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ATLAS

Artificial Intelligence Theoretical Foundations for Advanced Spatio-Temporal Modelling of Data and Processes

Task 3: Computational Intelligence base: Theoretical foundations

Report for the deliverable No. D3.3

Specification of the software tool for managing complex planar fuzzy spatial models

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Summary

This report presents the technical specification of the software tool for managing complex planar fuzzy spatial models. Specification is done according to the state-of-the-art open-source software components for the spatial modeling, GEOS architecture, OpenML approach and cloud-based service best practices. UML language was used for modeling. This software tool is the one of the key components in the ATLAS platform.

Keywords

UML, Client-server, Cloud based web application, GIS, fuzzy spatial models, uncertainty, ontology-based modeling

1. Introduction

In addition to functionalities comprising previously proposed fuzzy models of complex planar objects, our model of the software tool introduced two ontological models. The first model is an ontology of geospatial data which provides the semantic foundation of geospatial data integration and sharing. To manage uncertainties in data, the original ontology proposed in the paper "Geospatial data ontology: the semantic foundation of geospatial data integration and sharing" (2019) [1] was extended with elements that support fuzzy semantics of geospatial data relations. The second model is an ontology that describes Machine Learning domain [2]. The basis which we adopted for our software tool is an ontology described in the paper "A Machine Learning Ontology" (2020) [3], which consists of seven top classes (Algorithms, Applications, Dependencies, Dictionary, Frameworks, Involved, and MLTypes). We have modified this model to enable fuzzy descriptions of the classes Algorithms, Applications, Dependencies, and Frameworks expressing their suitability for the specific ML task.

This report consists of four sections. Following this introduction, several definitions and preliminaries related to imprecise spatial relations are presented in Section II. Section III Software specification is main part of this document and it contains main use-cases, architectural design, server and client packages and modules. Finally, Section IV contains concluding remarks.

2. Ontology based modeling of Complex planar fuzzy spatial models

In this section we are analyzing linear fuzzy space considering its applicability to spatial and temporal modelling. First subsection presents utilization of the linear fuzzy space for spatial modelling, while the second subsection considers its application to temporal modelling.

2.1. Spatial modelling - Model of 2D fuzzy spatial relations

In this subsection we present a model of fuzzy spatial relations, which can be used to describe imprecise spatial data from 2D images thus enabling semantic interpretation of images. Figure 1 represents the ontology of fuzzy spatial relations proposed in [4].

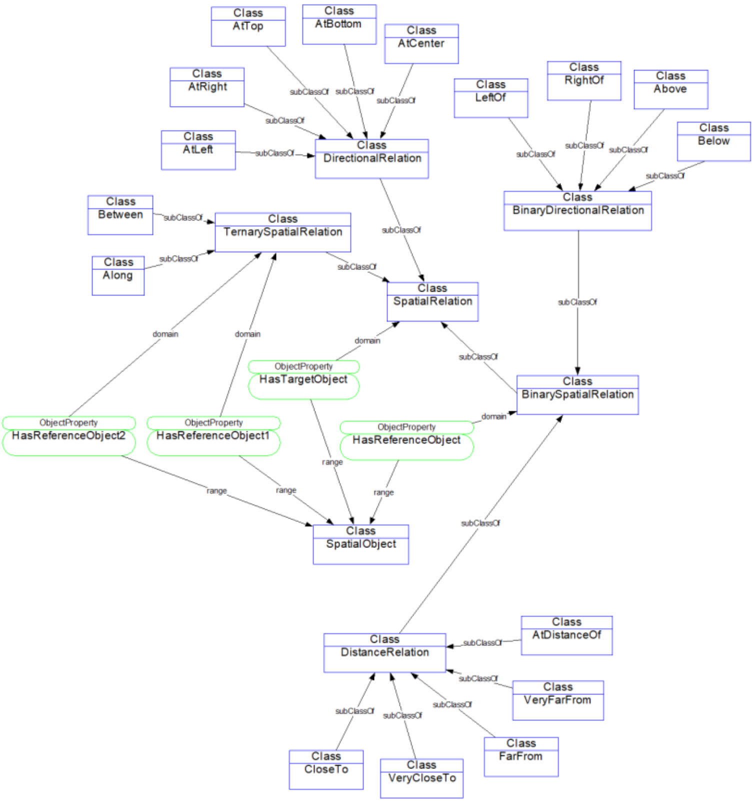

Figure 1 Ontology of fuzzy spatial relations

The ontology contains following basic concepts:

