contrast, continuous data, often resulting from a phenomenon (such as temperature, humidity, ecosystem ground occupation, forests, etc.), find a better representation in a raster. The space is then divided in regular cells using a grid having a resolution depending on the required precision, the sources, or any other criterion such as memory limits to load or store the data.

In the GIS context, fuzzy structures are represented in a raster way (Figs. 1 and 2). We propose in this paper a vector structure for fuzzy sets as well as implementation and coding inspired by the standard notation WKT as defined by the OGC.

The rest of this article is organized as follows: Sect. 2 presents the standard notation for classical structures as defined by the OGC. Section 3 gives our formalism based on previous ones. Section 4 presents the constraints on the topology when building the fuzzy polygons, the fuzzy set operation, and the fusion of two fuzzy sets. Section 5 gives the conclusion and perspectives of the study.

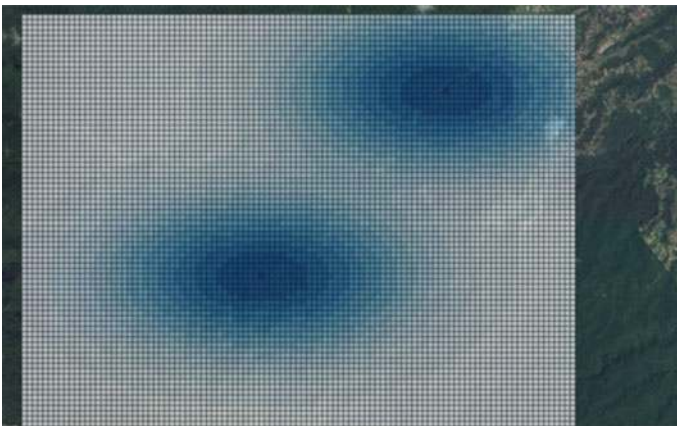


Fig. 2 Raster representation of fuzzy sets

2 OGC-SFS Formalism

In this section, we give a brief and partial description of WKT encoding, which is more detailed for polygons in order to prepare fuzzy description. For a complete description of WKT notation, readers are referred to [14].

2.1 Wkt

WKT (Well-Known Text) encoding allows the description of geometries with a simple string. Described points, lines and polygons can be the following:

simple or complex: A polygon is complex if it has an interior ring.

single or multiple (MULTI): composed of distinct objects

in two or three (Z) dimensions

with or without a measure (M) for each coordinate.

Table 1 gives some encoding examples, and Fig. 3 gives some illustrations.

3 Fuzzy Formalism

In this paper, we only deal with simple polygons (i.e., those without interior rings). The extension to complex polygons will be presented in another article. The main particularities with such polygons is the notion of interior and exterior, which is inverted for fuzzy rings starting from the interior ring of the fuzzy polygon.

Table 1 WKT examples

Geometry type	WKT example
XY POINT	POINT(850.12 578.25) One point
XYZ LINESTRING	LINESTRINGZ(10.0 15.0 30.2, 20.5 30.5 15.2, 25.90 45.12 75.6) Three summits
POLYGON	POLYGON((1.03 150.20, 401.72 65.5, 215.7 201.953, 101.23 171.82)) exterior ring, no interior ring POLYGON((10 10, 20 10, 20 20, 10 20, 10 10), (13 13, 17 13, 17 17, 13 17, 13 13)) exterior ring and interior ring
XY + M MULTILINESTRING	MULTILINESTRINGM((1 2 100.1, 3 4 200.0), (5 6 150.3, 7 8 155.4, 9 10 185.23), (11 12 14.6, 13 14 18.9))
MULTIPOLYGON	MULTIPOLYGON(((0 0,10 20,30 40,0 0), (1 1,2 2,3 3,1 1)), ((100 100,110 110,120 120,100 100))) Two polygons; the first one has an interior ring

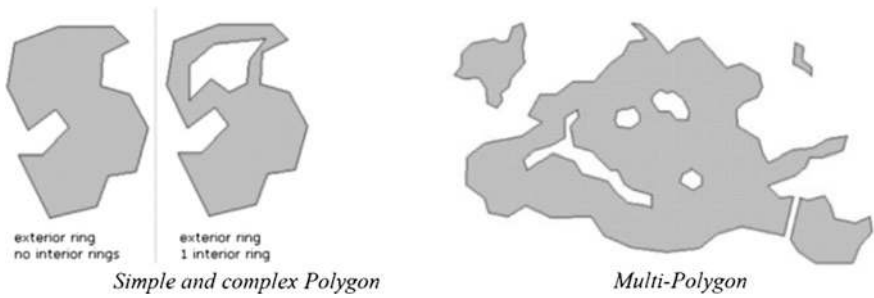


Fig. 3 Polygon and multi-polygon illustration

Fuzzy Ring

A fuzzy ring is a closed LineString representing a constant confidence value (C). The given notation in the WKT extension is as follows:

FuzzyRing C = LINESTRINGF(C , $X_1 Y_1$, $X_2 Y_2$, ..., $X_n Y_n$, $X_1 Y_1$)

With C in $[0,1]$

Fuzzy Polygon

A fuzzy polygon splits the space into two subspaces:

1. the exterior (*Ext*) of the fuzzy polygon is the subspace having a confidence (*Conf*) equals to 0: $Ext(FP) = \{(X, Y) | Conf(X, Y) = 0\}$
2. the interior (*Int*) of the fuzzy polygon is the subspace having a positive confidence (*Conf*): $Int(FP) = \{(X, Y) | Conf(X, Y) > 0\}$

FuzzyPolygon((ExteriorBorderFuzzyRing), (FuzzyRing C_1), ... (FuzzyRing C_n))

The Exterior ring has a confidence value = 0.

