I3OM – An Iterative, Incremental and Interactive Approach for Ontology Navigation based on Ontology Modularization

Ricardo Brandão[1], Paulo Maio[1] and Nuno Silva[1]
[1] *Knowledge Engineering and Decision Support Research Center, School of Engineering, Polytechnic of Porto*
Porto, Portugal
{jrmjb, pam, nps}@isep.ipp.pt

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Abstract: Although ontologies are used to describe a specific domain of interest, they can grow in size exponentially, compromising their usage. Furthermore, current ontology engineering tools do not effectively support the data/information visualization and navigation described through large ontologies. To address these issues, we claim that the experience and results of navigating/browsing ontology-described data can profit from the modularization of the ontologies underlying the repositories. For that, we propose the I3OM process that facilitates ontology-oriented navigation and contextualized information retrieval by combining different ontology modularization techniques into an iterative, incremental and interactive process.

1 INTRODUCTION

Ontologies are seen as an appropriate formalism to capture and represent the structure and semantics of data/information in the Web and, therefore, serve as the backbone of the Semantic Web (Berners-Lee et al. 2001). However, despite ontologies describe a specific domain of interest, their size and complexity tends to increase too (Del Vescovo et al. 2011). Thus, ontology understandability decreases as its complexity increases which consequently leads to an increase in human effort in apprehend and reuse them (Stuckenschmidt & Schlicht 2009).

Ontology-supported navigation is a recent research field that aims to assist the user in comprehending, searching and retrieving information from repositories described through ontologies (Franconi et al. 2010; Motta et al. 2011). However, current tools do not effectively support the navigation through ontologies (Dzbor et al. 2006), especially those inexperienced and non-experts users.

While ontology modularity (Parent & Spaccapietra 2009) partially tackles these issues, the existing algorithms do not consider the user in the loop, and thus are not able to fully respond to the user requirements.

This paper advocates the need to combine the user expertise and automatic ontology modularization algorithms in the ontology-supported navigation process. For that a novel iterative, incremental and interactive ontology modularization (I3OM) algorithm is proposed.

Next section details the context and requirements of the I3OM. Section 3 introduces the benefits of ontology modularization and the core definitions applied during the remaining of the paper. In section 4, the proposed I3OM process is described, further complemented with a walk-through example in section 5. In section 6, our proposal is compared to other works. Finally, section 7 summarizes the contributions and point out next research steps.

2 CONTEXT

The World Search (WS 2009) project aims to provide an application for a specific domain (e.g. health care, public administration) that supports domain experts during their quest for information resources. These resources are available in multiple and heterogeneous repositories. A resource is either (i) a text document, (ii) an user annotation of a (part of a) document or (iii) a set of facts in a knowledge base.

During the analysis of requirements, the development team observed that the users were interested neither in text-based searches only, nor in formal queries to the repository. Instead, users are interested in an elaborated combination of both. I.e. users want to have the chance to make a query that includes free-text and semantic specification of content. This combination is formally captured by the next function:

$$(res', sem\_ent') = query(text, sem\_ent, res)$$

where:

- $text$ is a user entered free-text;
- res is a set of resources (documents, annotations or facts) in which the user is interested for. It serves as example of the resources to retrieve;
- sem_ent is a (partial) formal specification of the required content based on a model, typically in the form of a set of taxonomy entities or ontologies entities. It serves as formal constraints to the query, i.e. only those resources semantically defined/annotated with those entities should be retrieved;
- res' is the set of resources retrieved to the user for visualization. This includes both the text-based retrieved resources (documents) and ontology-based retrieved resources (annotations and facts);
- sem_ent' is the set of relevant semantic entities that (i) belong to the formal model describing the resources, (ii) is representative of the semantics of the output resources (res') and (iii) enables the user to further refine the query.

The core of the problem lays on:

- the combination of the different input' types to the query;
- the required iterative approach that implies not only the retrieved resource (res') but also a set of semantic entities ($sem\_entities'$) that will support the refinement of the query.

