Integrating Ontology Knowledge into a Query Algebra for Multimedia Meta Objects

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Abstract. Efficient access to multimedia content can be provided, if the media data is enriched with additional information about the content's semantics and functionality. For making full use of domain-specific knowledge for a specific context this meta information has to be integrated with a domain ontology. In previous research, we have developed Enhanced Multimedia Meta Objects (EMMOs) as a new means for semantic multimedia meta modeling, as well as a query algebra EMMA, which is adequate and complete with regard to the EMMO model. This paper focuses on the seamless integration of ontology knowledge into EMMA queries to enable sophisticated query refinement.

1 Introduction

Today, large collections of multimedia resources are available, e.g. commercial and private video and audio collections, repositories of technical multimedia documentations, or distributed units of multimedia learning material. However, the reuse of this wealth of material requires the efficient access to specific information items. Text-based keyword searching alone is not sufficient for retrieving multimedia data. The way how multimedia content can be searched depends on the way how multimedia content is annotated, and whether domain specific knowledge can be integrated into the retrieval.

Within the EU-project CULTOS (see `www.cultos.org`), we have developed a novel approach for semantic multimedia content modeling – *Enhanced Multimedia Meta Objects (EMMOs)* [1] – suitable for the representation of InterTextualThreads (ITTs), i.e. complex knowledge structures used by researchers in intertextual studies to share and communicate their knowledge about the relationships between cultural artefacts. An EMMO constitutes a self-contained piece of multimedia content that indivisibly unites three of the content's aspects.

First, the *semantic aspect* reflects that an EMMO further encapsulates semantic associations between its contained media objects. For that purpose, we use a graph-based model similar to conceptual graphs. The links and nodes of the graph structure are labeled by *ontology objects* representing concepts of the domain ontology. Hence, an EMMO constitutes a unit of expert knowledge about multimedia content. Figure 1 shows the EMMO "Crucifixion in Popular

Texts", which is used as a running example throughout this paper. The media objects contained within the EMMO "Crucifixion in Popular Texts" are digital manifestations of the ancient bible text "Luke 23", the movies "Life of Brian" and "Tommy", and Madonna's video clip "Like a Prayer". The types of a media object are established through a reference to concepts of the domain ontology, e.g. *Ancient Text* or *Rock Opera*. By also labeling the associations with the corresponding concepts of the ontology, we can express that the ancient text "Luke 23" was *retold* by "Like a Prayer" and *influenced* "Life of Brian", which again *influenced* "Tommy". By modeling semantic associations and EMMOs as first-class objects, the EMMO model becomes very expressive in a way that it is possible to establish references to other EMMOs and to reify associations.

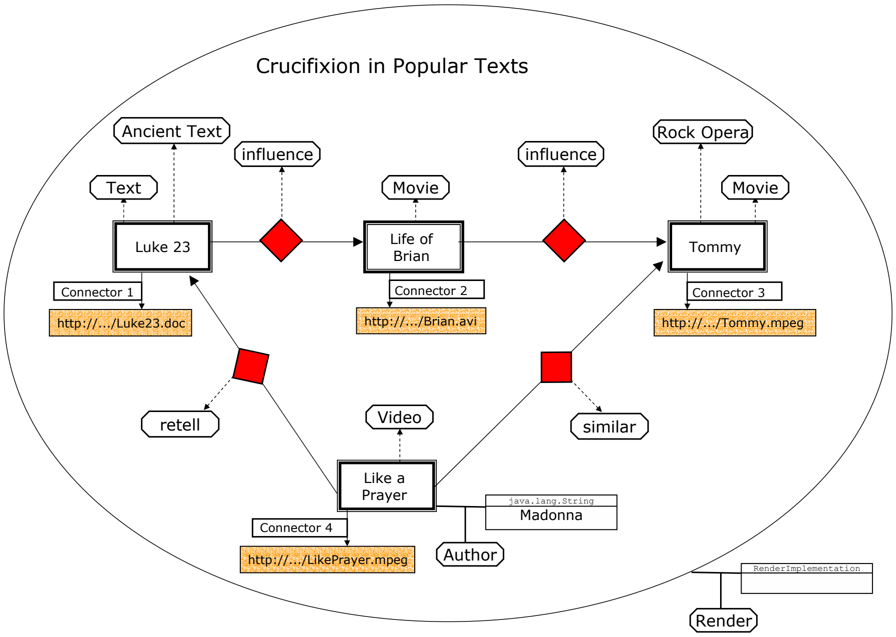

Fig. 1. Emmo "Crucifixion in Popular Texts" ($e_{popular}$)

