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EXECUTIVE SUMMARY OF THE DISSERTATION

Adaptive Management of Multimedia and Georeferenced Contents: the MAGIS Approach for Citizen Journalism

TESI MAGISTRALE IN MANAGEMENT ENGINEERING – INGEGNERIA GESTIONALE

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Abstract

The present dissertation illustrates a web-based framework where geographic maps are associated to knowledge, linking geographic elements with geo and temporal-referenced multimedia contents. Among the key features, multimedia content integration, time management and self-adaptivity to different application contexts are the most relevant ones. A hybrid approach is proposed to classify stored contents, that combines a Machine Learning (ML) technique for text classification with the intervention of human experts. A dynamically configured user navigation is hence proposed based on the adaptivity of the tool to dynamic classification of contents. Adaptive navigation is supported by a domain-specific ontology defined in this Thesis. The overall approach is presented in a framework and prototype named *Multimedia Adaptive Geographic Information System* (MAGIS), representing an extension to existing Geographic Information Systems (GIS), and conceptually devised as a common foundation to be adapted to different domain-specific implementations. A practical demonstration in the form of a web-based prototype is provided in one context, namely *Citizen Journalism (CJ)*, where users (both common and specialised) can tailor their navigation according to selected topics. The purpose of the CJ use case described in the Thesis is to detail how the framework gets instantiated in a semi-automatic way using both ML and human intervention.

1. Introduction

Among the most recent aims of geographic-based applications, the aim of enriching maps with georeferenced content is prominent, allowing one to explore selected areas and run thematic, multilevel analyses [1]. This is achieved by supporting exploration of various levels of interest and many zoom levels: from the largest one, enriching navigation by accessing more linked content, to the narrowest one, focusing on details of interest. In existing applications, some features are still lacking or awkward in highly dynamic contexts, like citizen journalism, where contents vary in real-time and in a seamless way.

This dissertation proposes a framework, called MAGIS, to associate structured and unstructured multimedia data to geographic maps, creating a web environment that can be navigated both geographically and temporally. The framework is a logical structure to be instantiated into domain-specific implementations via dynamic layers, which are obtained classifying content items according to topic-specific tags. These tags are interconnected through a domain-specific ontological structure.

The integration of structured data into geographic maps is already achieved by effective and widely used solutions, such as map thematization and choropleth maps [2]. In that kind of system, *data navigation* is typically carried out by applying filters on measurable values, and *data analysis* can be performed with statistical and analytical tools typical of business intelligence. Conversely, this proposal aims at integrating cartography with unstructured data, which appears as a less established area. Unstructured contents typically include media elements, such as images, videos, texts, or any other document file, together with a set of metadata describing the content item. Georeferenced multimedia is particularly important in fields like Cultural Heritage (CH) or the field of Citizen Journalism, which bring together heterogeneous types of content, like textual posts, pictures or video and audio recordings. In this Thesis, we present MAGIS in the area of Citizen Journalism, which deals with participatory news, local papers, blogs and social media.

Another feature of MAGIS framework is that contents can be linked to both spatial and chronological references. The framework is designed to manage the *temporal dimension* of information and the user can display the chronological placement of contents over time. For example, it will be possible to retrieve the content associated with a geographical area in a certain historic period or to inspect how a single element has evolved over time (e.g., pictures documenting variation of style of a building through interventions). Temporal information can be present optionally, only in contexts where this dimension is relevant. This is particularly important for historical events or journal news, which both contain inherent chronological contents.

By instantiation of the MAGIS framework, designers of a multimedia-based geographic information system can develop an application addressing a specific domain context. Therefore, a key feature of the MAGIS framework is its *adaptability* to different application domains, also named contexts. Sample contexts are history, architecture and urban planning, tourism, intangible CH, digital twinning of artefacts and buildings, and so on. For example, the model can adapt to the *intangible heritage* context using pictures of the different events occurring in each geo-referenced area, with videos, pictures, advertising posters, and recordings of musical tracks.

