Methodology for Constructing a New Framework for Querying a Semantic Network

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Abstract

An integrated statement is made concerning the semantic status of nodes in a propositional semantic network. Context is the interrelated condition in which something exists or occurs. Naturally, context-aware computing environments are based on the knowledge of the context. This is because users have the expectation that they can access whichever information and service they want, whenever they want, and wherever they are. In order to ensure that these expectations are satisfied the need of a context is clear. Query languages, such as SQL, and query user interfaces were developed for 'Closed World' systems, such as accounting systems, where information is comprehensively described within the limits of a context and a schema well-known to the users. In such systems, querying by associations of values in different database fields yields very high recall and precision. Querying individually hundreds of different kinds of properties leaves a huge recall gap to text retrieval, whereas a global restriction to "core metadata" deprives the systems of reasoning capability. Here I proposed a methodology which will help us in constructing a framework for querying a semantic network. The Two step methodology is proposed here. Using schema of the core ontology ISO21127 and specializations of it.

Keywords: Metadata, Information Retrieval, Semantic Network Searching, Ontology.

1. Introduction

Query languages, such as SQL, and query user interfaces were developed for some specific work such as accounting systems, where information is comprehensively described within the limits of a context and a schema well-known to the users. In such systems, querying by associations of values in different database fields yields very high recall and precision. In 'Open World' system, such as Digital Repositories or the Web, information may be organized by different people, using a schema in different ways, or even using different schemata and languages, and information is by nature incomplete. Therefore the traditional querying system becomes unreliable.

Nowadays, the most popular search method on web is the keyword based search in text documents, image captions and database fields. It usually yields high recall rate and a medium to low precision rate. The big search engines on the Internet may find millions of "hits" for some term, but only few documents may actually be the ones sought. Query term expansion using a thesaurus of synonyms and related terms may improve the recall, but may further deteriorate the precision. The user satisfaction is nevertheless relatively high. Since the system is very "responsive" to the users' requests, particularly, if a smart relevance page ranking system is used to increase precision. But in reality the satisfaction is mostly due to the huge number of redundant data in such systems with respect to the most known questions.

The Semantic Web overcomes the recall and precision gap problem for information not backed up by high redundancy, by resorting to rich formally structured metadata for documents of interest. The data are formulated in the "Semantic Web" under schemata "ontologies" that are globally accessible via Internet and can be combined to a certain degree. The most advanced Digital Library systems, such as the Europeana1 or cultureSampo, are based on this technology. However, the Semantic Web is an Open World system. Querying individually hundreds of different kinds of properties creates a huge recall gap compared to text retrieval, and querying a conjunction of even a few properties uses to frustrate the users with empty answers. A global restriction of the semantic network to "core metadata" on the other side deprives the systems of the reasoning capability and precision the Semantic Web promised. In order to fill this gap of precision and recall rates between keyword search and semantic search on metadata,
I propose a methodology for constructing a framework for querying a semantic networks based on a few "Fundamental Categories and Relationships".

2. Query Languages

It is remarkable that one wants to avoid the use of general programming languages for querying databases for various reasons: they usually require more effort, they are error-prone, and they are not conducive to query optimization. Ideally, a query language allows users to formulate their queries in a simple and intuitive way, without having any special proficiency in the technicalities of the database besides knowledge of the (relevant part of the) database schema .
The evaluation of a query is usually done in several stages:

(1) A *compilation* transforms it into an algebra expression
(2) Using heuristic rules, this expression is rewritten into one that promises a more efficient evaluation,
(3) From the latter expression, different query evaluation plans are constructed (e.g., taking into account different access paths for the data), and one of them is chosen based on statistical information on the actual content of the current database,
(4) This evaluation plan is executed using efficient algorithms for each single operation.
The properties expressive power, complexity of evaluation, and static analysis are correlated properties of a query language. More expressive power usually increases the complexity of query evaluation and static analysis. But even if two query languages have the same expressive power, they may vastly differ in terms of the complexity of static analysis and query evaluation.