Second, the *media aspect* describes that an EMMO aggregates the media objects of which the multimedia content consists, e.g. the EMMO "Crucifxion in Popular Texts" contains the text document "Luke23.doc", the MPEG videos "Tommy.mpeg" and "LikePrayer.mpeg", and the AVI video "Brian.avi".

Third, the *functional aspect* specifies operations on the content and on the semantic description of an EMMO that can be invoked and shared by applications; e.g. the EMMO "Crucifixion in Popular Texts" offers a rendering operation, which returns a presentation of the EMMO's content in different formats, such as SMIL or SVG.

EMMOs are *tradeable* – they can be bundled and exchanged in their entirety including media, content description, and functionality – and *versionable*, i.e. they can be modified concurrently in a distributed collaborative scenario.

To enable the efficient retrieval of EMMOs, we developed the *query algebra EMMA*, which is adequate and complete with regard to the EMMO model. By providing simple and orthogonal operators, which can be combined to formulate more complex queries, EMMA enables query optimization. Moreover, EMMA provides means to navigate through an EMMO's ontology-labeled graph structure by using navigational operators.

In order to make full use of the characteristics of the application domain, the query algebra needs to integrate *ontology knowledge.* The contribution of this paper is to present an efficient solution for the seamless integration of ontology knowledge into EMMA queries to enable sophisticated query refinement. We focus on concepts used for labeling associations, because the integration of ontology knowledge about these concepts is essential for enriching the expressive power of navigational operators, e.g. by including information about subconcepts.

The remainder of the paper is organized as follows. In Sect. 2 we discuss related approaches and standards. Section 3 introduces EMMA's operators for navigating an EMMO's graph structure. In Sect. 4 we define an ontology structure suitable for EMMOs and describe the integration of ontology knowledge into EMMA queries. Section 5 concludes this paper with an outlook on future work.

2 Related Work

The EMMO approach is in sofar unique as it incorporates a semantic, media, and functional aspect, as well as versioning support, in a homogeneous way. None of the standards for multimedia document models, such as SMIL [2] or SVG [3], and none of the standards for semantic media description, such as RDF [4], Topic Maps [5], Conceptual Graphs [6], or MPEG-7 [7] addresses all these aspects. Therefore, none of the query languages for those standards can fulfil all requirements with respect to the expressiveness of a query language for EMMOs. However, valuable aspects of their design have been incorporated into the design of the algebra EMMA.

The seamless integration of ontology knowledge is essential for enriching the expressive power of EMMA's navigational operators. Navigational operators allow to traverse the semantic relationships between entities contained within an EMMO. Standards for semantic media descriptions can be used to model multimedia content by describing the information it conveys on a semantic level, similar to an EMMO's semantic aspect. Therefore, we have analyzed query languages for RDF, Topic Maps, Conceptual Graphs, and MPEG-7, with the focus on their ability to navigate the graph structure and to integrate ontology knowledge.

Although there exist several query languages for *RDF*, there is no official standard yet. RAL [8], an algebra for querying RDF, and RQL [9], a declarative query language for RDF, both provide means to navigate the RDF graph structure and enable the integration of a very simple ontology structure described by an RDF Schema [10], but they cannot deal with more elaborate ontology constructs, such as the transitivity or symmetry of relationships.

For *Topic Maps* the situation is similar to that of RDF, i.e. there exist several query languages but no standard yet. Tolog [11], a logic based query language for querying Topic Maps, provides a crude way of graph navigation and very basic ontology support, but neglects to address more sophisticated ontology constructs commonly described within ontology structures. The approaches TMPath [12] and XTMPath [13] focus on the navigation of Topic Maps. However, they are not constructed as fully fledged query languages and do not provide any features for ontology integration.