The objective is to enable the model to be instantiated onto different contexts via self-adaption, based on *automatic content classification*. This issue is one *innovative feature* of our approach, that achieves *system adaptivity* to contexts. Its purpose is to automatically adapt the *navigation interface* to the available contents. In fact, one of the desired goals is to mitigate the *information overload* that would occur when showing all the content items at the same time.

To facilitate content navigation and reduce information overload, allowing users to focus on a subset of contents of their interest, the framework introduces *dynamic aggregation criteria* and reduces the multitude of objects that can appear on the map. Selection and aggregation are based on spatial navigation (map panning and zooming) on items chronology and, especially, on *thematic tags*. The selection and aggregation criteria are dynamic, namely, they depend on the available contents and on their classification.

The framework performs dynamic filtering and aggregation of content items based on three semantic properties, namely *location, time*, and *topic* as follows:

- Geographic location aggregation is obtained via spatial clustering, a technique typical of geographical maps.
- Time aggregation is based on a calendar hierarchy.
- Thematic topics aggregation is based on a domain-specific ontology and is implemented through layers.

The adoption of an *ontology* facilitates the exploration of associated knowledge, by considering correlations and logical connections among content items. Besides supporting context-adaptive presentation and information overload reduction, the ontology is used to achieve a *language-independent content navigation*, that often represents an issue in geographic systems [3].

The separation among distinct topics gives the possibility to *filter* the elements of interest during the navigation, or to *cluster* them according to spatial or semantic criteria, so reducing information overload. Therefore, the navigation of multimedia content is organised in *layers* representing different topics. The *basic* layer is the map itself where cartographic objects are visualised, while subsequent layers are automatically created to display topic-specific contents.

Layers are *dynamic* (not predefined), considering the available content and user preferences. The definition of layers requires that the contents be *classified:* the classification must be specific to the application context, namely, based on *context-specific tags*.

Coming to the implementation issues, the proposed framework is a Machine Learning (ML)-based software prototype that considers various contexts, such as urban planning, history, citizen journalism and participatory design, which can be used by experts and be enriched by users/citizens via specific upload tools, which also validate data before they are definitively stored. The interested reader is referred to ILAUD [4] for an initial discussion about the generation and use of maps in the contexts of urban design and participatory planning.

The Executive Summary is organised as follows. In Section 2, related work is presented. In Section 3, the approach to enriching maps with knowledge is explained. In Section 4, a demonstrative prototype shows how the framework has been implemented. In Section 5, the presented issues are summarised, and future work and conclusions are outlined.

2. Related work

Nowadays, geographic applications are a widespread object of study. Developers are implementing many different solutions that combine geo-referenced information related to a map, ending up with maps that can be used either as general interest exploration tools or as professional tools for advanced analyses purposes. Many geographic tools have been proposed in literature in different contexts, each based on thematic content to address specific needs. Among the most common applications, Geographic Information Systems (GIS) are software platforms specialised in gathering, managing, and analysing geo-referenced data.

GIS reveals deeper insights into data, such as patterns, relationships, and events, helping users in taking smarter decisions [5]. Some examples of GIS platforms available today are *ArcGIS* by ESRI [6], *GISMaker* by ProgeCAD [7], and *PostGIS*, the special database extender for the open-source object-relational database PostgreSQL [8]. MAGIS framework is to be considered – under this viewpoint – a GIS framework or a portion thereof, which can lead to the development of components to be eventually incorporated in a commercial product as add-on components.

Over years, developers have also implemented a GIS extension, namely 4-D maps, by including changes of map elements over time, leading to *Temporal GIS* [9]. Temporal information has been incorporated into spatial data models of GIS by time-stamping layers (the snapshot models [10]), attributes (space-time composites [11]), and spatial objects (spatiotemporal objects [12]). In [13] the main achievements of spatiotemporal modelling in the field of Geographic Information science are presented. The paper overviews Temporal GIS, spatiotemporal data models, spatiotemporal modelling trends and future trends in Temporal GIS.