- *SpatialRelation* – fuzzy spatial relation.
- *SpatialObject* – fuzzy spatial object (for example, a fuzzy polygon in linear fuzzy space as defined in [7]).
- *ReferenceSystem* – reference system in which spatial relation is described (one spatial relation can be described in many ways, depending on the view perspective).
- *TargetObject* – instance of the *SpatialObject* concept. Represents the object for which spatial relation is determined with respect to some *ReferenceObject* which is also an instance of the *SpatialObject* concept.
- *DirectionalRelation* – concept that extends *SpatialRelation* concept. Allows modelling of unary spatial relation that represents position of a target object on the image.
- *BinarySpatialRelation* – concept that extends *SpatialRelation* concept. Allows modelling of binary spatial relations between reference and target object.
- *BinaryDirectionalRelation* – concept that extends *BinarySpatialRelation*. Allows modelling of position of target object with respect to reference object, e.g. “left of”, “above”, etc.
- *DistanceRelation* – concept that extends *BinarySpatialRelation*. Allows modelling of distance of target object from reference object, e.g. “(very) close to”, “at distance of…”, etc.

Using these basic concepts of fuzzy spatial relations and concepts of linear fuzzy space (fuzzy point, distance, fuzzy polygon) we have defined following models for elementary spatial relations [markov master rad, sisy2013].

Definition 1. Let P be a two-dimensional matrix which represents digital image. We call the fuzzy set F a *fuzzy spatial relation* if its membership function μ_F maps every element $P[i,j]$ of the matrix P in the interval [0,1]:

$$\mu_F(P[i,j]): P \to [0,1]$$

Definition 2. Let P be a two-dimensional matrix that represents digital image, whose width and height are w and h, respectively. Then, for every pixel $P[i,j]$ determined by coordinates i and j, the membership function value of the fuzzy spatial relation *AtLeft* (“at left side of the image”) is calculated as:

$$\mu_{AtLeft,d,g}(P[i,j]) = \begin{cases} 1, & if\ i \leq d \\ 1-(i-d))/g, & if\ d < i \leq d+g \\ 0, & if\ i > d+g \end{cases}$$

where $\boldsymbol{d}$ is a constant which defines the core, and $\boldsymbol{g}$ is a constant that defines the fuzziness of this fuzzy set.

Definition 3. Let P be a two-dimensional matrix that represents digital image, whose width and height are w and h, respectively. Then, for every pixel $P[i,j]$ determined by coordinates i and j, the membership function value of the *AtBottom* ("at bottom of the image") fuzzy spatial relation is calculated as:

$$\mu_{AtBottom,d,g}(P[i,j]) = \begin{cases} 1, & if\ j < d-g \\ (j-(d-g))/g, & if\ d-g \leq j < d \\ 0, & if\ j \geq d \end{cases}$$

where $\boldsymbol{d}$ is a constant which defines the core, and $\boldsymbol{g}$ is a constant that defines the fuzziness of this fuzzy set.
Fuzzy spatial relations *AtRight* and *AtTop* can be defined in analogous manner.

Definition 4. Let P be a two-dimensional matrix that represents digital image, whose width and height are w and h, respectively. Then for every pixel $P[i,j]$ determined by coordinates i and j, the membership function value of the fuzzy spatial relation *AtCenter* ("at centre of the image") is calculated as:

$$\mu_{AtCenter,d,g}(P[i,j]) = \begin{cases} 1, & if\ i^2+j^2 \leq d^2 \\ 1-(l-d)/g, & if\ d^2 < i^2+j^2 \leq (d+g)^2 \\ 0, & if\ i^2+j^2 \geq (d+g)^2, \end{cases}$$

where l is distance of pixel $P[i,j]$ from the center of the image, d is a constant which defines the core of this fuzzy set, and g is a constant that defines the fuzziness of this fuzzy set.