Conceptual Graphs allow to specify query graphs to formulate any database query that can be expressed by SQL [14], but to the best of our knowledge, there is no explicit query algebra for Conceptual Graphs, therefore also no formal basis for integrating ontology knowledge into queries.

The same is true for *MPEG*-7. Although there are quite a few approaches adapting XQuery for querying MPEG-7 documents [15], there is no approach focusing especially on MPEG-7's `Graphs` tool defined for the description of content semantics (allowing to describe networks of semantically interrelated media objects).

To summarize, there are several approaches, like RAL, RQL, or Tolog enabling graph navigation and allowing to integrate primitive constructs of ontology structures, such as the concept-subconcept relationship; but more elaborate constructs, such as the transitivity or symmetry of relationships, cannot be integrated. Although establishing a comprehensive syntax for the navigation of graph structures, approaches such as TMPath or XTMPath provide no features for ontology integration. Thus, also with regard to the seamless integration of ontology knowledge, none of these query languages provides sufficient functionality.

3 Navigating an EMMO's Graph Structure

The formal basis of the EMMO model are *entities*. There exist four different specializations of entities:

- *ontology objects* represent concepts of an ontology,
- *logical media parts* represent media objects or parts of media objects, e.g. video scenes or book chapters,
- *associations* model binary relationships,
- *EMMOs* aggregate semantically related entities.

Each entity can be labeled by concepts of the ontology, i.e. each entity w associates a set $types(w)$ including its labeling ontology objects. Semantic relationships between entities are described by *directed associations* specifying a *source* and *target entity* for which the relationship holds. Thus, an EMMO describes a graph-like knowledge structure of entities with associations being labeled by ontology objects (representing concepts of the domain ontology) describing the edges of the graph structure.

Navigation through an EMMO is controlled by a *navigation path*, which is defined as a set of *sequences* of ontology objects. For each ontology object in a sequence, a mapping to the corresponding association within the EMMO is established to traverse the graph. We have defined *regular path expressions* over ontology objects for describing the syntax of a navigation path; and the *navigational operators* specify how those syntactic expressions are applied to navigate the graph.

For example, for a given EMMO, start entity, and regular path expression, the navigational operator *JumpRight* returns the set of all entities that can be reached by traversing the navigation path in the right direction, i.e. by following associations from source to target entities. Applying the operator *JumpRight* to the EMMO "Crucifixion in Popular Texts" ($e_{popular}$) , the starting entity "Luke 23" (l_{luke}), and the primitive regular path expression consisting of one single ontology object *influence* ($o_{influence}$) yields the logical media part representing the movie "Life of Brian" (l_{brian}), i.e.

$$\mathit{JumpRight}(e_{popular}, l_{luke}, o_{influence}) = \{l_{brian}\}.$$

In addition to one single ontology object, there exist two other primitive regular path expressions:

- "ε" refers to the empty entity and is interpreted by the operation *JumpRight* as absence of movement, e.g.:

$$\mathit{JumpRight}(e_{popular}, l_{luke}, \varepsilon) = \{l_{luke}\}.$$

- "_" refers to any arbitrary ontology object, e.g.:

$$\mathit{JumpRight}(e_{popular}, l_{prayer}, \_) = \{l_{luke}, l_{tommy}\}.$$

Regular path expressions may include two operators for the combination of other regular path expressions:

- Regular path expressions can be *concatenated* to specify a longer navigation path, e.g.:

$$\mathit{JumpRight}(e_{popular}, l_{prayer}, o_{retell} o_{influence}) = \{l_{brian}\}.$$

- "|" allows to combine two regular path expressions as alternative branches, e.g.:

$$\mathit{JumpRight}(e_{popular}, l_{prayer}, o_{retell} \,|\, o_{similar}) = \{l_{luke}, l_{tommy}\}.$$

Finally, there exist four unary operators to modify regular path expressions:

