AN ARCHITECTURE FOR FAST SEMANTIC RETRIEVAL IN THE FILM HERITAGE DOMAIN

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ABSTRACT

How to best perform a search over a dataset is a common field of research in the scientific community. Query engines are used when the information is handled by an ontology in order to obtain structured information semantically. A common issue that arises is when the same query is performed several times, as the query engine must check the domain every time in order to retrieve the information. In this paper, we propose an architecture that takes advantage of the concept of Reflexive Ontologies (RO) in order to achieve timely semantic retrieval. The proposed architecture is illustrated by a case study in the Film Heritage domain, showing a performance improvement and providing ground for further research and discussion.

1. INTRODUCTION

Nowadays, immense amounts of multimedia data are generated. Information society is more and more focused on the fast recovery and processing of such data in order to transform it into usable content for the user. An emerging approach to store and retrieve semantically enabled concepts and relationships is to use ontologies and search engines. However, when the same query has to be performed multiple times, the query engine must check the domain each time in order to retrieve the required information. This need to repeat queries addresses mainly the nature of the ontology storage mechanism itself as it will be shown in the proposed case study.

This paper proposes an architecture that takes advantage of the Reflexive Ontologies (RO) concept in order to perform a fast semantic retrieval. The proposed architecture has been validated with a case study in the Film Heritage domain, showing a performance improvement and giving ground for further research and discussion.

This paper is organized as follows. Section 2 introduces some basic concepts and a brief state of the art related to the technologies mentioned in the paper. Section 3 explains the concept of Reflexive Ontologies (RO), a case study in the Film Heritage domain, the CINeSPACE project [1] and the architecture for fast semantic retrieval.

Section 4 describes the results of the case study. Finally, Section 5 draws conclusions and proposes future work.

2. CONCEPTS AND STATE OF THE ART

2.1. Basic concepts related to ontologies

One of the most well-known definition for an ontology was provided by Tom Gruber [2], describing an ontology as 'the explicit specification of a conceptualization, a description of the concepts and relationships in a domain'. An ontology is considered to be standard when it is globally accepted, that is, when it provides a common understanding of a domain.

Ontologies can be built by many different languages. RDF(S) was developed to represent information in the Web. Therefore, the resources in the Web are identified by Web identifiers (Uniform Resource Identifier or URI) [3]. To make it machine readable, RDF inherits XML-based syntax. The RDF abstract syntax has a graph pattern, where the statements are represented as N-triples [4].

RDFS extends RDF by providing the ability to define RDF vocabularies such as classes, properties, types, ranges and domains. However, RDF and RDFS cannot express equality and inequality; enumerate property values; or describe unique, symmetric, transitive and inverse relationships among properties [3][5].

Another language for building ontologies is DAML+OIL [6], a combination of DAML (DARPA Agent Markup Language) and OIL (Ontology Inference Layer) [7]. It consists of a set of axioms asserting the relationships between classes and properties. DAML+OIL uses a Description Logic style model theory to formalize the meaning of the language [8] which reduces arguments and confusions, thus giving the language the ability to precisely represent the meanings of information. This ability is crucial for automatic reasoning, the goal of the Semantic Web.

However, there are some syntactic and semantic problems to make compatible DAML-OIL with RDF syntax [8]. Therefore, OWL [9] has been developed on top of RDF by W3C for Semantic Web. OWL has a layered architecture with successive layers or sublanguages, providing more expressivity: OWL Full corresponds to RDF; OWL DL is restricted to a DL/FOL fragment, allowing the use of DL reasoning techniques; and finally, OWL Lite has further restrictions intended to ease implementation and provide easy entry for those familiar with frame-like languages [3].

Finally, ontologies are a key issue in order to make semantic retrieval and searching. This process is understood as an information extraction phenomenon where new facts are inferred based on a context and domain. There are many ontology query languages, such as SPARQL, RQDL and OWL-QL.