3. Semantic Network

3.1 Definition of Semantic Networks

Semantic Networks are graphical knowledge representation schemes consisting of nodes,and links between nodes (Marra & Jonassen, 1996 Computer implementations of semantic networks were first developed for artificial intelligence and machine translation, but earlier versions have long been used in philosophy, psychology, and linguistics (J. F. Sowa, 1991). The nodes of the net represent objects or concepts and the links represent relations between nodes. The links are directed and labelled; therefore, a semantic network corresponds to a directed graph. From the graphical point of view, the nodes are usually represented by circles or boxes and the links are drawn as arrows or simple connectors between the circles. The structure of the network defines its meaning, depending on which nodes are connected to which other nodes. In practice, by defining a set of binary relations on a set of nodes, the network corresponds to a predicate logic with binary relations. Moreover, Semantic Networks are redundancy-free, since they can not have duplications of the same nodes.

3.2 Understanding Semantic Networks

In order to have a concrete example of what a Semantic Network is, let us look at Figure3.1, which is just composed of two nodes and a link. As can be seen, the node on the left labeled "person" is linked to the node on the right, labeled “living being”. The link is labeled “is-a”. Thus, the Semantic Network in questions describes a person as an example of living being. Indeed, technically speaking, the diagram represents the fact that there is a binary relation between a living being, such as a person, and the concept of person itself.

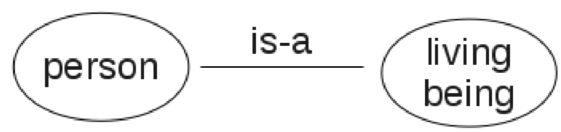

Figure 2.1: Example of Semantic Network

In Figure 2.2 another node with the label “cat”, as well as a “is-a” link from this node to the “living being” node, again representing that a cat is a type of living being.

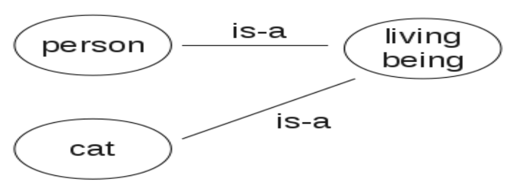

Figure 3.2: Example of Semantic Network (cont’d)

If a person called “David” and a cat called “Tom” are added, and David owns Tom, the structure of the network becomes apparent as shown in Figure 3.3. Clearly, a new link labelled "owns" would need to be added as well, in order to represent that David owns Tom.

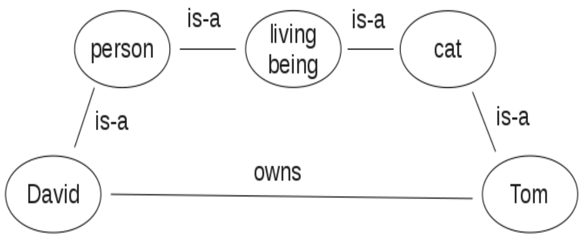

Figure 3.3: Example of Semantic Network (cont'd)

At this stage it is important to clarify a point which can create some semantic confusion. It is visible that the nodes belonging to this small network are not all of the same type. Indeed the nodes labeled "living being", "person" and "cat" represent the generic or meta or class concept of a living being, a person and a cat, respectively; in practice, they represent just abstract concepts. Instead, the nodes "David" and "Tom" represent an individual instance of the nodes "person" and "cat", respectively; in fact David is a person and Tom is a cat. In conclusion it is crucial to notice that there are two types of context, classes and individuals, although they are represented in the same way. Now, let us add another class node, labelled "place", that represents the abstraction of places in a category. Along with that, an instance of a place, labelled "home", is added. Thus, another "is-a" link and a new link, labelled "is-at", must be added to the node "home" and the node "David", respectively. These new additions are shown in Figure 3.4. The information now being represented is that David is a person and home is the place he is at.