- "?" added to a regular path expression describes its optionality, e.g.:

$$\mathit{JumpRight}(e_{popular}, l_{luke}, o_{similar}?o_{influence}) =$$
$$\mathit{JumpRight}(e_{popular}, l_{luke}, o_{influence} \,|\, (o_{similar}o_{influence})) = \{l_{brian}\}.$$

- "+" defines an iteration of path expressions, which is interpreted as navigation along the same regular path expression any number of times, but at least once, e.g.:

$$\mathit{JumpRight}(e_{popular}, l_{luke}, o_{influence}+) = \{l_{brian}, l_{tommy}\}.$$

- "∗" defines an iteration of path expressions, which is interpreted as navigation along the same regular path expression any number of times, e.g.:

$$\mathit{JumpRight}(e_{popular}, l_{luke}, o_{influence}*) =$$
$$\mathit{JumpRight}(e_{popular}, l_{luke}, \varepsilon \,|\, o_{influence}+) =$$
$$\{l_{luke}, l_{brian}, l_{tommy}\}.$$

- "−" allows to express the inversion of regular path expressions, i.e. to follow associations from target to source entities, e.g.:

$$\mathit{JumpRight}(e_{popular}, l_{luke}, o_{retell}-) = \{l_{prayer}\}.$$

Traversal along the opposite direction of associations can also be expressed with the navigational operator *JumpLeft*, e.g.:

$$\mathit{JumpLeft}(e_{popular}, l_{luke}, o_{retell}) = \mathit{JumpRight}(e_{popular}, l_{luke}, o_{retell}-) = \{l_{prayer}\}.$$

4 Integration of Ontology Knowledge

Ontologies provide a shared and common understanding of a domain and facilitate the sharing and reuse of knowledge [16]. They describe concepts, relationships, and constraints in the domain of discourse. The integration of ontology knowledge into EMMA queries has two appealing benefits.

First, knowledge inherent in a domain ontology can be seamlessly integrated into queries. Therefore, the user can pose imprecise queries, which are refined by drawing inferences over the ontological knowledge. For example, if the user asks for all media objects which had been *influenced* by the ancient bible text "Luke 23", he should also receive media objects which were indirectly *influenced* by the ancient bible text, e.g. the rock opera "Tommy". This can be accomplished if the transitivity of the ontology object $o_{influence}$ is known, i.e. defined in the ontology.

Second, ontology knowledge can be used for checking integrity constraints during the design and authoring process of EMMOs, e.g. only associations can be stored in the database which conform to the specified types regarding source and target entities. The integration of constraint checking into the EMMO authoring environment is still ongoing work, and will not be further discussed in this paper.

In the following, we will focus on concepts used for labeling associations, because the integration of ontology knowledge for those concepts is essential for enhancing the expressive power of navigational operators. We define an ontology structure suitable for the EMMO model, describe how the most common modeling constructs used in standard ontology languages like DAML+OIL [17] or OWL [18] can be represented within the structure, and exemplify how the ontology knowledge can be integrated into EMMA queries.

The definition of an ontology structure for EMMOs was inspired by the ontology structure definition in [19]. Any concept of the ontology which is used for labeling entities within the EMMO model is represented as ontology object within the EMMO model. As the EMMO model treats associations as first class objects, ontology objects can be used for labeling both, the nodes and the edges, within an EMMO's graph structure. However, as mentioned before, we will only discuss ontology objects for labeling edges in the following. We specify an *ontology structure* suitable for the EMMO model as 3-tuple $\mathcal{O} = \{\Theta, \mathcal{H}^{\Theta}, \mathcal{A}^{\mathcal{O}}\}$ consisting of

- a *set of ontology objects* Θ, representing the concepts of the ontology,
- a *concept hierarchy* $\mathcal{H}^{\Theta}$ describing the subclass relationship between ontology objects, i.e. $\mathcal{H}^{\Theta}$ is a directed relation $\mathcal{H}^{\Theta} \subseteq \Theta \times \Theta$ with $\mathcal{H}^{\Theta}(o_1, o_2)$ expressing that o_1 is a subconcept of o_2.
- a set of *ontology axioms* $\mathcal{A}^{\mathcal{O}}$, expressed in first order logic.