3 MODULARIZATION

Modularization refers to a situation where a thing (e.g. an ontology) exists as a whole but can also be seen as a set of parts (the modules) (Parent & Spaccapietra 2009). In the knowledge management (ontology engineering) scenario, by splitting an ontology into smaller parts, one is allowing the selective use of knowledge which (i) facilitates ontology reusability and share-ability (Stuckenschmidt & Schlicht 2009), (ii) reduces the human effort in understanding such ontology (Parent & Spaccapietra 2009), (iii) empowering the ontology manipulation, maintenance and evolution tasks (Parent & Spaccapietra 2009), (iv) improves the usage of reasoners (e.g. by Distributed Reasoning, by incremental reasoning) (Del Vescovo et al. 2011). Yet, another advantage of ontology modularization is the possibility of knowledge contextualization (different parts of the ontology may correspond to different contexts) and knowledge personalization, i.e. ownership and authorization (Parent & Spaccapietra 2009).

Several different approaches/techniques can be found on the literature, varying in terms of requirements and intents. In this paper, we are only interested in three distinct kind of approaches: (i) Ontology Partitioning (Del Vescovo et al. 2011; Stuckenschmidt & Schlicht 2009), (ii) Module Extraction (Seidenberg 2009; Hussain & Abidi 2010), and (iii) Ontology Summarization (Peroni et al. 2008; Zhang et al. 2009; Li et al. 2010). Next we describe each of these approaches. According to (d' Aquin et al. 2009), Ontology Partitioning is seen as the task of splitting up an ontology (cf. Definition 1) into a set of (probably disjoint) modules (cf. Definition 2) such that the union of all the resulting modules is semantically equivalent to the original ontology.

Definition 1 (Ontology) – An ontology $\mathcal{O}$ (also known as knowledge base) is a tuple $\mathcal{O} = (\mathcal{T}, \mathcal{A})$ where $\mathcal{T}$ is the terminological axioms and $\mathcal{A}$ is the assertional axioms. Both are defined based on a structured vocabulary $\mathcal{V} = (\mathcal{C}, \mathcal{R})$ comprised of concepts $\mathcal{C}$ and roles $\mathcal{R}$. Concepts (and roles) axioms are of the form $C \sqsubseteq D$ ($R \sqsubseteq S$) or $C \equiv D$ ($R \equiv S$) such that $C, D \in \mathcal{C}$ ($R, S \in \mathcal{R}$) respectively. For a set of individuals $\mathcal{I}$, concepts and roles assertions are of form $C(a)$ or $R(b, c)$ such that $C \in \mathcal{C}$, $R \in \mathcal{R}$ and $a, b, c \in \mathcal{I}$.

The semantics related to an ontology is provided by an interpretation $\mathfrak{I}$ over a domain Δ such that it maps: (i) the elements of the domain to the ontology instances, (ii) the subsets of the domain to the ontology concepts, and (iii) the binary relations on the domain to the ontology roles.

An ontology partitioning identifies the key topics of an ontology and splits it into several fragments (Stuckenschmidt & Schlicht 2009). Typically, each key topic gives rise to a fragment which is usually called as module (cf. Definition 2).

Definition 2 (Module) – A module $\mathcal{M}$ of an ontology $\mathcal{O} = (\mathcal{T}, \mathcal{A})$ is defined as $\mathcal{M}(\mathcal{O}) =$

$(\mathcal{T}', \mathcal{A}')$, where $\mathcal{T}' \subseteq \mathcal{T}$ and $\mathcal{A}' \subseteq \mathcal{A}$ are the axioms dealing with (i) concepts $\mathcal{C}'$, (ii) roles $\mathcal{R}'$ and (iii) individuals $\mathcal{I}'$ such that: (a) $\mathcal{C}' \subseteq \mathcal{C}$, (b) $\mathcal{R}' \subseteq \mathcal{R}$ and (c) $\mathcal{I}' \subseteq \mathcal{I}$ respectively. Accordingly, an ontology module is *per se* an ontology too.

Ontology partitioning is formalized as follows.

Definition 3 (Ontology Partitioning) – The Partitioning task is seen as a function $\rho: \mathcal{O} \rightarrow \mathcal{P}$ where an ontology $\mathcal{O}$ is splitted into a set of modules $\mathcal{P}$ with Nelements (modules) such that $\mathcal{P} = \{\mathcal{O}_1, \mathcal{O}_2, \dots, \mathcal{O}_N\}$.