SPARQL [10] and RDQL [10] are some examples of RDF query languages. The former has been adopted by W3C as the means to query ontologies built using RDF and has been extended to support OWL format. Based on SQL, it can query visual graph patterns along with their conjunctions, disjunctions and optional patterns. Its name is a recursive acronym that stands for SPARQL Protocol and RDF Query Language. Using SPARQL [11] for querying OWL is very cumbersome because of its triple semantics.

The latter is a query language for RDF in Jena [12] models. It provides a data-oriented query model so that there is a more declarative approach to complement the fine-grained, procedural Jena API.

The third OWL Query Language (OWL-QL) [13] is a formal language and protocol for a querying agent (client) and an answering agent (server) in a query-answering dialogue using OWL. It has been designed to be easily adaptable to other declarative formal logic representation languages, including first-order logic languages such as KIF [14], RDF, RDFS and DAML+OIL.

2.2. Semantic retrieval from large ontologies

The Classical Model of Information Retrieval also called Google model of information retrieval is based on a linear series of five basic steps [15]. In the first step, the user specifies using some input language or Natural language-like search specification. The second step is to perform the actual search using the specified query. The third step is to filter the results, this filtering is done by scoring the returned results with respect to the specified search query, and then using the score of each result to decide in which order it should be presented to the user. Step four involves presenting the filtered results to the user. In the final step, the user selects those results that he or she decides are useful from the presented search results. This classical model of information search can thus be understood as a linear single-shot repeatable process.

However, when accessing largely populated datasets or ontologies, the mechanisms to open, store and retrieve the concrete information of interest are not apparent, as the ontologies do not store explicitly their patters of usage. Therefore, this paper proposes the use of RO to improve this situation in real world examples of the Film Heritage domain.

2.3. Semantic applications in the Heritage Domain

Cultural Heritage may be defined as the legacy of objects and intangible manifestations of a society inherited from its past, including for instance, those objects of historical, artistic or ethnographic relevance [16]. A wide range of organizations (e.g. museums, libraries) store and conserve works of art, collections of artifacts and digital libraries of audio-visual materials, which may be considered as Cultural Heritage documents. This content can be exploited by different applications, usually entailing operations like searching, accessing and retrieving. Hence, an indexation process is required.

Metadata, defined as data about data, has to be added to the content. MPEG-7, Multimedia Content Description Interface [17], is an ISO/IEC standard (ISO/IECJTC1/SC29/WG11) developed by the Moving Picture Experts Group (MPEG). The Data Definition Language (DDL) part specifies the syntactic rules that have to be fulfilled by the description tools. MPEG-7 XML (*Extensible Markup Language*) based syntax makes it platform independent and a reliable option for information interchange.

However, syntactic metadata is not always enough and semantic metadata is also needed. Several efforts have been made in order to express MPEG-7 in a machine-readable form so that it can be re-used and better suited to heterogeneous and distributed environments. The W3C emphasizes four of them [18].

Hunter [12, 19] has developed an ontology which partially covers the Multimedia Descriptor Scheme (MDS) written in RDFS. The mapping is done using an upper-level ontology. Tsinaraki´s ontology was specified in OWL-DL and in this case the whole MDS was translated. Tsinaraki *et al* worked on a methodology and software for the interoperability of OWL with the complete MPEG-7 MDS, so that domain ontologies described in OWL can be transparently integrated with the MPEG-7 metadata [17]. Moreover, DMAG's ontology was defined in OWL-Full and it is the one which best covers the MPEG-7 standard. It was automatically generated by a generic tool developed by the authors whose goal was to make the integration of other specific ontologies with MPEG-7 easier.

Finally, INA's ontology can not be considered as an MPEG-7 based ontology due to its incompleteness. It is built in OWL-Full.