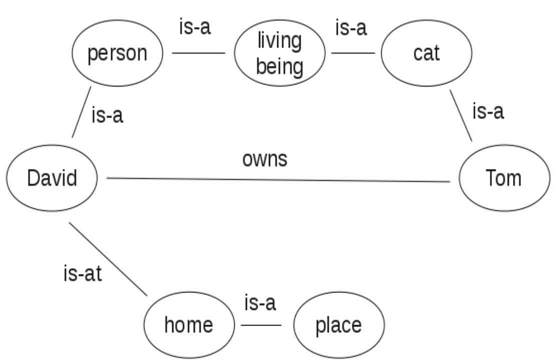

Figure 3.4: Example of Semantic Network (cont'd)

As the number of nodes increases, the meaning of the respective links need to be considered. It should be apparent that not all links are alike. Indeed, some links express only relationships between nodes, and are therefore assertions of the nature of the relationship between two different nodes. For example, the link "is-at" in Figure 3.4, which describes the relationship that the person David is at the place home. The "is-a" links in Figure 3.4, instead, are structural links, in that they provide "type" information about the node. It is clear since this information is about the node itself and not about the relationship it has to be a different type of node. For instance, the node "home" is an individual instance of the class node labelled "place". In Figure 3.5, more nodes and links are added to the original network. There is now a "posture" class node with an instance node labelled "sitting". The link "has-posture" conveys the information that the person David has the posture "sitting" in a given moment. We also added a class node labelled "appliance" with an instance node labeled "television", which in turn is related to the person "David" by means of the link "uses". Then, we added a class node labelled "room" and a respective instance labelled "living room". Finally, we added a new link labelled "is-in", that connects the nodes "David" to the node "living room", and the node "living room" itself to the node "home".

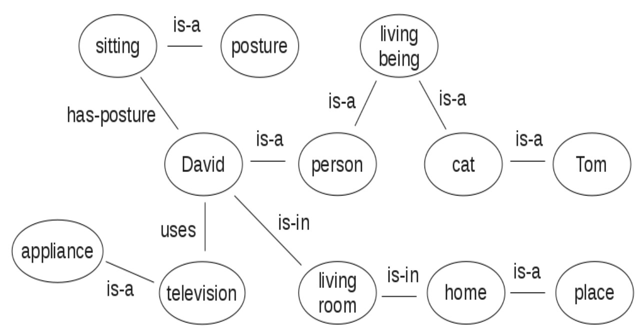

Figure 3.5: Example of Semantic Network (cont'd)

The network in Figure 2.5 now provides a representation for information about the nodes belonging to it. For instance, a person called David is the owner of a cat called Tom, and at the moment he is sitting in the living room, using a television. Another important characteristic of the node-link representation is the implicit "inverse" of all relationships represented by a link. Indeed, if there is a link going from one node to another, this also implies the reverse, and it means that there is a link from the second node to the first. in Figure 3.6, for example, there are two nodes labelled "David" and "television" with the link labelled "uses". The direction of the relationship is that "David uses a television". In practice "David" is a subject and "television" is the object, and "uses" is the verb or action or link between them.

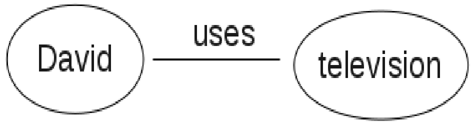

Figure 3.6: Symmetric relationships in Semantic Networks

This "David uses television" relation implies the inverse relationship that "television isused-by David", as shown in Figure 3.7.

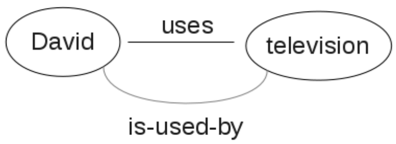

Figure 3.7: Symmetric relationships in Semantic Networks (cont'd)

3.3 Inferring Knowledge with Semantic Networks

With any kind of knowledge representation scheme, it is possible to infer knowledge that is not directly represented by the scheme. The ability to work with incomplete knowledge sets a knowledge representation apart from a database (Marra & Jonassen, 1996).