Definition 5. Let P be a two-dimensional matrix that represents digital image, whose width and height are w and h, respectively. Let $\tilde{p}$ be a linear fuzzy polygon in a linear fuzzy space. For the polygon $\tilde{p}$ that represents a reference object, we define two points: $maxTop$ (polygon point with smallest j coordinate), *maxBottom* (polygon point with largest j coordinate). If every pixel $P[i,j]$ is determined by coordinates i and j, then the membership function value of the fuzzy spatial relation *RightOf* ("right of") is calculated as:

$$\mu_{RightOf,g}(\tilde{p},P[i,j]) = \begin{cases} 1, & j_{maxTop} \leq j \leq j_{maxBottom}, i > right(j,\tilde{p}) \\ 1-\dfrac{g*\cos^{-1}(\theta)}{\pi}, & j < j_{maxTop}\ or\ j > j_{maxBottom}, i > right(j,\tilde{p}) \\ 0, & otherwise \end{cases}$$

where function $right(i,\tilde{p})$ returns maximal value of i coordinate from points of polygon $\tilde{p}$ whose j coordinates are equal to j coordinate of pixel $P[i,j]$. Value θ represents an angle which $P[i,j]$ forms with point *maxTop* (if $j < jmaxTop$), or point *maxBottom* (if $j > jmaxBottom$), and constant g represents fuzziness of this fuzzy set.

Definition 6. Let P be a two-dimensional matrix that represents digital image, whose width and height are w and h, respectively. Let $\tilde{p}$ be a linear fuzzy polygon in a linear fuzzy space. For the polygon $\tilde{p}$ that represents reference object, we define two points: *maxLeft* (polygon point with smallest i coordinate), *maxRight* (polygon point with largest i coordinate). If every pixel $P[i,j]$ is determined by coordinates i and j, then the membership function value of the fuzzy spatial relation *Above* ("above") is calculated as:

$$\mu_{Above,g}(\tilde{p},P[i,j]) = \begin{cases} 1, & i_{maxLeft} \leq i \leq j_{maxRight}, j < above(i,\tilde{p}) \\ 1-\dfrac{g*\cos^{-1}(\theta)}{\pi}, & i < i_{maxLeft}\ or\ i > i_{maxRight}, j > above(i,\tilde{p}) \\ 0, & otherwise, \end{cases}$$

where function $above(i,\tilde{p})$ returns maximal value of j coordinate from points of polygon $\tilde{p}$ whose i coordinates are equal to i coordinate of pixel $P[i,j]$. Value θ represents an angle which $P[i,j]$ forms with point *maxLeft* (if $i < imaxLeft$), or point *maxRgiht* (if $i > imaxRight$), and constant g represents fuzziness of this fuzzy set.

Fuzzy spatial relations *LeftOf* and *Below* are defined analogously.

Definition 7. Let P be a two-dimensional matrix that represents digital image, whose width and height are w and h, respectively. Let $\tilde{p}$ be a linear fuzzy polygon in a linear fuzzy space. Then, for every pixel $P[i,j]$ determined by coordinates i and j, l is a distance between $P[i,j]$ and reference object $\tilde{p}$, and the membership function value of the fuzzy spatial relation *(Very)CloseTo* ("(very) close to") is calculated as:

$$\mu_{CloseTo,d,g}(\tilde{p},P[i,j]) = \begin{cases} 1, & if\ l \le d \\ 1-\dfrac{l-d}{g}, & if\ d < l \le d+g \\ 0, & if\ l > d+g, \end{cases}$$

where d is a constant that defines the core of fuzzy set, and g is a constant that defines fuzziness of this fuzzy set. Values of d and g for relation *VeryCloseTo* should be smaller than those for relation *CloseTo*.

Definition 8. Let P be a two-dimensional matrix that represents digital image, whose width and height are w and h, respectively. Let $\tilde{p}$ be a linear fuzzy polygon in a linear fuzzy space. Then, for every pixel $P[i,j]$ determined by coordinates i and j, l is a distance between $P[i,j]$ and reference object $\tilde{p}$, and membership function value of fuzzy spatial relation *(Very)FarFrom* ("(very) far from") is calculated as:

$$\mu_{FarFrom,d,g}(\tilde{p},P[i,j]]) = \begin{cases} 1, & if\ l > d \\ \dfrac{l-(d-g)}{g}, & if\ d-g < l \le d \\ 0, & if\ l < d-g, \end{cases}$$

where d is a constant that defines the core of fuzzy set, and g is a constant that defines fuzziness of this fuzzy set. Value of d for relation *VeryFarFrom* should be bigger than for relation *FarFrom*.