A module extraction aims to extract a focused fragment (or module) of the original ontology given a specific topic of interest (Hussain & Abidi 2010). The topic of interest is captured by the notion of signature (cf. Definition 4).

Definition 4 (Signature) – A signature $\mathcal{S}$ to extract a module $\mathcal{M} = (\mathcal{T}', \mathcal{A}')$ from $\mathcal{O} = (\mathcal{T}, \mathcal{A})$ is defined as $\mathcal{S}(\mathcal{O}) = (\mathcal{T}'', \mathcal{A}'')$ where $\mathcal{T}'' \subseteq \mathcal{T}' \subseteq \mathcal{T}$ and $\mathcal{A}'' \subseteq \mathcal{A}' \subseteq \mathcal{A}$ are the axioms (concepts $\mathcal{C}''$, roles $\mathcal{R}''$ and individuals $\mathcal{I}''$) specifying the context of the module to be extracted such that: $\mathcal{C}'' \subseteq \mathcal{C}' \subseteq \mathcal{C}$, $\mathcal{R}'' \subseteq \mathcal{R}' \subseteq \mathcal{R}$ and $\mathcal{I}'' \subseteq \mathcal{I}' \subseteq \mathcal{I}$.

A module extraction is formalized as follows.

Definition 5 (Module Extraction) – The Module Extraction task is seen as a function $\sigma: (\mathcal{O}, \mathcal{S}) \rightarrow \mathcal{M}$ where an ontology module $\mathcal{M}$ is extracted from an ontology $\mathcal{O}$ according to a given signature $\mathcal{S}$.

Ontology summarization provides a succinct representation (or compressed version) of the ontology (referred to as summary) emphasizing the topics contained in an ontology according to visualization and navigation purposes (Zhang et al. 2009; Li et al. 2010).

Definition 6 (Summary) – A summary description $\mathcal{D}$ of an ontology $\mathcal{O} = (\mathcal{T}, \mathcal{A})$ is defined as $\mathcal{D}(\mathcal{O}) = (\mathcal{T}', \mathcal{A}')$ where $\mathcal{T}' \subseteq \mathcal{T}$ and $\mathcal{A}' \subseteq \mathcal{A}$ are the axioms specifying the concepts $\mathcal{C}'$, the roles $\mathcal{R}'$ and the individuals $\mathcal{I}'$ that summarize the ontology such that: $\mathcal{C}' \subseteq \mathcal{C}$, $\mathcal{R}' \subseteq \mathcal{R}$ and $\mathcal{I}' \subseteq \mathcal{I}$ respectively.

Ontology summarization is then formalized.

Definition 7 (Ontology Summarization) – The Ontology Summarization task is seen as a function $\varphi: \mathcal{O} \rightarrow \mathcal{D}$ where a description $\mathcal{D}$ is generated to summarize the ontology $\mathcal{O}$.

It is worth notice that from the perspective of an ontology, the notions of (i) module ($\mathcal{M}$), (ii) signature ($\mathcal{S}$) and (iii) summary ($\mathcal{D}$) have similar formal definitions. However, these notions differ on their purpose and in extension (in terms of set inclusion), such that:

- $\mathcal{S} \subseteq \mathcal{M} \subseteq \mathcal{O}$
- $\mathcal{D} \subseteq \mathcal{M} \subseteq \mathcal{O}$

No relation can be defined between $\mathcal{S}$ and $\mathcal{D}$.

4 I3OM PROCESS

The I3OM' proposal presented here is an assisting tool for iteratively, incrementally, and interactively navigate and retrieve information from repositories described by ontologies. We argue that the combination of ontology modularization techniques into an iterative, interactive and incremental process helps the users perceiving the original knowledge base by reducing its complexity and size. The approach is novel in several aspects:

- Iterative, because the process phases are repeated several times (iterations);
- Incremental, because the result is being progressively built/refined along the iterations;
- Interactive, because the user is requested to participate in the process by refining/indicating the navigation direction;
- Semantic-based, because the process relies on and is driven by the $\mathcal{T}$-box underlying the data $\mathcal{A}$-box;
- The refinement process is not a progressive intersection of terminological terms (e.g. concepts), but instead is a signature-based ontology modularization whose modules are not disjoint in any iteration.