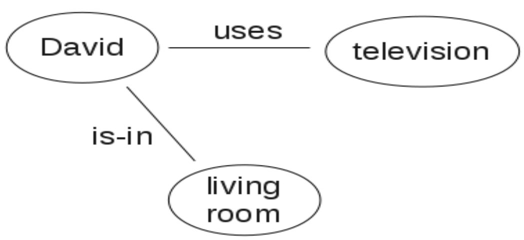

Figure 3.8: What can we infer from this extraction from 3.5

To give an example of what can be found out from the Semantic Network in figure 3.5 that is not directly represented, let us consider Figure 3.8. It is nothing but the an extraction of Figure 3.5 containing only three nodes and two links. The information explicitly represented is that a person called David is using a television and that he is in the living room.

By tracing the path from the node "living room" to the node "David" via the link labeled "is-in" and then from the node "David" to the node "television" via the link labeled "uses", it is possible to infer that the television is in the living room by inferring a link labelled "is-in" between the node "television" and the node "living room", as shown in Figure 3.9. This means that this information does not need to be explicitly represented in the original network, for it can be easily inferred later. From a mathematical point of view, composing links occurs by placing them end-to-tail. This composition creates a new link.

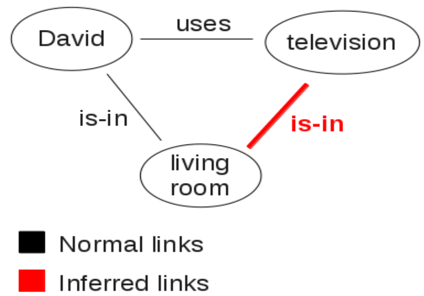

Figure 3.9: Example of knowledge inferring in Semantic Networks (cont'd)

The destination of the first must be the source of the second. By composing links, new relationships between nodes can be found and described. Such a process is also called chasing links and the terminology introduced comes from a branch of mathematics called Category Theory (Marra & Jonassen, 1996).

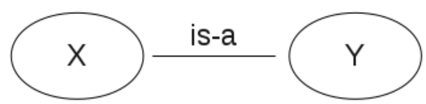

Figure 3.10: Simple example of instancing in Semantic Net

Looking at Figure 3.10 and formalising the whole lot from a logical point of view, we can say that if x is an individual and y is class, the link "is-a" between them can be interpreted as the following formula:

$$y(x)$$

E.g.: cat(Tom).

Instead, if x and y are classes, the link between them can be interpreted as the following formula:

for all Z $x(Z) \rightarrow y(Z)$

E.g.: for al Z cat(Z) → living_being(Z).

Finally, if a class or an individual has some properties, these can be translated to binary predicates: for all Z y(Z) → property(Z, value) class property(x, value) individual

In conclusion, coming back to our original example, Figure 3.11 shows the results of more link chasing. As you can see, additional relationships are derived, e.g., a person has a posture, may own a cat and may use appliances.

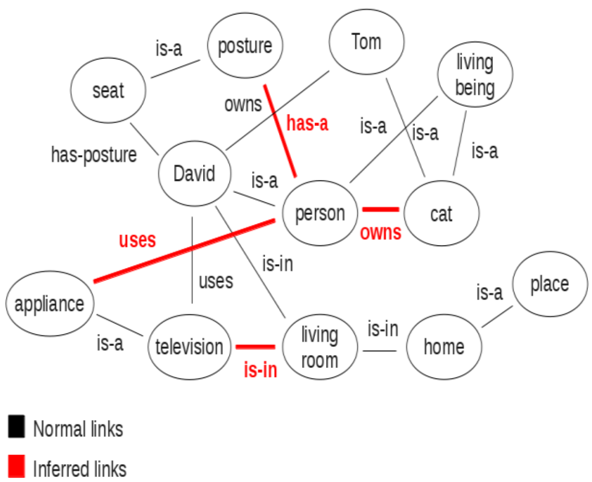

Figure 3.11: A more complicated example of inference in Semantic Networks

3.4 Advantages and disadvantages of Semantic Networks

As we saw thus far, Semantic Networks are characterized by a high representational and expressive power, which is why they constitute a powerful and adaptable method of representing knowledge. In particular, Semantic Networks present the following advantages:

_ Many different types of entities can be represented in Semantic Networks.