The ExteriorBorderFuzzyRing = FuzzyRing0.

The rings are listed in an ascendant order of confidence value. It is possible to have several rings with the same confidence (see Fig. 4).

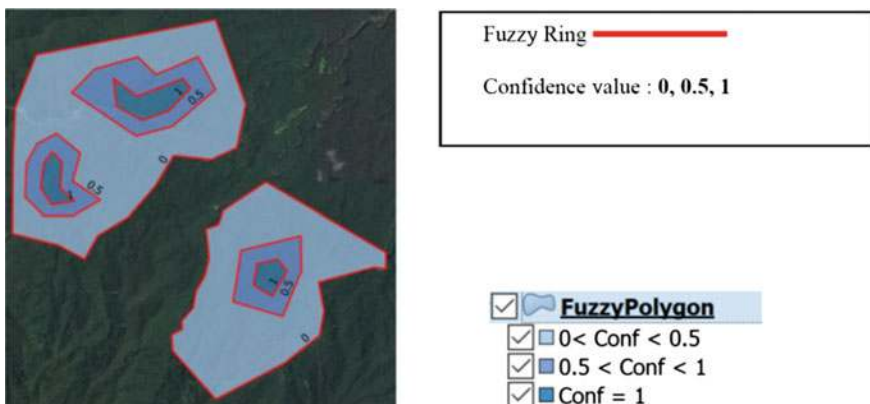


Fig. 4 Multi fuzzy polygon illustration

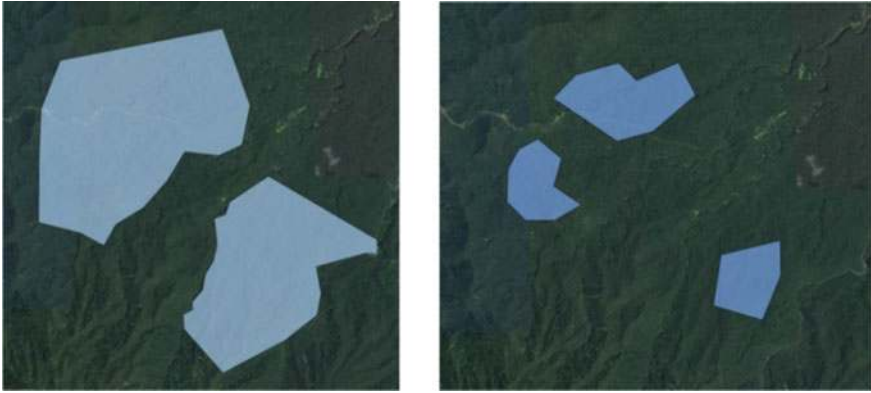


Fig. 5 Fuzzy polygon for confidence >0 and >0.5

By similarity with the previous notation, each fuzzy ring with confidence C taken separately can be viewed as a fuzzy polygon with the same confidence (FP_C) with one ring separating the space into two subspaces (see Fig. 5).

1. The exterior (*Ext*) of the fuzzy polygon is the subspace having a confidence (*Conf*) lower than C : $Ext(FP_C) = \{(X, Y) | Conf(X, Y) \leq C\}$
2. The interior (*Int*) of the fuzzy polygon is the subspace having a confidence (*Conf*) greater than C : $(Conf) : Int(FP_C) = \{(X, Y) | Conf(X, Y) > C\}$

A fuzzy multi-polygon is based on the WKT multi-polygon, and is a set of fuzzy polygon.

FuzzyMultiPolygon = MULTIPOLYGON((FuzzyPolygon₁),..., (Fuzzy Polygon_m)).

The extended WKT notation corresponding to Fig. 4 is as follows:

```
MULTIPOLYGON( ( (0, 636509.52544101 1790082.24725461, ...,
638329.97928085 1788083.94830689), (0.5, 636530.7885287
1788728.42395832, ..., 636640.38068263 1787639.0679111), (0.5,
637406.21786877 1789870.69902808, ..., 638042.35004102
1788857.08355125), (1, 636635.43399854 1788435.28033697, ...,
636590.60850521 1788064.5607564), (1, 637689.83884426
1789731.97180041, ..., 637743.94207098 1789302.2811451)), ((0,
639381.8755922 1787737.17118929, ..., 640929.70958006
1786226.83502128), (0.5, 639655.63021098 1787134.25010224, ...,
639655.63021098 1787134.25010224), (1, 639901.14677616
1786931.41452703, ..., 639901.14677616 1786931.41452703) ) )
```



Region with confidence in $[0,0.5[$
 $FP_0 \setminus FP_{0.5}$



Region with confidence in $[0.5,1[$
 $FP_{0.5} \setminus FP_1$

Fig. 6 Fuzzy set operations

4 Constraints on Topology and Fuzzy Set Operations

Constraints

The building of a fuzzy set is governed by some rules and constraints on the topology in order to guarantee the well-formed structure.