By adding information about historical events to maps, Historic Atlas tools illustrate the evolution of historic events and phenomena characterising different geographical areas in a certain era. One example is *GeaCron* [14], an interactive Global Historic Atlas from 3000 B.C.

Other GIS platforms focus on map-based tools to run specific *data analyses*, especially exploiting Big Data and making use of ML and Data Mining algorithms. This makes the role of the map shift from an independent tool to a basis for the integration of additional instruments. Study [15] introduces ML models and their potential applications to geospatial data, with a particular focus on artificial neural networks and statistical learning. Authors in [16] propose the *Picterra Tool* [17] as "A relatively easy to use interface that allows users to upload remote sensing images whereby users can identify and train an automated detector to find and detect objects of interest". In [18], some socio-economic indicators (i.e., residents, unemployment, migration, and elderly) were predicted based on OpenStreetMap (OSM) using ML algorithms.

Recently, new types of GIS have been implemented to make the system flexible enough to collect multimedia content as well. In contrast to traditional GIS, *Multimedia GIS* (MM-GIS) [19] can collect, analyse and store data in unstructured formats, i.e., text, images (pictures) and graphs as well as audio (sound), animations and video (moving pictures). Current examples of MM-GIS on the market are *ArcGIS Insights* and *ArcGIS StoryMaps* by ESRI [20], [21].

The user interface is an aspect of GIS where further improvements are still needed. Some research has highlighted the need for more dynamic and adaptive map layers, as in [22].

An innovative theme recently investigated regards queries in natural language applied to GIS, which require a semantic representation of geographic objects. Semantic analysis tools, typically based on an *ontology*, allow some logic or probabilistic deductions from a base of geo-referenced data. To improve the quality of noisy and ambiguous data of OSM caused by its simple and open semantic structure, [23] proposes the development of an OSM Semantic Network to compute semantic similarity through co-citation measures, providing a novel semantic tool for OSM and GIS communities.

The exploitation of semantic meaning to facilitate content navigation is often assisted by the presence of an ontology, as in [24], whose support is beneficial in the specialisation of concepts within each context, such as in the CH domain described in [25].

3. Adding Knowledge to Maps

3.1. The MAGIS Approach

To tackle the *classification requirements* discussed above, the MAGIS framework and tool adopt a hybrid approach based on Artificial Intelligence (AI) combined with human expertise. In this hybrid approach, the classification is carried out by a combination of an *expert-driven* and a *supervised ML-driven* process. Specifically, a domain expert defines an ontology that includes context-specific semantic categories, and then manually classifies a training set of contents. Then, the contents gradually collected during the life cycle of MAGIS are automatically classified by the ML algorithm, associating each content to an ontology node.

Classifying each content item manually is a resource (time, money, effort) -intensive operation. When content is classified manually in a crowdsourcing way, e.g., by volunteer contributors, it can be less intensive but prone to inadequate classification. Therefore, in order to import contents from massive existing archives with no need for manual classification of contents, *automatic classification* is extremely beneficial, particularly if it can be performed at run time.

Instead, manual classification is preferable when content items are a few and training a ML model is unjustified, or when no associated metadata are available. The human expert can also intervene on-demand when some *confidence indicators* about automatically classified data are lower than a given threshold.

To classify content topics, MAGIS relies on textual metadata associated to multimedia items, which are typically a textual title or a short description (e.g., a title or a caption from a picture), a post on social media, or a text taken from a blog, a forum, or an online newspaper. The classification phase is based on text analysis performed with AI tools [26], allowing automatically analysing texts and extracting relevant information. Directly analysing the media could be an option, but many different algorithms would be needed according to the type of content; therefore, this approach is currently excluded from MAGIS.

What makes dynamic classification valuable is that a predefined content classification would not be suitable for different thematic contexts, while content navigation based only on textual search is heavily limited by language dependence.

By adopting an ontology in MAGIS, it is possible to dynamically manage the granularity of aggregation criteria and to perform content selection. For instance, if the number of items available for a given content topic is too limited, the navigation layer is built on the upper hierarchical level topic. If too many items are retrieved, the navigation layer is split into a lower-level hierarchy. This way, one can automatically move upwards and downwards the hierarchy according to available contents. This dynamic approach is a novelty of this proposal.