Definition 9. Let P be a two-dimensional matrix that represents digital image, whose width and height are w and h, respectively. Let $\tilde{p}$ be a linear fuzzy polygon in a linear fuzzy space. Then, for every pixel $P[i,j]$ determined by coordinates i and j, l is a distance between $P[i,j]$ and reference object $\tilde{p}$, and membership function value of fuzzy spatial relation *AtDistanceOf*("at distance of") is calculated as:

$$\mu_{AtDistanceOf,d,g}(\tilde{p},P[i,j],r) = \begin{cases} 1, & if\ r-d < l \le r+d \\ 1-\dfrac{l-(r+d)}{g}, & if\ r+d < l \le r+d+g \\ \dfrac{l-(r-d-g)}{g}, & if\ r-d-g < l \le r-d \\ 0, & otherwise, \end{cases}$$

where r is parameter of the relation and represents desired distance from the reference object. Constant d defines the core of fuzzy set (allowed deviation from desired distance), a constant g defines the fuzziness of fuzzy set.

Previously defined elementary fuzzy spatial relations can be combined with use of operators *AND*, *OR*, *NOT*, and *SUBTRACT*, thus obtaining more complex fuzzy spatial relations. Following are the definitions of these operators.

Definition 10. Let F and G be two elementary fuzzy spatial relations. Then AND (conjunction) is a binary operator that composes relations F and G in such way that value of membership function for each pixel $P[i,j]$ is calculated as *minimum* of membership function values of F and G for pixel $P[i,j]$:

$$AND\big(\mu_F(P[i,j]),\mu_G(P[i,j])\big) = min\big(\mu_F(P[i,j]),\mu_G(P[i,j])\big).$$

Definition 11. Let F and G be two elementary fuzzy spatial relations. Then OR (disjunction) is a binary operator that composes relations F and G in such way that value of membership function for each pixel $P[i,j]$ is calculated as *maximum* of membership function values of F and G for pixel $P[i,j]$:

$$OR\big(\mu_F(P[i,j]),\mu_G(P[i,j])\big) = max\big(\mu_F(P[i,j]),\mu_G(P[i,j])\big).$$

Definition 12. Let F be an elementary fuzzy spatial relation. Then NOT (complement) is a unary operator that behaves in such way that value of membership function for each pixel $P[i,j]$ is calculated as *complementary* of membership function value of F for pixel $P[i,j]$:

$$NOT\big(\mu_F(P[i,j])\big) = 1-\mu_F(P[i,j])$$

Definition 13. Let F and G be two elementary fuzzy spatial relations. Then $SUBTRACT$ (subtraction) is a binary operator that composes relations F and G in such way that value of membership function for each pixel $P[i,j]$ is calculated as *minimum* of membership function value of F and *complementary* membership function value of G for pixel $P[i,j]$:

$$SUBTRACT\left(\mu_F(P[i,j]), \mu_G(P[i,j])\right) = min\left(\mu_F(P[i,j]), 1 - \mu_G(P[i,j])\right).$$

3. Specification of the software tool

Complex fuzzy temporal and spatial experiment modeling depends on software tool and data models which allows scientists to define, edit and remove large number of spatial samples. GIS tools are specialized for this kind of tasks but they are not adjusted to specific experiment driven modeling and it is hard to be included as integral part of Integrated Research Environment IRE.

3.1 Functional design

We are planning to build IRE as web-oriented platform where users can access through web browser so we are focused to web-based GIS libraries. There are several open source Javascript libraries for mobile-friendly interactive maps like: Leaflet and OpenLayers.

OpenLayers supports following formats: GeoRSS, KML (Keyhole Markup Language), GML (Geography Markup Language), GeoJSON and map data from any source using OGC-standards as WebMapService or WebFeatureService while Leaflet supports only basic formats like KML, GML and GeoJSON.

Figure 2. shows the main Use Case diagram with list of main software tool functions.