_ Semantic Networks provide a graphical view of the problem space and therefore they are relatively easy to understand.

_ They can be used as a common communication tool between different fields of knowledge, e.g., between computer science and anthropology.

_ They allow an easy way to explore the problem space.

_ Semantic Networks provide a way to create clusters of related elements.

_ They resonate with the ways in which people process information.

_ They are a more natural representation than logic (using meaning axioms).

_ They are characterized by a higher cognitive adequacy than logic-based formalisms.

_ Semantic Networks allow the use of efficient inference algorithms (graph algorithms).

_ They have a higher expressiveness than logic (e.g., they allow properties overriding).

Semantic Network also have some limitations, which frequently lead to some epistemological problems. Such limitations can be summarized in three main points.

4. Semantic Network with Query Languages

Here I proposed my concept with the help of query languages. Here query language is used with semantic network, through which problems found previously in searching systems have been reduced. These problems are recall and precision gap, complexity of semantic network etc. The **more analytical** and generic a global model is in the sense of formal ontologies, the **less obvious** it is for the user how a simple, intuitive question relates to the ontology. If the ontology expands very much to **application specific** and natural language properties, the user is **overwhelmed by the number of choices** and looses recall. The complexity of querying comes from properties that are transitive and cause inheritance of properties along those property paths, such as actors, place, time inherited from super- to sub events, materials from parts to wholes, subjects from a thing to its copy or derivative, narrower terms and geospatial areas inheriting broader ones, etc. Another approach is the use of natural language queries, which are automatically mapped to associations of triples of the implemented ontology by a built-in dictionary of matching terms and synonyms and some inference mechanism, such as the Power Aqua system. This approach relieves the user from learning the ontology terms, but it inherits all the well-known **polysemy of natural language**, which deteriorates precision, and provides even worse recall than the explicit use of ontology terms, because the user has no idea what can be asked or can be answered. Other natural language search systems, such as Swoogle[8] and SemSearch[9] do not interface to a triple store. The most common approach to reduce the complexity of querying is to **reduce the complexity of the Semantic Network** itself.

Generally in an unbearable loss of knowledge that could be rendered by the metadata. If such "simple" metadata are to be created individually for all elements of complex correlation graphs characteristic for history, interesting works of arts and e-science data, the **same facts have to be repeated** manually hundreds to ten-thousands of times, which is ineffective and error-prone, and in no ways "simple". Further, there are many relevant queries these "core fields" do not cover. All these systems **cannot be scaled up to higher precision.**

5. Methodology

5.1 Categorization

Whereas our current implementation is based on the CIDOC CRM and extensions, our approach can be applied to other ontologies in an analogues way. However, much of its reasoning capability depends on explicit event representation, which is also present in the ABC Harmony model, DOLCE, BFO, Europeana EDM and other ontologies. Our target domain is the generic search for things, ideas, people, and facts from the past - characteristic for Digital Libraries, cultural historical research, science, business intelligence and political inquiries. We draw on rich previous experience in the cultural domain (such as Polemon Project) and explicit queries collected from archaeologists and museum curators in 3D-COFORM.