Algorithm 1 captures the I3OM approach. The process is comprised by two distinct steps: *Step 1* (line 1 to 6) and *Step 2* (line 7 to 12).

In *Step 1*, the algorithm starts by splitting $\mathcal{O}$ into a set of modules $\mathcal{P}$ by the Ontology Partitioning $\rho(\mathcal{O})$ which ensures that all the knowledge of the original ontology is preserved in the respective modules and is recovered by joining all the modules (Del Vescovo et al. 2011). Afterwards, a summarization algorithm is applied to each module $\mathcal{M}_i \in \mathcal{P}$. Each resulting summary $\mathcal{D}_i$ contains the main topics of the extracted module. Consequently, the set of the resulting summaries X contains the main topics of the original ontology organized by modules. A conservative ontology summarization algorithm is required in order to guarantee that every ontology entity is reachable through X. Accordingly, in each iteration of the I3OM process, X provides a global view of the ontology that allows the further specification and/or refinement of the query upon $\mathcal{O}$.

Algorithm 1. I3OM

Require: An ontology $\mathcal{O}$ and a signature $\mathcal{S}$

Ensure: A summary $\mathcal{D}$ of the relevant ontology module is provided together with a set of complementary summaries X.

1: $\mathcal{P} = \rho(\mathcal{O})$
2: $X = \emptyset$
3: **for all** $\mathcal{M}_i \in \mathcal{P}$ **do**
4: $\quad \mathcal{D}_i = \varphi(\mathcal{M}_i)$
5: $\quad X = X \cup \{\mathcal{D}_i\}$
6: **end for**

Step 1

7: **do**
8: $\quad \mathcal{M}_c = \sigma(\mathcal{O}, \mathcal{S})$
9: $\quad \mathcal{D}_c = \varphi(\mathcal{M}_c)$
10: $\quad (\mathcal{S}, bool) = combine(X, \mathcal{D}_c)$
11: **while** $(bool)$
12: **return** $(X, \mathcal{D}_C)$

Step 2

Next, the algorithm extracts a module from the ontology and summarizes it (*Step 2*). In line 8 a contextualized module $\mathcal{M}_c$ is extracted from the entire ontology $\mathcal{O}$ with regard to a given signature $\mathcal{S}$ (provided by the user) through $\sigma(\mathcal{O}, \mathcal{S})$. Yet, since the current signature may contain axioms belonging to several of the initial ontology modules $\mathcal{P}$, the resulting contextualized module may not correspond to any module in $\mathcal{P}$. Instead, the resulting contextualized module may be subsumed by:

- a single initial module ($\mathcal{M}_c \sqsubseteq \mathcal{M}_i \in \mathcal{P}$); or
- the union of multiple initial modules ($\mathcal{M}_c \sqsubseteq \{\forall j{:}\, \mathcal{M}_j \in \mathcal{P}\} \sqsubseteq \mathcal{O}$).

The contextualized module $\mathcal{M}_c$ is further summarized in order to obtain a contextualized summary $\mathcal{D}_c$ (line 9). Thus, $\mathcal{D}_c$ represents the semantic context (i) to the previous user query and (ii) to the semantic resources to be retrieved as response to the query.

The $combine$ function (line 10) represents the application module that makes use of I3OM, either automatically or through the user. The input of the $combine$ function is the set X obtained in *Step 1* and the set $\mathcal{D}_c$ processed in the current iteration. This function allows the selection of a set of entities ($\mathcal{S}$) to constraint the next iteration according to four intends:

- Constraint focus: it occurs when the user only selects ontology entities from $\mathcal{D}_c$ and all of them are subsumed by the ontology entities selected in the previous iteration;
- Expand focus: it occurs when the signature selection includes ontology entities of previous iteration and adds new ones existing in $\{X - \mathcal{D}_c\}$;
- Shift focus: it occurs when the selected signature is comprehended in $\{X - \mathcal{D}_c\}$;
- A combination of the previous three.

In any of these cases, $bool$ takes the Boolean value *"true"*. Alternatively, the $combine$ function might decide to stop the I3OM process. In such case, $bool$ takes the Boolean value of *"false"*.

