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Assessing the integration of ontology tools in Content Network architectures

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***Abstract*—The realm of this paper is the provision of multimedia services based on matching users' preferences and multimedia content descriptions. The main concept explored is the usage of ontology tools for mitigating frailties found in tag based matching processes due to their lack of semantic knowledge and their context dependence. The integration of ontology tools in CN architectures based on open standards (MPEG-7 and IMS) is proposed and assessed in this paper. The results obtained via non-functional tests enable to conclude that these tools provide enhanced matching results without a negative impact on both the CN size and its performance.**

***Index Terms*—Content Network, Ontologies, Audiovisual Metadata, MPEG-7, RDF.**

I. Introduction

In the recent past, Web 2.0 technologies and applications such as blogs, vblogs and video broadcasting were increasingly being driven by community-based interactions and have gained more and more importance in the Internet. In addition to their contribution to blur the distinctions between content consumers and producers, Web 2.0 related tools have also fostered content tagging as another important functionality in the complete content production-consumption chain. This later functionality [1] allows users to categorize and organize content by associating words or phrases (i.e., tags) with the content they post, publish, or broadcast over the Internet.

Albeit useful, the simple usage of tags does not create a very strong mechanism for indexing regarding its reach and persistency. This is mainly due to the two following facts: user created multimedia content items have typically a very small number of associated tags; and many of the terms (tags) used are ambiguous or depend on context (e.g., creator profile, time and location). One of the practical consequences of this frailty on search-based multimedia services and applications is that available and adequate content may not be found when queries from a different context are used. Attempts to solve this problem via cluster indexing and page-rank-like algorithms in the tag space have not been very successful [2]. Moreover, due to their latent semantics, attempts to "mine" their meaning are always problematic due to ambiguity and the previously mentioned context dependency (e.g., the multiple meanings of 'goal').

This paper proposes and assesses the usage of ontology tools as a key component of content network architectures, described in Section II, in order to extend the reach and persistence of search-based multimedia services and applications. By using common and standardized ontology and multimedia description tools, described in Section III, it is possible to enhance the results obtained on matching content descriptions and users' queries that are produced in different contexts (reach) and, that this matching is still possible even when there is a context change (persistence). In Section IV this proposal is assessed using a set of relevant metrics for search-based multimedia services and applications. The paper closes by addressing the extension of this approach to different multimedia standards and to the dynamic composition and orchestration of multimedia services in the Web 3.0 and MPEG-21 realms.

II. Content Network Architecture

The active participation of the network infrastructure in the management, creation, distribution, and consumption of content is the chief and distinguishing characteristic, from Content Delivery Networks (CDN), of a new type of networks known as Content Networks (CN) [3]. Previous works [4] [5] have described the design and implementation of a CN platform whose global functionality is supported by the following systems:

- a communication system that provides an abstraction for the transport and delivery network as well as the associated signaling for the development of applications and services (e.g, session set-up, maintenance, closing);
- an information system composed mainly of multimedia content descriptions (namely media profiles and metadata) providing indexing and searching functionality for both multimedia content and services; and
- a service provision system based on a web service interface that enables the appropriate level of abstraction for the application knowledge by providing a rich semantic service information (e.g., control flow, inputs and outputs, preconditions and effects, etc.).

During the provision and consumption of multimedia services using this platform, the communication system routes signaling messages and content flows and yet is not aware of their semantic meaning, a role played by both the information system and semantic web service interface. In turn, the information system is agnostic in respect to the services composition performed by the application using its semantic

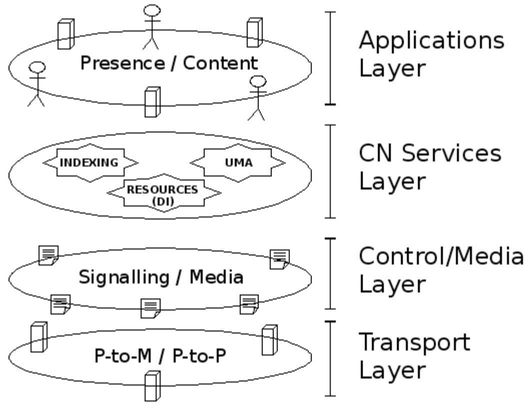

Fig. 1. CN Architecture

web service interface. In the design and implementation of the multimedia systems described in [5] the Content Network layered architecture represented in Figure 1 was used. The implementation options for this architecture were consistent with the goal of enhancing the reach and persistence of multimedia search services. Namely, the two bottom layers representing the media and signaling transport and control functionalities required by the communication system were implemented using an IMS architecture thus providing the support for heterogeneous terminal and networks access.

