Ontology-Driven Imagery Analysis

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Abstract
This paper presents a new paradigm for imagery analysis where imagery is annotated using terms defined in ontologies, enabling more powerful querying and exploitation of the analysis results. The ontology terms represent the concepts and relationships necessary to effectively describe the objects and activities within a domain of interest. A platform for viewing and editing imagery annotations is described along with a specialized semantic knowledge base capable of efficiently querying the information using semantic, spatial, and temporal qualifiers. The ontologies used for representing the annotations and domain of interest are also described.

Introduction

Imagery analysis is the process of examining overhead imagery, identifying the objects and activities present in the image, and correlating this data with information not available in the image to derive new knowledge. Current practices for capturing imagery analysis results as narrative text or in relational databases become a burden when an analysts needs to search past reports, correlate facts across multiple reports, and search for specific examples of general scenarios.

The purpose of this paper is to describe an imagery analysis environment where observations are recorded as structured annotatations using descriptive semantic concepts defined in an ontology, enabling more powerful search and exploitation of the annotations than can be achieved using traditional methods. The first section describes the user environment for the ontology-driven imagery analysis application. The second section describes the specialized knowledge base developed to enable efficient storage and retrieval of the annotations. The third section describes the ontologies developed to achieve the goals of the application.

Imagery Analysis Environment

The imagery analysis application is implemented as a plugin for the ESRI ArcMap GIS [1], a popular image analysis tool. The plugin includes a custom layer for viewing geo-registered imagery and marking annotations as well as custom user interface controls for creating new and searching existing annotations. The user interface controls' content is generated dynamically based on the ontology terms and relationships in the knowledge base. This allows users to immediately leverage modifications and enhancements to the domain ontology without having to wait for deployment of new version of the application.

The user creates new annotations by using the custom controls to describe the observation using the semantic terms defined in the domain ontology. The application automatically captures the timestamp and geospatial details of the annotation. By capturing the temporal and spatial extent of the observation, annotations can be linked and searched using time, space, and description regardless of whether they originated from one or more images.

When viewing imagery, the user can use the custom query controls to filter the visible annotations based on spatial, temporal, or semantic qualifiers. For example, when viewing an airport, the user can choose to only show observations of support vehicles within the hangar area within the past 7 days. This search relies on the ability of the knowledge base to understand what qualifies as a support vehicle and to efficiently eliminate observations that occur outside the specified spatial and temporal extent.

The user environment also includes an advanced query interface that allows the user to write custom queries that cannot be defined using the UI controls. As an example, this interface allows the user to query for all cases where aircraft maintenance was observed twice within the same week, within the same airport.

Spatiotemporal Semantic Knowledge Base

The knowledge base (KB) is the repository for all data in the system. This includes data created by the analyst along with any inference from the ontology. The knowledge base therefore must support fast access using spatial extents, temporal extents, and combinations thereof. The knowledge base uses the Jena Semantic Web Framework [2] for query and graph processing, BBN's Asio Parliament KB [3] as an underlying RDF [4] storage mechanism, and libraries from BBN's Openmap GIS [5] application for spatial indexing.

Custom Jena Graph interfaces were developed to integrate Asio Parliament KB and the spatial and temporal indexes into the knowledge base. The custom interfaces encapsulate the implementation details, allowing transparent use by the query interface. The custom graph interface for the indexes facilitates ordering and splitting the queries between the semantic and spatiotemporal processing components.

Ontology Design

The implemented ontology is designed to formalize a conceptual model of the world, enable a dynamic, context relevant user interface, and meet the data requirements of the overall system. The ontology is structured into three separate, but interrelated component ontologies. The foundational ontology formalizes the conceptual model used by the system and exists independent of the analytical domain. The domain ontology captures concepts of unique relevance to a domain (e.g. Air Defense). The application ontology meets the particular information requirements of the imagery analysis system. Each of these ontology components is discussed in more detail in the sections below.

Foundational Ontology

The foundational ontology is designed as an application independent, domain agnostic, conceptual model of the world,. It contains formalizations of basic notions of time and space and is a suitable model for information systems that maintain information about objects in the physical world over time. The foundational ontology is an integration and augmentation of best-of-breed, publicly available ontologies. The temporal representation used is OWL-Time [6,7], a product of the W3 Semantic Web Best Practices and Deployment Working Group. It includes interval and instant based time representations and is aligned with XML Schema built-in data types. This alignment eases application of existing RDF and XML software tools. The concrete geospatial representation is an adaptation of GeoRSS [8], which includes a profile of the Geography Markup Language (GML) [9]. Use of GML makes exchange of geospatial data with external tools feasible. OWL-Time and GeoRSS have both been integrated with the Basic Formal Ontology (BFO) [10]. BFO is a widely studied and published formal ontology that enumerates concepts at the highest levels of abstraction. In particular, all entities in the BFO formulation of the world are either continuants or occurrents. Continuants are those entities that have a continuous existence and endure through time. Examples include a piece of rock or the planet Earth. Occurrents are those entities that are bound in time and include processes and events. Examples of occurrents include walking the dog and the lifecycle of a frog.

Domain Ontology

The domain ontology used in this application formalizes air defense concepts. Many of these air defense concepts are adapted from publicly available sources of information on air defense topics, such as the Federation of American Scientists. The ontology is also aligned with National System for Geospatial-intelligence (NSG) feature catalog to promote reuse. This catalog provides a list of features and some relationships among the features. Names of features from the catalog are consistent with names used in the ontology. The NSG feature catalog does include subsumption (subclass/superclass relationships). These relationships are added, where appropriate, when NSG features are added to the domain ontology.

The domain ontology is aligned with the foundation ontology in order to determine which concepts are appropriate to populate the form-based UI for a given function. Specifically, some classes are subclasses of IndependentContinuant to express that they are standalone entities which an analyst can use to annotate an image (e.g. MiG-21). Other classes are subclasses of Qualities to indicate that these concepts can only be used as temporally changing attributes of an IndependentContinuant (e.g. the operational status of a MiG-21). Another example of alignment with the foundational ontology is that some classes are subclasses of Process. This indicates that these classes are to be used to indicate that some process or event is taking place (ex. fueling a MiG-21).

Application Ontology

The application ontology represents data that is specific to the function of this application. In other words, it contains application specific information. The imagery analysis application ontology includes image metadata such as the date and time an image was taken and the name of the file.

Results

The resulting environment provides an application through which a user can examine and annotate geo-registered imagery using air defense concepts and relationships described in the domain ontology. The inference capabilities provided by the ontology enable the system to automatically enrich each annotation and draw further conclusions. This allows users to search for annotations using abstractions and characteristics that were never specifically captured by the analyst. The spatiotemporal capabilities of the knowledge base combined with the semantics of the ontology enable analysts to efficiently query for observations that occur within a spatiotemporal extent or are related spatially or temporally. Finally, the representation of the ontology and data allows the annotations to be easily linked to annotations from other intelligence sources.

Conclusion

This paper presents an imagery analysis environment that allows imagery to be annotated using highly descriptive semantic concepts and relationships defined in an ontology. By combining efficient semantic storage and retrieval techniques with efficient spatial and temporal indexing, these annotations can be queried and exploited in more powerful ways than can be achieved using traditional keyword search or relational database techniques.

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