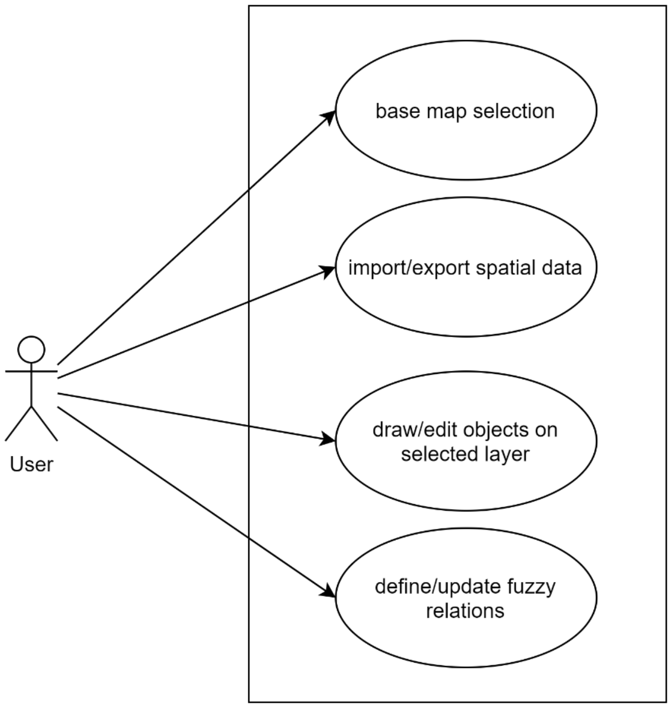

Figure 2. Functional design

Base map selection allow user to choose underlaying map. On top of base map all spatial data are organized in following hierarchy: project, layer and objects. Project contains more layers. All objects in one layer share at least one common

characteristic (for example, same date or same sensor or same country). Objects are defined according to ontology described in 2. They are represented by semantically connected set of basic fuzzy geometry models described in [5].
Data can be imported or exported in several different standard formats: GeoJSON, KML, GML or FuzzyGeoJSON.
Main parts of this software are tools for fuzzy models and fuzzy relations manipulation. Those tools are implemented by OpenLayer extension to support fuzzy spatial models and fuzzy relations.

3.2. Software architecture

Architecture used in this specification allows multiple clients share the same data which is stored in relational or NoSQL data storage. Server host manage all client requests divided into two main groups: functional and security. Functional part is implemented in Microservice architecture as collection of weakly coupled or completely independent components. Both Client and Server are designed in multitier software design pattern with separated model, view and controller layers. DB Servers are hidden inside private network.

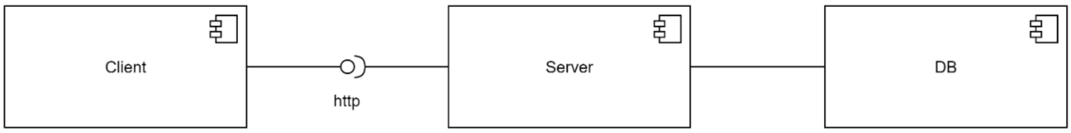

Figure 3. Client server architecture

3.3. Server

Server is implemented as the collection of the REST services. Those services enable bidirectional communication between client components and database. Along with basic CRUD operations on spatial and temporal data it allows fuzzy extensions of discrete geometry object definitions.

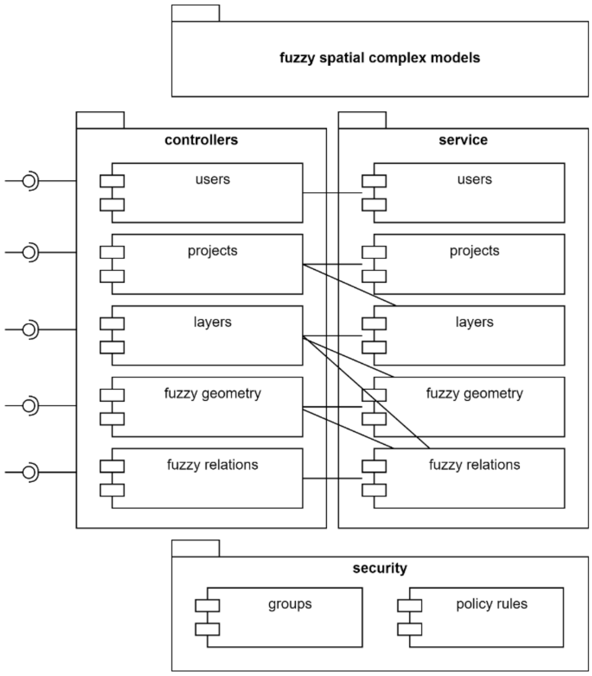

Figure 4. Server's packages and modules
Server consists of four main packages: data models, controllers, services and security (Figure 4.).