In turn, the proposed ontology tools will be part of the CN services layer. This layer is populated with the web services that provide elementary functionalities, e.g., MPEG-21 Universal Multimedia Access (UMA) and Digital Item (DI) Identification and Descriptions. These services are exposed and described using semantic web services tools and technologies, therefore allowing the provisioning of new networked multimedia applications that are composed at the applications layer and make use of these elementary features.

III. Using ontology tools in the CN

In the implementation of the information system a Scribe P2P platform is used for providing the functionality of a PUBLISH, SUBSCRIBE/NOTIFICATION store and query model. This is a key aspect in the context of this paper due to the following reasons: the reach and scalability of P2P systems; the persistence property provided by the store and query model used; and mostly, because the integration of ontology tools in the CN is implemented via transformations operated over the indexing keys used in Scribe. In the proposed CN architecture semantic indexing and filtering services are built by matching user preferences and media descriptions, expressed using MPEG-7 Multimedia Description Scheme (MDS) tools. The semantic model for expressing user preferences is based on keywords (i.e., tags) which leads to frailties related to ambiguity and context dependence as previously mentioned and exposed in the following use cases.

The three MPEG-7 coded description snippets in Figure 2 refer to three different multimedia content segments where Cristiano Ronaldo: scores a goal playing for Manchester

```
...
<Description>
 <Media> Manchester United versus Chelsea match </Media>
  <SemanticBase id="CR" xsi:type='FootBall-PlayerType'>
   <Label> Cristiano Ronaldo </Label></SemanticBase>
  <SemanticBase xsi:type='EventType'>
   <Label> Goal </Label>
   <Relation type='agent' target='CR'/></SemanticBase>
</Description>
...
<Description>
 <Media> Real Madrid versus Milan match </Media>
  <SemanticBase id="CR7" xsi:type= 'FootBall-PlayerType'>
   <Label> Cristiano Ronaldo </Label></SemanticBase
  <SemanticBase xsi:type='EventType'>
   <Label> Goal </Label>
   <Relation type='agent' target='CR7'/></SemanticBase>
</Description>
...
<Description>
 <Media> Cristiano Ronaldo Interview </Media>
  <SemanticBase id="CRi" xsi:type='PersonType'>
   <Label> Cristiano Ronaldo </Label></SemanticBase>
  <SemanticBase xsi:type='Abstraction'>
   <Label> World Best Player </Label>
   <Relation type='goalOf' target='CRi'/>
  </SemanticBase
</Description>
...
```

Fig. 2. MPEG-7 content description examples

```
...
<UserPreferences>
 <UserID> Rita </UserID>
  <SearchandFilteringPreferences>
   <Label> Person </Label>
   <SearchandFilteringPreferences><Label> Goal </Label></...
</UserPreferences>
...
<UserPreferences>
 <UserID> Alice </UserID>
  <SearchandFilteringPreferences>
   <Label> CR7 </Label>
   <SearchandFilteringPreferences><Label> Goal </Label></...
</UserPreferences>
...
<UserPreferences>
 <UserID> Xabi </UserID>
  <SearchandFilteringPreferences>
   <Label> CR9 </Label>
   <SearchandFilteringPreferences><Label> Goal </Label></...
</UserPreferences>
...
```

Fig. 3. User Preferences examples

United FC (number 7 jersey); scores a goal playing for Real Madrid FC (number 9 jersey); and is interviewed expressing his personal ambitions (goals) to be the best football player in the world. These descriptions are stored in the CN information system and can be referred (e.g., queried or subscribed) via their respective Scribe keys. Figure 3 illustrates the content preferences of three users: Rita, interested in the social aspects of persons (their goals); Alice a ManUnited supporter; and Xavi a Real Madrid afficionado. Using a simple matching process between the descriptions in Figure 2 and 3 would provide the following, results: Rita and Alice with no content; and Xavi with the goal scored by CR7 for ManUnited. From the users' perspective these results would certainly be disappointing given the content that was available in the CN.