Applications in the Cultural Heritage domain show great potential in the application of semantic technologies. There are several current and previous European projects in that previous domain. For example, the art-E-fact project, whose objective was the creation of a generic platform for Interactive Storytelling in mixed reality to enable artistic expression within a cultural context in the virtual and the physical worlds [20]. The Domus Naturae project presents a complex, web-based virtual museum application, integrating several tools for flexible management of heterogeneous and highly structured knowledge, following the W3C's recommendations [21]. Finally, the REACH project (New Forms of Distributed Organization and Access to Cultural Heritage) aims at developing of a system of unified access and management of information that related to the Greek Cultural Heritage [22].

3. PROPOSED ARCHITECTURE FOR THE USE OF *RO* WITHIN THE CINeSPACE PROJECT

3.1. Description of the Reflexive Ontologies

Reflexivity is a property of self-reference in an abstract structure of a knowledge base, i.e. "knowing about itself". When an abstract knowledge structure can persistently maintain every query performed on it, and store those queries as individuals of a class that extends the original ontology, it is said that such an ontology is reflexive [9]. Hence, a Reflexive Ontology (RO) can be defined as follows:

"A Reflexive Ontology is a description of the concepts, and the relations of such concepts in a specific domain, enhanced by an explicit self-contained set of queries over the instances."

It can be considered that any abstract knowledge structure of this kind is essentially a set of structured contents and relationships. The mathematical concept of a set and its properties can be applied to the knowledge structure for its formalization and handling. Figure 1 depicts the Reflexive Ontologies approach. When a given ontology is extended with the reflexivity concept, the ontology is enhanced in the following ways:

(*i*) Speed. Querying the ontology (query process) is time linear in the worst case if the query has been previously stored. If the query has not been asked before, then a typical ontology query via an API is performed. When the new set of answers is retrieved, it is added to the reflexivity class.

(*ii*) Incremental nature. This feature adds knowledge about the domain. As more questions are asked, more knowledge is stored in the ontology. The questions and answers are effectively a guide to infer "things" about the ontology.

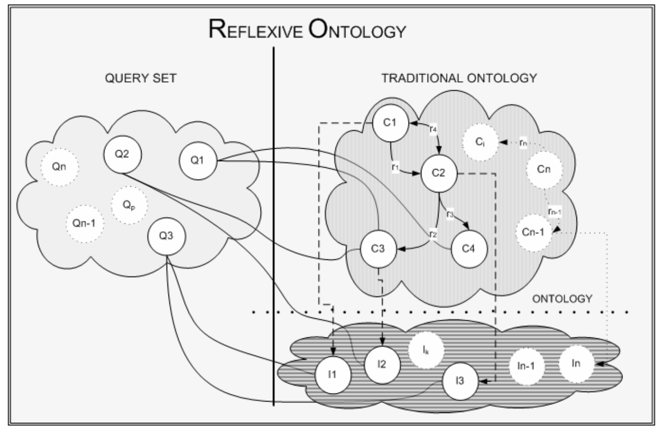

Figure 1. Reflexive Ontology Schema

(*iii*) Self containment of the knowledge structure in a single file. This feature includes the storage of the model, the relations between the elements of the model, the individuals (instances) and the queries over such individuals.

3.2. Description of CINeSPACE project

Films are unquestionably a part of Cultural Heritage. Problems of current systems for accessing Cultural Heritage resources which deal with film objects include some of the following aspects: distributed sources which store huge amounts of information; different formats of the contents, ranging from traditional ones such as paper to advanced multimedia objects; and finally, and what is more crucial for the content providers, lack of systems which support currently the needs of the user such as enriched content, interaction with the information, usability, and exchange of experiences with other users.

Taking into account these gaps detected by some European cities with a strong connection with the film sector, CINeSPACE [23] aims at designing and implementing a mobile rich media collaborative information exchange platform, scalable, accessible through a wide variety of networks, and therefore, interoperable and Location-Based for the promotion of Film Heritage, going beyond the current state of the art.