5 WALK-THROUGH EXAMPLE

To demonstrate the proposal we present now a real walk-through example. For that we use the EKAW ontology (EKAW 2011) that has a $\mathcal{SHIN}$ Description Logics expressivity and it is composed by 74 concepts, 33 object properties, and it has no data properties and individuals.

In *Step 1*, the ontology is split into four modules $\mathcal{P} = \{\mathcal{M}_1, \mathcal{M}_2, \mathcal{M}_3, \mathcal{M}_4\}$. Each one of these modules is further summarized such that $X = \{\mathcal{D}_1, \mathcal{D}_2, \mathcal{D}_3, \mathcal{D}_4\}$. Table 1 and Table 2 illustrates the obtained results. These results do not change along the iterations (*Step 1* is performed once).

Table 1: Metrics of the modules obtained in *Step 1*.

	$\mathcal{M}_1$	$\mathcal{M}_2$	$\mathcal{M}_3$	$\mathcal{M}_4$
No. of Classes	56	4	34	5
No. of Properties	30	2	11	2

Table 2: Summaries obtained in *Step 1*.

$\mathcal{M}_i \in \mathcal{P}$	$\mathcal{D}_i \in X$
$\mathcal{M}_1$	$\mathcal{D}_1 = \left\{\begin{matrix} Document, Event, Session, \\ Scientific\_Event, Paper \end{matrix}\right\}$
$\mathcal{M}_2$	$\mathcal{D}_2 = \{Location\}$
$\mathcal{M}_3$	$D_3 = \left\{\begin{matrix} Person, PC\_Member, Possible\_Reviewer \\ Conference\_Participant, Organisation \end{matrix}\right\}$
$\mathcal{M}_4$	$\mathcal{D}_4 = \{Event, Research\_Topic\}$

Next, *Step 2* is performed for the first time (iteration 1). In this iteration the input signature is empty ($\mathcal{S}_1 = \emptyset$). Consequently, the contextualized module and its summary are also empty ($\mathcal{M}_{c_1} = \mathcal{D}_{c_1} = \emptyset$).

According to the output of the $combine$ function ($\mathcal{S}_i$ in Table 3), *Step 2* runs from iterations 2 to 5.

Table 3: Characteristics of the Extracted Contextualized Modules and its Summary

It. (i)	Input Information	$\mathcal{M}_{c_i}$		$\mathcal{D}_{c_i}$
	$\mathcal{S}_i$	No. of Concepts	No. of Properties	
1	$\mathcal{S}_1 = \emptyset$	0	0	$\mathcal{D}_{c_1} = \emptyset$
2	$\mathcal{S}_2 = \{Document\}$	31	10	$\mathcal{D}_{c_2} = \left\{ \begin{matrix} Document, Paper, Review \\ Submitted\_Paper, Assigned\_Paper \end{matrix} \right\}$
3	$\mathcal{S}_3 = \{Paper\}$	20	8	$\mathcal{D}_{c_3} = \left\{ \begin{matrix} Document, Paper, Person \\ Submitted\_Paper, Assigned\_Paper, \end{matrix} \right\}$
4	$\mathcal{S}_4 = \{Submitted\_Paper, Event\}$	34	12	$\mathcal{D}_{c_4} = \left\{ \begin{matrix} Document, Paper, Session, \\ Scientific\_Event, Event, \\ Submitted\_Paper \end{matrix} \right\}$
5	$\mathcal{S}_5 = \{Organisation\}$	6	0	$\mathcal{D}_{c_5} = \left\{ \begin{matrix} Organisation, \\ Academic\_Institution \end{matrix} \right\}$

The input to the $combine$ function provided by *Step 2* ($\mathcal{D}_{c_i}$) is also depicted in Table 3 together with few characteristics of the contextualized module $\mathcal{M}_{c_i}$ from which $\mathcal{D}_{c_i}$ is obtained.