It has been extensively demonstrated that the representation of domain knowledge in the form of domain ontologies can enhance the retrieval accuracy in content semantic retrieval

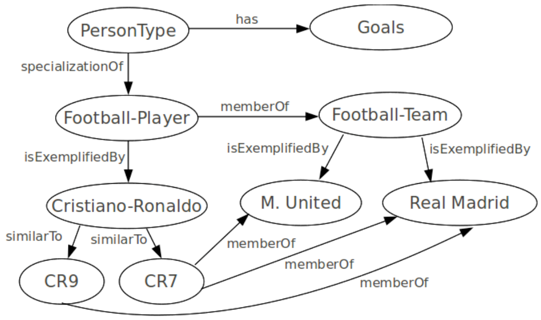

Fig. 4. CN Indexing Ontology Implementation

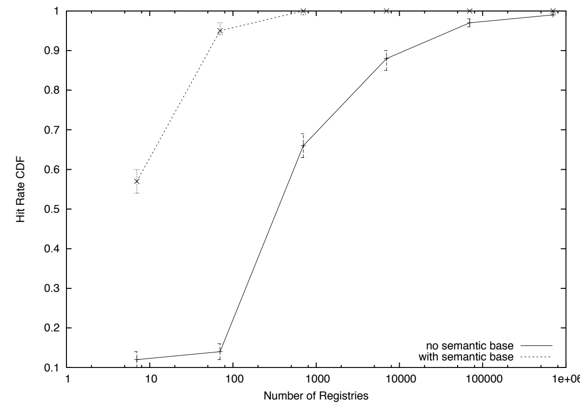

Fig. 5. CN Ontology Quality Test

and filtering [6]. For example, the authors of [7] propose that, in the multimedia realm, the domain-specific ontology should be composed of Instance-Description Metadata describing content instances (e.g., Cristiano Ronaldo scores a goal) and Application-Specific Metadata expressing context-related knowledge (e.g, the relations describing Cristiano Ronaldo as a football player from different teams and known by different names).

The expression of Instance-Description Metadata using the semantic constructs provided by MPEG-7 MDS is illustrated in Figure 2. MPEG-7 MDS also provides the tools for the description of semantic entities via the *SemanticBaseType* attribute. Using this construct, its extensions and relations that can be expressed between them, the CN indexing ontology can be used to guide the matching of entity instances. For the running example this Application-Specific Metadata can also be represented using Resource Description Framework (RDF) [8] triples as illustrated in Figure 4 where relations are represented as directed arcs. The appropriate reasoning upon the domain knowledge expressed in Figure 4 enables the redefining the indexing keys (implemented in the CN by Scribe topic-keys), for example: that the keywords CR7 and CR9 can be used instead of the name Cristiano Ronaldo and that a football player is also a person. By using these richer and more refined terms as indexing keys a broader resource location process is obtained, therefore extending the reach of multimedia content queries and subscriptions. In the running example Rita would be provided with both the interview and the two goals; Alice and Xavi with both goals. These results demonstrate that the use of ontology tolls provide an extended reach (all the different tags used for identifying Cristiano Ronaldo are matched, and he is also considered as a person), and persistence to queries and subscriptions (an 'old' preferences keyword - CR9 - can still produce matching results). In addition to this, the powerful search capabilities associated with RDF-based metadata means that it's also possible to state potentially very complex queries when ontology tools are used, namely by expressing user interests and preferences not only via keywords but also via logical operators and strong typing. This more complex expression of queries would enable that football goals are excluded from Rita's results (ontology tools provide disambiguation for the too different meanings of goal: action and mental state), and Alice and Xabi are provided only with the goals scored for their favorite team (by reasoning upon CR7 different affiliations).

IV. Tests and Results

Using an implementation [5] of the complete architecture a set non-functional tests were conducted for measuring relevant objective quality of service parameters, and thus allowing the assessment of the impact of using ontology tools in the CN content indexing process. In the experimental setup the CN database was populated, using a power law distribution, with a set of registries that correspond to the topics (i.e., keywords) for which multimedia content was available. In all results presented in the remainder of this section the error bars are defined for a 95% confidence interval.

The first test aimed to assess the benefits of using a ontology for semantic indexing and filtering during the resource location process. This test scenario consisted in searching (1000 queries) the CN database with and without semantic indexing. Figure 5 shows the cumulative distribution function (CDF) of obtaining at least one response against the number of registries in the CN database. These results clearly demonstrate the quality improvement in the querying hit rate when semantic indexing is used on the CN via ontology tools. These differences are particularly relevant when there are only a few registries in the database. This can prove very useful when dealing with the long tail phenomena [9] that is present in the actual content that is published in the Internet (e.g., youtube, Flicker).