CINeSPACE enables users to interact with Location-Based multimedia contents while navigating a city: San Sebastián (Spain), Venice (Italy) and Glasgow (Scotland). Audiovisual information is delivered through a small low-cost wireless Head Mounted Display with a high definition screen situated near to the eye and audio phones. CINeSPACE also comprises a small camera able to record or send what the user is 'seeing'. This information is uploaded to a database through a WLAN hot spot in order to create collaborative experiences with other end users.

3.3. Proposed Architecture

This section describes the proposed architecture for the fast semantic retrieval of information stored in an ontology. The architecture is structured in a six layer schema (Figure 2) to achieve modularity in system implementation. The architecture uses the MPEG-7 Compliant Ontology of the CINeSPACE European project [24].

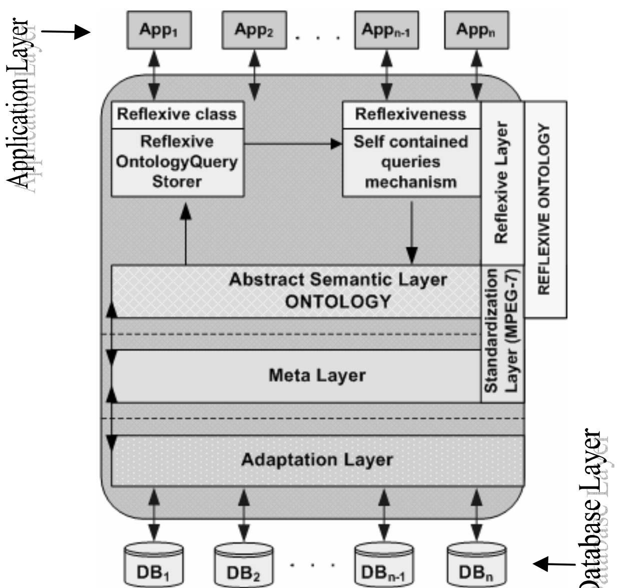

Figure 2. Proposed Architecture.

3.3.1. Application Layer

The Application Layer is responsible for query management of the requests of the user and the retrieval of relevant content. The first time that a user logs onto the system, his/her multimedia profile is loaded, or created if it does not exist. This layer also manages the state of the user, tracking his/her interactions with other users that are currently logged.

User profiles are used to introduce personalization functionality into the system.

Geo-reference information is the key factor in retrieving the content to be delivered to the user within the CINeSPACE project. However, other aspects of the personalization techniques may also be used (e.g. language, device, user demographic and areas of interest).

3.3.2. Reflexive Layer

The Reflexive Layer is an extension [22] that adds a new class to the base ontology (Abstract Semantic Layer) providing the schema for reflexivity, which provides the ontology, programmatically, with a mechanism to query and perform some logic on the queries that allows the handling of the reflexivity.

This layer processes the queries from the Application Layer. If the requested query or a sub part of it has not been done before, the new query is stored in the ontology with its individuals-results pair by the *ReflexiveOntologyQueryStorer*. This means that the following time a user makes the same query, the elapsed time is less than the time taken for the first query due to the *self contained queries mechanism* returning directly the individuals previously found.

3.3.3. Abstract Semantic Layer (MPEG-7 Compliant Ontology)

This layer includes an MPEG-7 Compliant Ontology built up basically by a specific vocabulary used to describe a certain reality and a set of explicit assumptions regarding the intended meaning of the vocabulary.

It includes objects, concepts and words (e.g. city, monument). It should be pointed out that it is not enough to agree on the terms of the vocabulary, but also that extra information about these terms is needed, for example, the relationship amongst objects (e.g. monuments belonging to a city), attributes and properties (e.g. the name of the monument) and constraints (e.g. each monument has a unique name).

The Abstract Semantic Layer can be considered as a translation layer. Using the Reflexive Layer, a user makes queries through the Abstract Semantic Layer, which are translated to a language understood by the Meta Layer.