3.2. MAGIS Functional Architecture

MAGIS includes several software components intended to manage the whole lifecycle processes, from acquisition and storage to analysis and presentation of the related contents.

In general, the development of a geographic-based application involves four relevant sets of activities [5] on data:

1. *Acquisition* collects thematic data and metadata from different data sources.
2. *Representation* organises the acquired data into a unified formal codification.
3. *Analysis* manipulates and queries data to extract information and knowledge useful for thematic analysis.
4. *Visualisation* renders the output of the analysis available to end-users through an appropriate visual representation.

In MAGIS implementation, *Acquisition* is performed when data are collected from external sources; *Representation* refers to mapping acquired data into an ontological structure; *Analysis* is related to the automatic content classification and retrieval; *Visualisation* refers to the navigation interface and content filtering.

The functional architecture of the proposed cartographic system is shown in Figure 1, together with its components and modules. The overall framework is aimed at both individual citizens and Public Administrations or professional users, such as architects and urban designers, university researchers or media professionals. Each category can authenticate to the platform and will be granted access to different contents and functionalities according to their needs and roles.

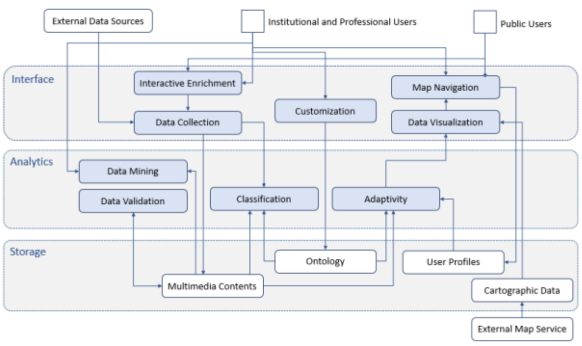

Figure 1 - The framework components

The *Storage* area contains a spatial database for cartographic data, and a database storing information about contexts and multimedia data. The *User profiles* module manages data accesses and users' preferences, which is important for selective navigation and recommendation. The *Ontology* module is the core of MAGIS: it organises multimedia contents for content classification and retrieval.

The *Analytics* area contains the key algorithms performing analyses and data aggregations. The *Classification* module implements the grouping of contents based on thematic tags and manages their connection with ontological classes. The *Adaptivity* module uses the context-specific ontology to organise the presentation and navigation of content on the map. *The Data Validation* module assesses the quality of data acquired from external sources and contributors, while *Data Mining* will allow – in a later development stage – qualified users to conduct complex analyses by combining structured data with multimedia content.

The *Interface area* uses information about users' profiles and data types to discriminate access to multimedia. A public (open access) set of data allows people to navigate the map and enrich it with their multimedia content. A private set is instead dedicated to registered professional users who can customise their view on the map, by defining their classification ontology. The *Data Visualisation* and *Map Navigation* modules aim at reducing information overload by presenting to users an adaptive content organisation, driven by the context-specific ontology, and implemented by dynamic clustering and filtering.

3.3. MAGIS Data Model

In this paragraph, the basic elements of the ontology for cartographic knowledge are presented (geographical objects, georeferenced data, and relationships with each other) that enables semantic analysis, navigation, and dynamic maintenance of the content associated with the map.

The general ontology is a *meta-structure* of concepts that is valid for all domain contexts and plays the role of an abstract reference from which the data model is derived. To adapt to different contexts, the data model is generic and extendable. This structure is then required to be made concrete into a domain-specific second-level ontology according to the application field.

The ontology represents both the geographic elements that constitute the map layer and classes representing media contents, organised into different thematic topics, and including their metadata, as shown in Figure 2.

The schema is divided into two main areas enclosed into dotted-line frames. On the top part of the figure, the classes related to the management of cartographic data are placed. The central class is the *Map Element*, representing the generic item that constitutes a certain portion of the map layer. It is defined with its geographic coordinates and can represent a single point (e.g., a monument), a line (e.g., a street) or a polygon (e.g., an area).