In the second test a non-semantic base CN database was artificially populated with extra keywords so that it could provide the same results as when ontology tools are used. The purpose of this test was to measure how the number of topics created in the CN database evolved with the number of registries, and thus, assess the database size scalability. The results illustrated in Figure 6 show that in both cases this growth is sub-linear, and that the CN database size when

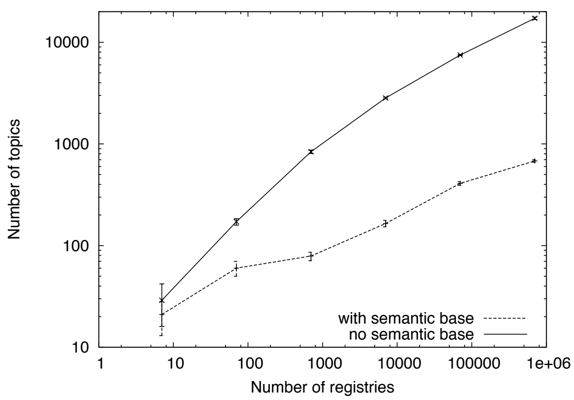

Fig. 6. CN Database Size

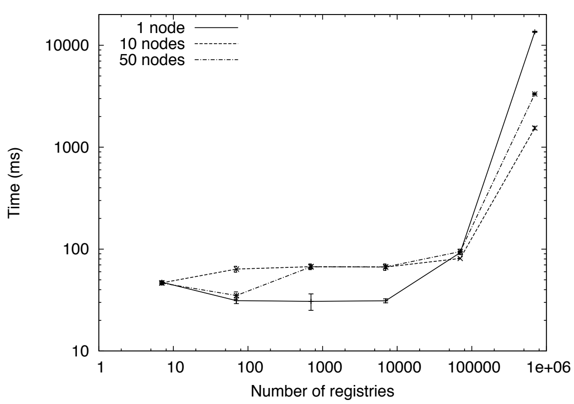

Fig. 7. Query First Response Time

ontology tools are used is an order of magnitude smaller and it increases in a more controlled way.

The third test consisted in executing a single query and waiting for the first response using 1, 10, and 50 CN nodes when the ontology tools are used (for fairness reasons the non-semantic based version to be used should be the same as in the second scenario thus producing the same results). The purpose of this test is to assesses the scalability and efficiency of the CN and how the CN behaves under different configurations (e.g., number of nodes, database size). Figure 7 shows that while the database doesn't have a significant size the best performance is achieved by using just one CN node. When the database size increased significantly the best configuration was found with ten CN nodes. The fact that this was not achieved when the number of nodes was the largest (50) may indicate that the time spent by CN nodes in the P2P message flow may in certain conditions (notably small database sizes) impair the CN performance. In any case it can be concluded that for reasonable database sizes (<100.000 entries) the delay introduced by the CN with ontology tools is very small (<100 ms) and therefore adequate for practical purposes.

V. Conclusions and Future Work

The chief problem tackled in this paper is how to find appropriate multimedia content in scenarios where this content is highly dynamic or dispersed (e.g., streaming video, interpersonal communications, Web 2.0 powered web sites) and at the same time to take in to account terminal and network heterogeneity and users' context and preferences.

In previous works [4], [5] the proposed CN platform has already demonstrated that powerful features can be implemented by using open standards and technologies (e.g., IMS, MPEG-7,-21). In this paper the main goal was to demonstrate that the usage of ontology tools in the CN architecture can extend the reach and persistence of multimedia content search based services without a negative impact on the CN performance (i.e., database size and responsiveness).

Although a set of non-functional tests demonstrated that this is the case, there are still several aspects that are worthy of consideration, namely to assess it at a larger scale. The two possible and desirable dimensions for this scale increase are: the Content Network size (number of multimedia items, descriptions, ontology classes, CN nodes); and the Content Network reach (e.g., by deploying it on the PlanetLab testbed). Another line of research is to apply ontology tools not only to description semantics but also other services that are part of the complete multimedia chain (e.g., the MPEG-21 Digital Rights Management tools), and to other multimedia metadata standards (e.g., Dublin Core, EBU P/META and SMPTE Descriptive Metadata Scheme-1).

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