The main constraint is that there is no intersection (neither point nor lines) between the fuzzy rings.

This leads to a succession of rings (or polygons) inclusion. They represent a followed suit with the following rule:

$$C_1 > C_2 \Rightarrow FP_{C_1} \subset FP_{C_2} \text{ Then } FP_1 \subset \dots \subset FP_0$$

Fuzzy Set Operation

A fuzzy set is a set of regions labeled with a confidence. The regions represent a partition of the space from the highest confidence (1) to the lowest (0). The region with confidence between C_1 and C_2 is obtained with the set difference between FP_{C_1} and FP_{C_2} (Fig. 6).

Fuzzy polygon fusion

When two or more fuzzy polygons split the same geographical area, they must be merged. The set operation sequence allowing merging the fuzzy polygons is as follows:

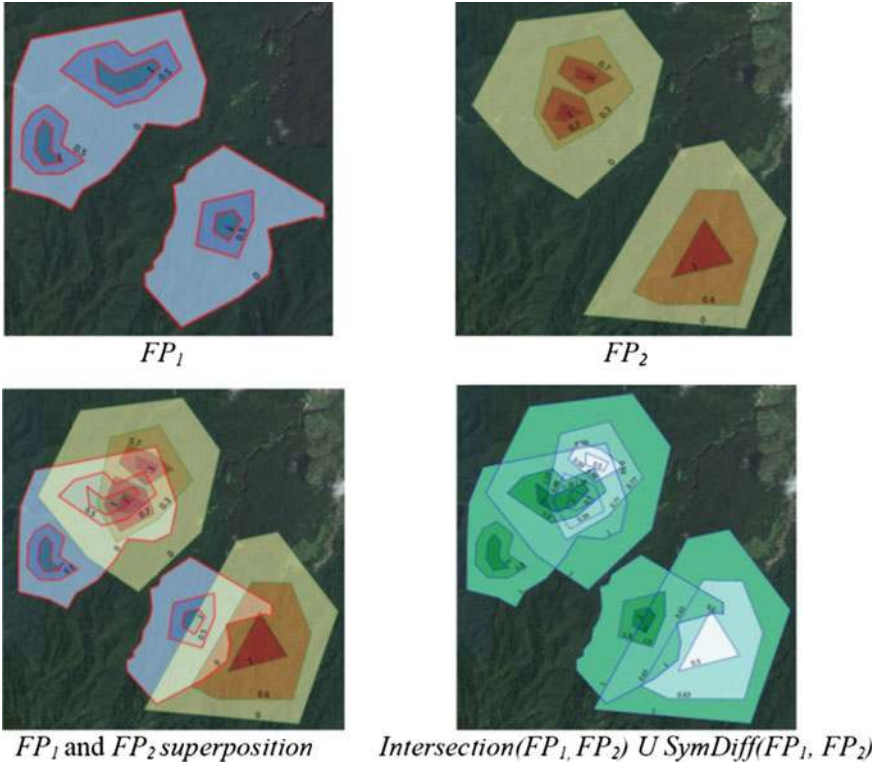


Fig. 7 Fuzzy polygons merge

1. I = Intersection between FP_1 and FP_2
2. SD = Symmetrical difference between FP_1 and FP_2
3. Merge Set = Union of I and SD

Figure 7 illustrates this principle.

The resulting fuzzy polygons have two confidence values. Depending on the nature of FP_1 and FP_2 , the meaning of the confidence of these two values can be ordered in a two-objectives way or within a single expression.

In Fig. 7, the expression used to display the resulting set is $(C_1 + 1)/(C_2 + 1)$.

5 Conclusion and Perspectives

We present in this paper an overview of fuzzy-vector structures within GIS based on the OGC standard WKT encoding. It also presents constraints and basic operation such as sub-region extraction and fuzzy-polygon fusion. A complete description of the

encoding of complex fuzzy polygons, as well as all of the operators, will be given in a future paper.

Management scripts are developed in JAVA and Python for a better integration within a GIS tool. Currently, we are working on a better representation of fuzzy polygons. Indeed, when a two-fuzzy polygon model shows two structures evolving close to each other (such as two types of forest or other ecosystems), and having a transition that spreads over a long distance, the diffuse border involves an overlap of the corresponding fuzzy polygons. We must develop a tool allowing us to automatically visualize the two fuzzy polygons at the same time.

Finally, in a classification perspective based on the fuzzy point of view, this approach raises the question of such a transition [9]. Belonging to one of the original classes or to another new one. This question will be discussed in another issue and will deal with multi-label classification, emerging class, and overlap classification.

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