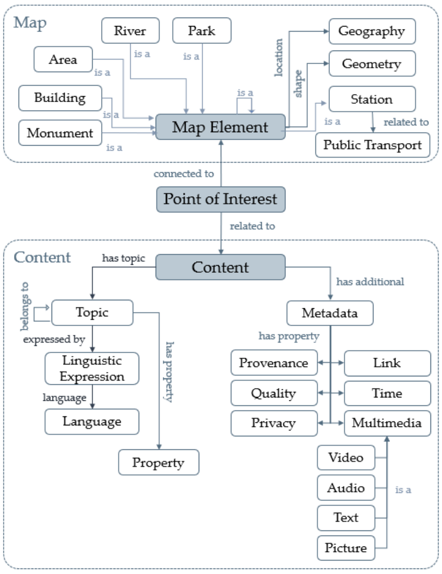

Figure 2 - The general meta-ontology

The bottom part of the figure is related to the content items managed by the framework. The central element *Content* is surrounded by a set of other classes and subclasses that represent its attributes and properties. A group of classes deals with the nature of the content item including the temporal dimension. The media element is managed as a link so that potentially any type of document or unstructured dataset can be managed. A central role is also played by the *Topic* of the multimedia, which is the key for the classification phase.

The link between the two main areas is the class *Point of Interest* (POI). The choice to separate the POI from content items allows aggregating various contents related to the same place (such as artworks housed in a museum or events that happen in the same location).

Figure 3 represents the *time dimension* of content. Time is characterised by different levels of granularity and different aspects that can be associated with it. For instance, it can map the date when a web article was written or published, when a picture was taken, or when a document was edited. It can also represent the moment when the *subject* of the content item (e.g., an event) takes place, like the date of a theatre performance or the time window of a museum exhibition.

Declining this structure according to different temporal units of measure, the ontology becomes able to classify the uploaded data according to temporal tags, like the day of the week, the month, or the year, or to assign a time instant or a time interval allowing the user to investigate time-related queries. The representation of a *time hierarchy* facilitates information retrieval rather than a single timestamp. For instance, a user may be interested in investigating the sport-related journalistic news published during a certain month in a certain geographic area.

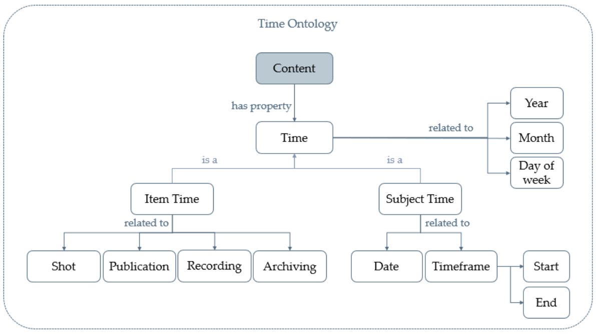

Figure 3 - Details about time dimension in the ontology

Another qualifying aspect of this data model is the *integrated management* of aspects related to the origin or provenance of contents. Issues related to data privacy, ownership, licensing, and reliability are included by design into the data model, to distinguish data sources that are to varying degrees authoritative, trusted, voluntary, institutional, and so on.

This is meant to allow importing and fetching *multimedia content* from different sources. Data may be provided by various users, professionals, or volunteers, or from massive data sources such as already existing data archives and hence heterogeneous in format and quality.

3.4. Data Analysis and Content Classification

As previously introduced, the content classification module is a critical component to achieve the system adaptivity to various contexts. The objective of content classification is the identification of tags describing the content. When information is contained in texts, we deal with techniques of text analysis. With this aim, two main classes of techniques can be used, i.e., *Text Extraction* and *Text Classification*, both exploiting ML and AI methodologies [26], such as Natural Language Processing (NLP).