3.3.4. Meta Layer

This layer handles the connection between the metadata and the information in the databases. The following requirements should be fulfilled when defining the metadata:

(i) **Localization using geo-reference**, specifying latitude and longitude of the multimedia information (Location-based services);

(ii) **User customization**, identifying the visitor via personalization (related to the usage of the Content Management);

(iii) **Visual appearance** related to the device of the user and its capabilities (e.g. Mobile Phone, PDA, Magnifiers).

The Meta Layer includes the MPEG-7 descriptions of multimedia content, first in XML, as MPEG-7 is XML based and then, a mapping to equivalent Java classes. Hence, the Abstract Semantic Layer communicates with the Meta Layer via the Java classes, whilst the Database Layer communicates with the Meta Layer via the XML files.

3.3.5. Adaptation Layer

There are two types of data providers within the CINeSPACE project depending on whether they have their own Database and Meta Layer or not. If the Database and Meta Layer exist, an Adaptation Layer should be defined to translate the existing Database and Meta Layer to the Meta Layer in the proposed architecture.

3.3.6. Database Layer

Located at the bottom of the figure, the multimedia content and other additional information are found at this layer, which aggregates structured and unstructured information received from various sources and fed this aggregated data to the upper layers. This is due to the fact that the Meta Layer will translate data to the meta ontology if required.

4. CASE STUDY AND EXPERIMENTS

This section presents a brief description of the ontology designed for CINeSPACE project, as well as the experiments conducted and the results.

4.1. The MPEG-7 Compliant Ontology for the CINeSPACE project

A specific MPEG-7 Compliant Ontology has been built in the CINeSPACE project, which includes some of the fields, concepts and relationships defined by MPEG-7 extended with new ones to fulfill the requirements of the CINeSPACE project (Figure 3). The metrics of this OWL model include 44 classes; 38 object-type properties; 21 data-type properties and 63 individuals.

Due to the Location-Based nature of CINeSPACE, the main queries are related to geo-reference information stored in the MPEG-7 Compliant Ontology. As the position of the users changes in time and the multimedia content should be browsed in relation to their position, it is highly probable that the exact same query may be performed many times over the ontology, as concurrent users employ the system.

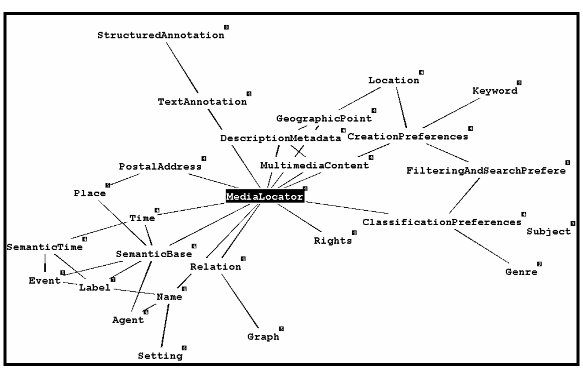

Figure 3. MPEG-7 Compliant Ontology.

This query set is not the only type that could be asked. However, it can be said that these are the most common queries within the context of CINeSPACE, which can be written in natural language as follows:

Retrieve all the multimedia content…

(i) … around this geo-reference data.
(ii) … in black and white colour.
(iii) … visualized by the $user_x$.
(iv) … created yesterday by $user_x$.

Among all of the possible queries that can be made to an MPEG-7 Compliant Ontology, a complex set of test queries, composed of six queries has been chosen to test the proposed architecture as shown in Table 1.

$$Q = \{q_1 \cup q_2 \cup q_3 \cup q_4 \cup q_5 \cup q_6\}$$

Table 1. Simple input queries.

q_1 = CLASS GeographicPoint with the PROPERTY Latitude GREATER THAN *A*
q_2 = CLASS GeographicPoint with the PROPERTY Latitude SMALLER THAN *B*
q_3 = CLASS GeographicPoint with the PROPERTY Longitude GREATER THAN *C*
q_4 = CLASS GeographicPoint with the PROPERTY Longitude SMALLER THAN *D*
q_5 = CLASS GeographicPoint with the PROPERTY LatOrientation EQUALS TO *E*
q_6 = CLASS GeographicPoint with the PROPERTY LongOrientation EQUALS TO *F*