Figure 2 illustrates a small portion of the Ontology of Intertextuality used in the CULTOS project as defined in [20].

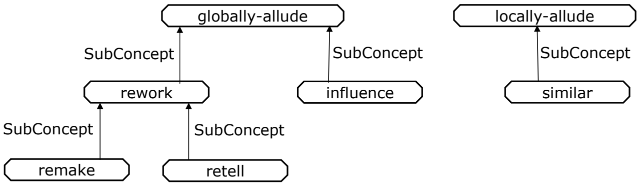

Fig. 2. Extract from the Ontology of Intertextuality

The set of ontology axioms $\mathcal{A}^{\mathcal{O}}$ allows to specify properties and restrictions of concepts, and defines relationships or properties of relationships between concepts. We can specify that some specific ontology objects are dedicated for describing associations within the EMMO model, e.g.

$$(\{o_{globally-allude}, o_{rework}, \ldots, o_{similar}\} \subseteq \mathcal{CR}) \quad \in \quad \mathcal{A}^{\mathcal{O}}, \qquad (1)$$

with $\mathcal{CR} = \{o \in \Theta \mid \forall w \in \Omega \land o \in types(w) \rightarrow w \in \Lambda\}$ describing the set of all ontology objects used for labeling associations, Ω the set of all entities, Λ the set of all associations, and $types(w)$ the set of ontology objects labeling the entity w.

Example 1. The hierarchical structure of concepts in Fig. 2 specifies that the concept $o_{globally-allude}$ has two subconcepts o_{rework} and $o_{influence}$. Integrating this knowledge into the EMMA query

$$\mathit{JumpRight}(e_{popular}, l_{luke}, o_{globally-allude}) = \emptyset$$

yields the expanded query:

$$\mathit{JumpRight}(e_{popular}, l_{luke}, o_{globally-allude} \,|\, o_{rework} \,|\, o_{influence}) = \{l_{brian}\}.$$

Thus, a user requesting all entities which were *globally alluded* by the ancient bible text "Luke 23", receives the logical media part "Life of Brian" because the EMMO "Crucifixion in Popular Texts" specifies that it was *influenced* by the bible text.

Example 2. However, incorporating the knowledge about the hierarchical structure of concepts into the query of a user asking for all entities being *globally alluded* by Madonna's video clip "Like a Prayer", i.e.

$$\mathit{JumpRight}(e_{popular}, l_{prayer}, o_{globally-allude}) \quad = \quad \emptyset.$$

yields the expanded query

$$\mathit{JumpRight}(e_{popular}, l_{luke}, o_{globally-allude} \,|\, o_{rework} \,|\, o_{influence}) = \emptyset.$$

still returning the empty answer set because the concept o_{retell} is not a direct subconcept of the concept $o_{globally-allude}$.

To enable also query expansion with indirect subconcepts, we can define the *transitivity of the concept hierarchy* within the set of ontology axioms, i.e.

$$\left(\forall o_1, o_2, o_3 \in \Theta \quad \mathcal{H}^{\Theta}(o_1, o_2) \wedge \mathcal{H}^{\Theta}(o_2, o_3) \rightarrow \mathcal{H}^{\Theta}(o_1, o_3)\right) \in \mathcal{A}^{\mathcal{O}}. \qquad (2)$$

Example 3. By incorporating the knowledge about the transitivity of concepts into the query of Example 2, this yields the expanded query:

$$\mathit{JumpRight}(e_{popular}, l_{prayer}, o_{globally-allude} \,|\, o_{rework} \,|\, o_{influence} \,|\, o_{retell} \,|\, o_{remake}) = \\ = \{l_{luke}\}.$$

Within the ontology axioms, we can also define *transitive concepts*, i.e. concepts for which an iteration of the corresponding path expression can be defined without changing the semantics of the concept, e.g.

$$(o_{influence} \in \Theta_{\text{TRANS}}) \in \mathcal{A}^{\mathcal{O}}, \qquad (3)$$

with $\Theta_{\text{TRANS}} = \{o \in \mathcal{CR} \,|\, \forall a_1, a_2 \in I(o) \quad \mathit{target}(a_1) = \mathit{source}(a_2) \quad \rightarrow \exists a_3 \in I(o) \quad \mathit{source}(a_3) = \mathit{source}(a_1) \wedge \mathit{target}(a_3) = \mathit{target}(a_2)\}$ describing the set of all transitive ontology objects, $I(o) = \{w \in \Omega \mid o \in \mathit{types}(w)\}$ the set of all entities labeled by the ontology object o, and $\mathit{source}(a)$ and $\mathit{target}(a)$ the source and target entities of association a (see Fig. 3).