Text extraction is meant to extract pieces of data that already exist within any given text (e.g., keywords, prices, company names, product specifications etc.). In this category of algorithms, *Keyword Extraction* and *Entity Recognition* are probably the most appropriate applications for this framework. Text extraction can be used to index data and generate tags that can become part of the ontology or recognise POIs.

Text classification is the process of assigning predefined tags or categories to unstructured text. Within this category, *Topic Analysis* is a supervised ML algorithm that can recognise the most relevant topics in a text. In this project, after training performed under the supervision of a domain expert, the algorithm can be used to automatically classify new contents according to the current ontology of tags.

For automatic classification, among the solutions available online, the supervised *Short Text Classifier* developed by *MonkeyLearn* [27] has been identified as a suitable candidate for this analysis. The reasons for this choice stand in the following benefits:

a. It is specialised in short texts, which applies well to the input data of this project (i.e., the title and the brief description of the media).
b. Besides a predefined bag of words, the user can define his own set of tags to use in the classifier, improving personalisation.
c. *MonkeyLearn* website offers a free Academic plan.

Once data have been collected, semantic tags describing their topics must be assigned, starting from available metadata. These domain-specific tags describe contents according to the topic ontology specified by experts at system definition time, or during the application life. Semantic tags will form the basis of domain-specific knowledge navigation tools, such as layering (subdividing contents based on sub-topics or other properties), filtering and faceted search [28] (selecting only a subset of contents) or clustering (grouping contents based on some user-defined criteria), in combination with the time dimension, when available.

4. The MAGIS Prototype: Functionalities and Use

To test the features of the framework, a web-based prototype application was developed, named MAGIS (Multimedia Adaptive Geographic Information System). The prototype simplifies the general ontology of the framework, and the way contents are stored and managed, as it is a pure demonstrative implementation. Geographic data constituting the base map layer have been taken from *OpenStreetMap*, an open-source platform available on the web [29].

The selected example domain is *Citizen Journalism* (CJ), which collects news and journalistic articles giving an overview of facts and events of a defined geographic area. Contents will include local news, environmental reports, fashion, or cultural events. Possible open data sources can be exploited for news and articles, e.g., considering local social media pages (e.g., the Facebook page '*Eventi Milano*' [30]), municipal websites (e.g., '*Comune di Milano*' [31]) or local online newspapers (e.g., *Milano Today* [32]). Once collected and stored in a proper database, content items have been assigned to defined points of interest thanks to an interactive assignment to a map location.

The intent is to obtain a dynamic adaptive system, designed to adapt not only to different thematic contexts but also to contents that vary over time, therefore not entirely available in advance. This is achieved *via self-adaption*, based on automatic content classification on a set of semantic tags. Figure 4 shows the ontology of semantic tags that has been used for CJ prototype.

The *Classification* is performed by a mixed approach that combines a domain-specific ontology designed by a domain expert with a ML text classification algorithm (the Support Vector Machine was chosen after a comparison with

Multinomial Naïve Bayes) operating on content metadata. This avoids the need to manually classify each item, allowing massive content import or fetching contents in real-time from the Web. Before training the algorithm, some comparative tests have been carried out with a limited set of data to define the most suitable combination of setting parameters (type of algorithm, tagging language, stopwords, etc.).

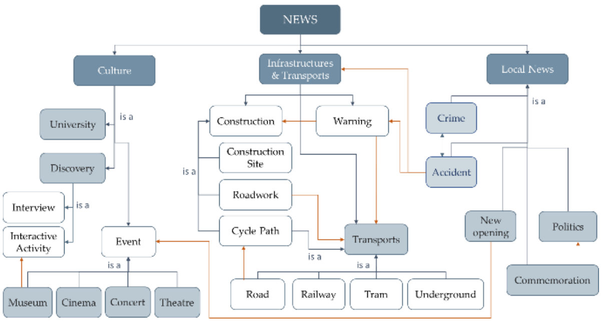

Figure 4 - Tag Hierarchy Citizen Journalism

The ontology, instantiated by domain-specific contents, becomes a tool supporting the presentation layer of the multimedia geographic system. Ontology-based classification is aimed at facilitating content navigation through selection and aggregation tools, automatically tailored to contents and faceted search, to reduce information overload during the georeferenced knowledge search and navigation.