β_1=0.0035, the radius in degrees around the current latitude

β_2=0.0035, the radius in degrees around the current longitude

x, queried latitude

y, queried longitude

$A<x<B,\ A=x-\beta_1,\ B=x+\beta_1$

$C<y<D,\ C=y-\beta_2,\ D=y+\beta_2$

E={North, South}, F={West, East}

A simplified use case in the CINeSPACE project would be the following:

(i) The Application Layer receives a query informing that the user is physically located at the position 43.3205º N, 1.9883º W (Playa de la Concha, San Sebastian) with a CINeSPACE compliant device.

(ii) The system checks the state of the user, validating that he/she has the rights to use the system and that there are videos can be rendered.

(iii) It checks the profile of the user and notices that the user is in the 30-35 year old age group, speaks Spanish and is mostly interested in romantic films.

(iv) The Application Layer requests videos of romantic films, if possible with Spanish soundtrack, or at the very least subtitled. If available, those videos that have more probability to be known by a member of this age group will be returned.

(v) The Application Layer retrieves the videos and sends them to the user after checking the user has the rights to watch them.

4.2. Description of the experiments

The main goal of the trials conducted is to verify the effectiveness of the proposed architecture, querying the MPEG-7 Compliant Ontology and comparing it with a more traditional approach, based on a OWL query engine. Using the proposed architecture, a reduction in computational time is presumed when compared non-RO based approaches. In order to validate the hypothesis, a series of experiments has been designed.

The experiments were carried out on IBM Compatible PC with Windows XP, 512Mb RAM, with a Pentium IV processor 2.66 GHz. running the SUN Java virtual machine V1.6. The test dataset (images and videos) included 63 image and video items. The MPEG-7 Compliant Ontology has been queried within the CINeSPACE framework using the Jena API. Then, the ontology using the proposed architecture has been queried (including the RO approach). Table 2 depicts the variables used in the trials. There are two independent variables: the Type Experiment (TE) with values 0 (with RO) or 1 (without RO); and the input query values (IQV_i) with ten different combinations.

Table 2. Variables of the experiments.

Name of variable	Abbreviation	Range
Type Experiment	TE_i	i={0,1}
Input Query Values	IQV_i	i={0..9}
Time	t_{ij}	i={0,1} j={0..9}

Each input value is a quadruple of latitude, latitude orientation (N,S), longitude, and longitude orientation (E,W). Time is a dependent variable (t_{ij}) needed to return the results (answers to the queries).

Table 3 depicts the values for each IQV_i (quadruple data) independent variable. The dependent variable (t_{ij}) is the time (in milliseconds) needed to return: all the matches for each query. The design of the experiment is considered as factorial type because two independent variables (TE_i and IQV_i) have been used.

Table 3. Input query values.

IQV_i	Latitude	Lat. Orient.	Longitude	Long. Orient.
IQV0	45.7267	N	12.5700	E
IQV1	43.5358	N	2.6564	W
IQV2	43.5364	N	2.6471	W
IQV3	45.7264	N	12.5693	E
IQV4	45.7272	N	12.5690	E
IQV5	45.9102	S	12.5897	E
IQV6	56.4437	N	4.4320	W
IQV7	56.4440	N	4.4323	W
IQV8	43.5356	N	2.6478	W
IQV9	56.4479N	N	5.1203	W

Trials were made during two days, one day for each type of experiment, with and without RO. Experiments were carried out in two passes: without RO in the first pass, and with RO in the second pass. The system clock was used to accurately measure execution time.

4.3. Results of the experiments

Table 4 displays the obtained results, including the number of matches of each type of experiment. Using the reflexivity concept, an average query time of 49.9 ms. was obtained, resulting a time save of 3977.5 ms. The number of matches are the same in both cases, with and without RO. The difference between the types of experiments comes from the time to get that number of matches. There are some input values which have the same number of matches.