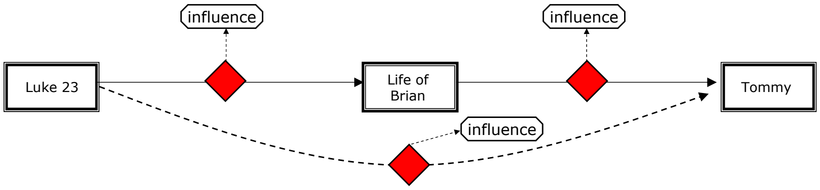

Fig. 3. Integrating the knowledge that $o_{influence}$ refers a transitive concept

Example 4. Integrating the knowledge that $o_{influence}$ references a transitive concept into the EMMA query

$$JumpRight(e_{popular}, l_{luke}, o_{influence}) = \{l_{brian}\}$$

expands the query to

$$JumpRight(e_{popular}, l_{luke}, o_{influence}+) = \{l_{brian}, l_{tommy}\}.$$

In a similar way we express *symmetric concepts*, i.e. concepts for which all associations can be traversed in both directions, i.e. source and target entities can be exchanged without changing the semantics of the concept, e.g.

$$(o_{similar} \in \Theta_{\mathrm{SYM}}) \in \mathcal{A}^{\mathcal{O}}, \tag{4}$$

with $\Theta_{\mathrm{SYM}} = \{o \in \mathcal{CR} \,|\, \forall a_1 \in I(o)\, \exists a_2 \in I(o)\, (source(a_1) = target(a_2) \wedge source(a_2) = target(a_1))\}$ describing the set of all symmetric ontology objects (see Fig. 4).

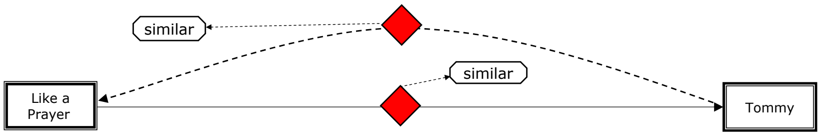

Fig. 4. Integrating of the knowledge that $o_{similar}$ refers a symmetric concept

Example 5. By incorporating the knowledge that $o_{similar}$ references a symmetric concept, the EMMA query

$$JumpRight(e_{popular}, l_{tommy}, o_{similar}) = \emptyset$$

is expanded to

$$\begin{aligned}&JumpRight(e_{popular}, l_{tommy}, o_{similar}) \cup JumpLeft(e_{popular}, l_{tommy}, o_{similar}) = \\ &JumpRight(e_{popular}, l_{tommy}, o_{similar} \,|\, o_{similar}-) = \\ &= \{l_{prayer}\}.\end{aligned}$$

Finally, we can also express that two concepts are *inverse* to each other, i.e. if an association is labeled with the inverse concept, then source and target entities have to be exchanged to keep the semantics intact, e.g.

$$((o_{retell}, o_{is-retold}) \in \Theta_{\text{INV}}) \in \mathcal{A}^{\mathcal{O}}, \tag{5}$$

with $\Theta_{\text{INV}} = \{(o_1, o_2) \in \mathcal{CR} \times \mathcal{CR} \,|\, \forall a_1 \in I(o_1)\, \exists a_2 \in I(o_2)(source(a_1) = target(a_2) \wedge source(a_2) = target(a_1))\}$ describing the set of all pairs of inverse ontology objects (see Fig. 5).