Second iteration starts by the $combine$ feeding the I3OM algorithm with $\mathcal{S}_2$. Considering $\mathcal{S}_2$ a new contextualized module is extracted and summarized as $\mathcal{D}_{c_2}$. Considering X and $\mathcal{D}_{c_2}$ the $combine$ returns $\mathcal{S}_3$ which contains only an entity ($Paper$) of $\mathcal{D}_{c_2}$. Therefore, the $combine$ is constraining the focus of the relevant information. This is further confirmed by the characteristic of the extracted contextualized module as well by its summary ($\mathcal{D}_{c_3}$). Next, considering X and $\mathcal{D}_{c_3}$the $combine$ returns $\mathcal{S}_4$ which contains an entity ($Submitted\_Paper$) of $\mathcal{D}_{c_3}$ and another entity ($Event$) of $X - \mathcal{D}_{c_3}$, which suggests that the $combine$ is expanding its focus. This suggestion is confirmed by the characteristic of the extracted contextualized module as well by its summary ($\mathcal{D}_{c_4}$). Finally, considering X and $\mathcal{D}_{c_4}$, the $combine$ returns $\mathcal{S}_5$ which contains no entities of $\mathcal{D}_{c_4}$, but only an entity ($Organisation$) of $X - \mathcal{D}_{c_4}$, which means the $combine$ is shifting its focus. This is proved by the resulting contextualized module and its summary ($\mathcal{D}_{c_5}$).

This real walk-through example demonstrated the capabilities and effectiveness of the I3OM process in supporting the different intends of querying/retrieving information: constraining, expanding and shifting.

6 RELATED WORK

The KC-Viz (Motta et al. 2011) is a plugin for the Neon Toolkit (Neon Toolkit 2012) that enables the user to visualize and navigate through ontologies. This approach exploits the Key Concepts Extraction (KCE) (Peroni et al. 2008) ontology summarization algorithm to identify concise overviews of the ontology and support the ontology navigation starting from the most useful concepts for making sense of an ontology. This is enhanced by a powerful user interface comprehending a panoply of graphical features (e.g. zooming, layout customization) (Motta et al. 2011).

However, while KC-Viz supports ontology navigation, it does not allow the user to focus on a particular set of entities and its related entities (i.e. a contextualized module). On the contrary, our approach enables the user to focus on an ontology module according to a set of selected entities. Moreover, KC-Viz navigation is carried through a tree-structure, which only reflects the subsumption relations. Therefore, it (i) only allows the user to focus on the sub-classes of a node, and (ii) it does not capture other types of relations. As our approach relies on the Module Extraction task in each iteration, all relations are always available to the user/application. Additionally, while all the ontology is reachable in every iteration of I3OM, in KC-Viz this is not always true. Yet, the powerful user interface features of KC-Viz are useful and can be exploited by the I3OM' $combine$ function.

7 SUMMARY AND DISCUSSION

The proposed ontology modularization-based process benefits from the advantages that each particular modularization technique has. While splitting the ontology into smaller modules that emphasize the topicality of the ontology and enhance the visualization, Ontology Partitioning guarantees that all the knowledge of the original ontology is preserved (d' Aquin et al. 2009). Ontology Summarization has the ability to extract the key entities out of the ontology which may represent the key areas covered by the ontology. Module Extraction extracts specialized knowledge from different topics according to a signature. This signature is indeed a core concept in the proposal as it allows the interaction between the application/user and the automatic process in a stateless way.

Preliminary experiments with the I3OM prototype showed that users are able to easily, efficiently and effectively navigate through the ontology, reaching their goal in a small number of iterations. Further, the more the users are proficient with a search approach (text-based search vs. ontology-based search), the fast they answer the questions and less intellectual effort they put on the task. Observations showed that the time spent to answer a question with the I3OM system decreased in the latter questions despite these questions were not simpler than the earlier ones. Moreover, medium and high-proficient users expressed their sympathy for the I3OM approach, while answering the questions faster with the IO3M system. However, these experiments also demonstrate that the combination of third-party ontology modularization algorithms into the I3OM process is not trivial and demands significant improvements in order to deal with ontologies having disparate set of characteristics. Therefore, this issue is requiring our current and future attention.

Another identified major issue, which is not directly related to the I3OM process but, instead, is related to the World Search project overall approach concerns the GUI module. In fact the users expressed concerns about the supplied GUI, suggesting the need to better track the results/iteration. In this respect, the GUI must automatically adapt (change based on several factors such as (i) the user proficiency, (ii) the content' complexity of the provided semantic context (e.g. shown by means of a tree or a graph) and (iii) provide specific interaction for the orthogonal ontological dimensions (e.g. time and space).

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