The website of the prototype can be found at the following web address [33]. Figure 5 shows an overview of the user interface, where points of interest are depicted by markers on the map Clicking on a marker, a list of associated content items is shown aside the map, each correlated by a few metadata and a picture representing the news, if available.

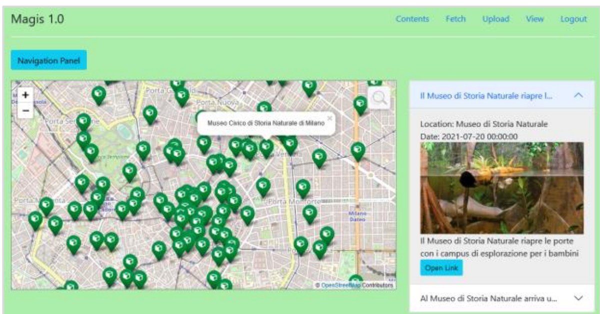

Figure 5 - MAGIS User Interface

By using the "Navigation Panel" button, a list of keywords allows to filter contents based on the topic and the time span selected by the user (Figure 6). The highest filtering level classifies contents according to the three main topic hierarchies, namely *Culture, Transports* and *Local News*. Clicking on each class, a drop-down list appears showing the related tag hierarchy. The topic tree is dynamically generated starting from the ontology and the contents collected for each topic category.

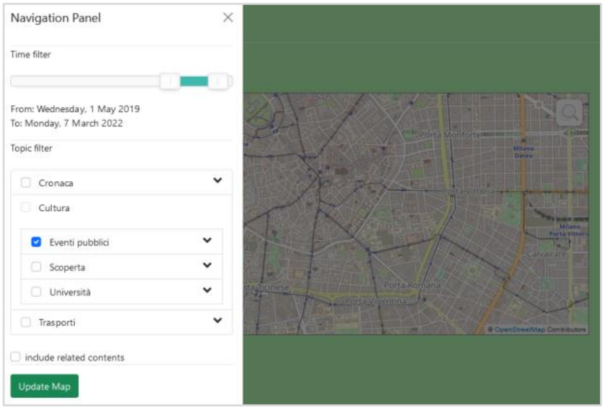

Figure 6 - MAGIS Filter Panel

5. Comments, Future Work and Conclusions

In this dissertation, the MAGIS framework (Multimedia Adaptive Geographic Information System) is presented together with a data model to associate semantic content to cartographic elements. Multimedia management, temporal references and adaptability are the key features. This conceptual structure can be adaptively instantiated by specific applications in different domain contexts.

To test the features of MAGIS, a prototype application has been developed. The intent is to obtain a dynamic adaptive system, designed to adapt not only to different thematic contexts but also to contents that vary over time, therefore not entirely available in advance. This is achieved *via self-adaption*, based on automatic content classification and a set of semantic tags. A hybrid approach combining human intervention and ML algorithm is used to classify contents into topic ontologies, that lay the foundations of a layer-based organisation. The navigation interface is equipped with adaptive filtering based on the topic ontology, which helps retrieve contents of interest and reduce information overload.

The development of MAGIS prototype in the Citizen Journalism domain context successfully tested the feasibility and the effectiveness of the proposed solution. The next step will be automating content collection and fetching with the objective of massively importing large datasets of geo-referenced multimedia contents. Future implementations could deepen content validation and data quality control, also improving the data enrichment module, based on citizens' contribution.

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This project work has been published with the following titles:

1. *"A Framework for Adaptive Context and User-Related Management of Multimedia Contents (short paper)"* in Companion Proceedings of the 15th European Conference on Software Architecture (ECSA 2021) [34].
2. "*Semantic Adaptive Enrichment of Cartography for Intangible Cultural Heritage and Citizen Journalism*" in Proceedings of the 2022 Future of Information and Communication Conference (FICC) [35].

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