Table 4. Results obtained from the test cases (TE_i values in milliseconds).

IQV_i	Number of matches	TE_0 (ms.)	TE_1 (ms.)
IQV_0	8	47	3261
IQV_1	1	47	3570
IQV_2	1	31	3294
IQV_3	7	47	3450
IQV_4	7	47	3840
IQV_5	0	62	4620
IQV_6	1	47	4168
IQV_7	1	62	4435
IQV_8	1	47	4826
IQV_9	0	62	4810
		49.9	4027.4

Figure 4 shows the number of matches of the queries. The query numbers IQV_1 and IQV_2, for example, have the same number of matches, but differing elapsed execution times.

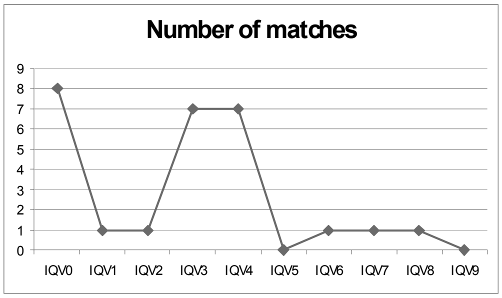

Figure 4. Number of matches.

Time consumption querying the ontology without RO can be considered near-linear, as shown in Figure 5.

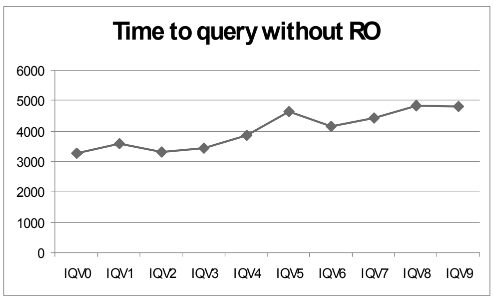

Figure 5. Time query graphic without RO.

The execution time in the case of the proposed architecture is also near-linear (Figure 6). The difference between both cases is the time range between 3000 and 5000 ms. without RO whereas between 30 and 70 ms. with RO.

When the Reflexive Layer receives a query, it goes through all the individuals stored as queried results. When it finds an identical query, it returns those values. Therefore, the maximum time taken is the equivalent to the time taken to walk through the array to its last element. This can be an explanation of the peaks depicted in Figure 6 (IQV2, IQV5, IQV7, IQV9). In fact, IQV5, and IQV9 emphasize this time when any possible answers are found in the ontology.

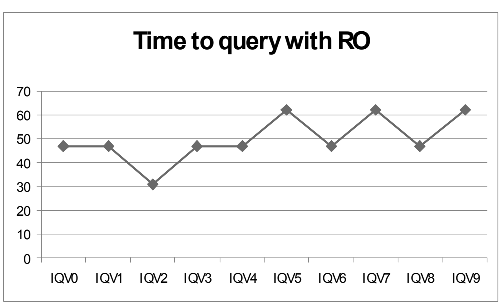

Figure 6. Time query graphic with RO.

5. CONCLUSIONS AND FUTURE WORK

This paper introduces a novel concept for a fast query recovery in the Film Heritage domain. An architecture that takes advantage of the Reflexive Ontologies concept has been implemented in order to perform a fast semantic retrieval. This architecture has been designed for the European CINeSPACE project (IST FP6- 034990) and it has been evaluated by a series of experiments over a dataset from the project. The hypothetical efficiency gain has been demonstrated as substantiated by the results detailed. A reduction in computational time has been achieved through the use of the proposed architecture.

Regarding future work, the reflexivity concept will be extended in order to work with non-static ontologies, that is, ontologies with an augmented number of individuals.

Within the context of the CINeSPACE project, the ontology will be extended including the mapping with the CIDOC Conceptual Reference Model [26] (CIDOC-CRM) and the International Federation of Information Technology and Travel & Tourism [27] (IFITT) concepts as these ontologies are directly related to the Cultural Heritage field.

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