3.4. Client

Client components (Figure 5.) are designed as set/collection of web plugins or independent components which allow end user to manipulate different map views, define, update and delete geometry and fuzzy spatial complex models.

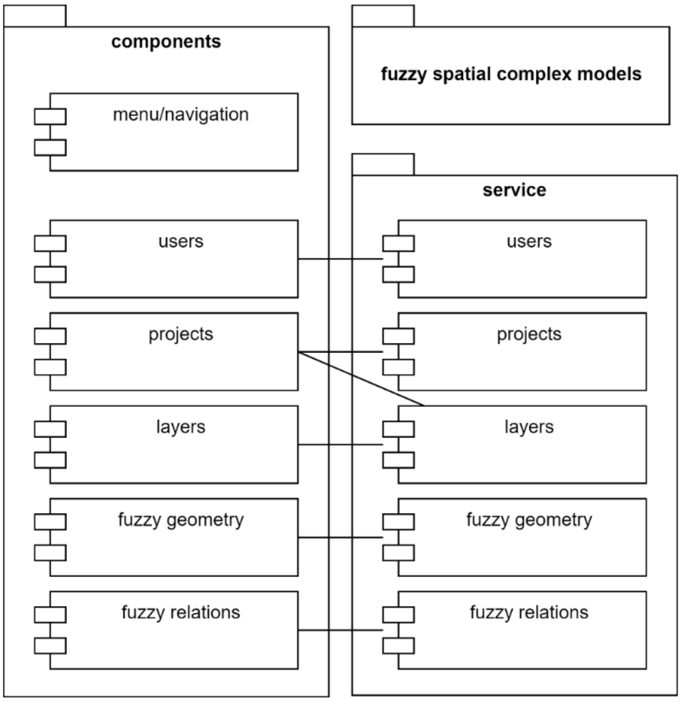

Figure 5. Client packages and modules

Design pattern used in client specification is multi-tier with three main layers: model – view – controller. Component part contains both html view and javascript controller. Service package contains all modules which will implement communication with server side.

4. Conclusion

This report presents a specification of the software tool for managing complex planar fuzzy spatial models and mathematical model of the fuzzy spatial relations.
Specification is presented using UML language with main use-case diagram, architecture design, server and client packages and modules.

Software tool for managing complex planar fuzzy spatial models mainly will be used for training set preparation but it will be used for result visualization and all other use-cases where uncertainty and imprecision in spatial data is present.

The proposed specification and models of fuzzy spatial relations are intended for GIS (imprecise spatial object modeling), but also apply to various other domains such as image analysis (imprecise feature extraction), robotics (environment models), etc.

References

[1] Yaser Bishr, Werner Kuhn, Ontology-Based Modelling of Geospatial Information, 3rd AGILE Conference on Geographic Information Science – Helsinki/Espoo, Finland, May 25th – 27th, 2000

[2] Juliao Braga, Joaquim L R Dias, Francisco Regateiro, A MACHINE LEARNING ONTOLOGY, frenxiv.org, Novembar 2020

[3] Vaishak Belle and Ioannis Papantonis. Principles and practice of explainable machine learning. arXiv preprint arXiv:2009.11698, 2020

[4] C. Hudelot, J. Atif, I. Bloch, Fuzzy spatial relation ontology for image interpretation, Fuzzy Sets and Systems, Volume 159, Issue 15, 2008, Pages 1929-1951,ISSN 0165-0114,

[5] Obradović Đ., Konjović Z., Pap E., Rudas I.J. (2013) Fuzzy Geometry in Linear Fuzzy Space. In: Pap E. (eds) Intelligent Systems: Models and Applications. Topics in Intelligent Engineering and Informatics, vol 3. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-33959-2_8