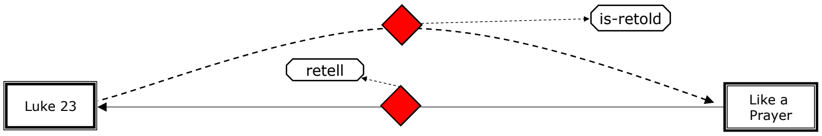

Fig. 5. Integrating the knowledge that o_{retell} and $o_{is-retold}$ reference inverse concepts

Example 6. Knowing that the ontology objects o_{retell} and $o_{is-retold}$ refer to two inverse concepts expands the EMMA query

$$JumpRight(e_{popular}, l_{luke}, o_{is-retold}) = \emptyset$$

to the query:

$$JumpRight(e_{popular}, l_{luke}, o_{is-retold}) \cup JumpLeft(e_{popular}, l_{luke}, o_{retell}) =$$
$$JumpRight(e_{popular}, l_{luke}, o_{is-retold} \,|\, o_{retell}-) =$$
$$= \{l_{prayer}\}.$$

Figure 6 enhances Fig. 2 by a graphical representation of the ontology axioms, i.e. the concept *influence* is marked as transitive, the concept *similar* as symmetric, and the concepts *retell* and *is-retold* as being inverse to each other.

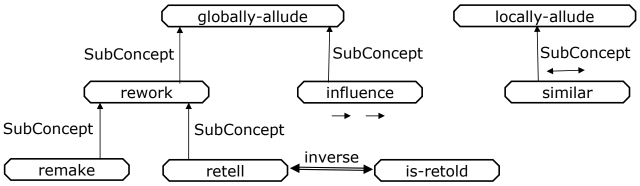

Fig. 6. Ontology of Intertextuality enhanced by Ontology Axioms

Since DAML+OIL does not provide modeling constructs for symmetric properties, it was not adequate as representation language for an ontology structure.

However, OWL specifies all the modeling constructs used within an ontology structure, i.e. constructs for expressing transitive, symmetric, and inverse concepts. Therefore,we could use Protege-2000 as authoring tool for ontology, and import the resulting OWL description into an EMMO environment. Figure 7 shows the OWL representation for the ontology in Fig. 6.

```
<rdf:RDF
     xmlns:rdf ="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
     xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
     xmlns:owl="http://www.w3.org/2002/07/owl#" >
    <rdf:Property rdf:ID="globally-allude"/>
    <rdf:Property rdf:ID="rework">
        <rdfs:subPropertyOf rdf:resource="#globally-allude"/></rdf:Property>
    <owl:TransitiveProperty rdf:ID="influence">
        <rdfs:subPropertyOf rdf:resource="#globally-allude"/></owl:TransitiveProperty>
    <rdf:Property rdf:ID="remake">
        <rdfs:subPropertyOf rdf:resource="#rework"/> </rdf:Property>
    <rdf:Property rdf:ID="retell">
        <rdfs:subPropertyOf rdf:resource="#rework"/></rdf:Property>
    <rdf:Property rdf:ID="is-retold">
        <owl:inverseOf rdf:resource="#retell"/></rdf:Property>
    <rdf:Property rdf:ID="locally-allude"/>
    <owl:SymmetricProperty rdf:ID="similar">
        <rdfs:subPropertyOf rdf:resource="#locally-allude"/></owl:SymmetricProperty>
</rdf:RDF>
```

Fig. 7. OWL representation of the Ontology of Intertextuality

However, by representing the ontology in the standard formats, such as OWL, more complex inferences drawn form the ontology knowledge cannot be integrated into EMMA queries. Therefore, we plan to develop our own ontology description language compatible with the EMMO model allowing for sophisticated reasoning on EMMOs.

5 Conclusion

We have developed the query algebra EMMA, which enables the access to all aspects regarding the EMMO model, and provide means to integrate ontology knowledge. Currently, we are in the process of integrating ontology-based constraint checking into the EMMO authoring process. Future work will focus on the development of an ontology description language that is compatible with EMMOs to offer advanced question-answering capabilities. Furthermore, we will compile a comprehensive set of use cases for query evaluation and carry out a case study in the domain of eLearning to evaluate the feasibility of our approach in a real-word environment.

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