In a typical Web search engine, searches would homogeneously return just Webpages, or, in a Digital Library, only documents. In a Semantic Network however, users can retrieve any instance of any class known to the system. Therefore, we firstly divide the entities of our universe of discourse into a set of relevant "Fundamental Categories" that appear to be founded deeply in our intuitive understanding of the world in this or a similar form. These FCs serve as domains and ranges of Fundamental Relationships described below. As in "core metadata", we try to cover the domain with as few FRs a possible that a user can easily learn, but still to be able to make some powerful distinctions keyword search cannot do, such as discerning places from people with the same name. In case of ambiguities, we prefer recall over precision. In the selection of the FCs, we follow the tradition of Ranganathan, CIMI's 4Ws and others. In our implementation, we have selected:

1. *Thing* = crm:E70.Thing10, comprising material and immaterial things, a special case of "What" and Ranganathan's "Matter".
2. *Actor* = crm:E39.Actor, comprising persons, organisation, offices and informal groups, equal to "Who" and Ranganathan's "Personality".
3. *Event* = crm:E2.Temporal_Entity, comprising states, historical and other periods in the sense of the CRM (crm:E4.Period), and events (crm:E5.Event) and activities (crm:E7.Activity) in the narrower sense. It is equal to Ranganathan's "Energy". In some cases, periods can be regarded as a "When".
4. *Place* = crm:E53.Place, geometric extents in space, on earth and on objects, often related to or even identified by some stable and prominent configuration of matter, such as a settlement. It is equal to "Where" and Ranganathan's "Space".
5. *Time* = crm:E52.Time-Span, a date-time interval, a special case of "When" and equal to Ranganathan's "Time".
6. *Concept* = crm:E55.Type, comprising all kinds of universals, such as types of things, people, events, places, species etc. This is a special case of "What". Ranganathan and many library subject catalogues do not distinguish between particular things and types of things; however FRBR introduces the notion of "Concept".

These categories should cover the domain of interest as a "base level" distinction, but are neither completely disjoint nor absolute. Disjointness is actually not helpful for recall. For instance, a settlement can be at least a "Thing" and a "Place". A person (Actor) undergoing surgery, or in an excavated tomb, may be described, besides others, in terms of properties of a "Thing". This may be appear odd in other contexts. A modern biologist would regard species as "Things", i.e., human inventions with creators and other historical attributes, whereas other domains may see species only as Concepts. Therefore, the FCs should be adjustable/adjusted to the audience by adding or subtracting "less prototypical" subclasses, or even by extending. In the cultural-historical context, which we initially anticipated, queries with numerical values as parameters rather rare (except for dates and geo-cordinates). However, in the 3D processing domain, such queries do occur. Therefore we will add in the future "crm:E54_Dimension" to the FCs, but the generic treatment of different metrics we have not (yet) explored.

5.2 Designing Relationships

In addition to the URIs, we assign to all RDF nodes textual (non-unique) labels with names or titles. Some also have descriptions in rdf:literal form. A user formulating a query in our system may first type in a keyword. A full text search into all literals returns the associated nodes in the browser, together with minimal metadata and icons. Each node is marked by the FC it is an instance of

For a more precise query, a user must first "select" (in the sense of the the SQL Select statement) a FC his question is about (In a normal Digital Library, this may be fixed to "document"). Then the user must compose a sort of Where Clause. The most simple one consists of a flat list of properties with range values, combined by AND or OR. The design challenge is to find a minimal set of relationships, "FRs", intuitive to the user and easy to learn, that widely cover the respective discourse with high recall and a precision enough not to be "flooded" by unrelated answers. Fauconnier and Turner observed that our subconscious maintains are much more elaborate semantic network than we are aware of, from which our conscious produces seemingly simple relations by "compression" along different dimensions, which then appear in our language. "Frames", as he calls them, of categories of constituents of respective situations allow for subconscious expansion of the meaning of attributes such as "the baby is safe", "the beach is safe", "the vacuum cleaner is safe". Following Fauconnier's research it becomes obvious that there are intuitive conscious concepts that, if turned directly into an ontology or schema - as many metadata specialists suggest - will not be suitable to support the actual reasoning humans do with these concepts. Consequently we look for selected natural expressions that can be expanded in terms of our semantic network. Further, Pustejovsky observed how language disambiguates words by the relations to other words in a phrase. For instance, "he spoke to the museum" versus "he walked around in the museum", or "he went through the door" versus "he painted the door" (from) seems contradictory in an ontology, but do not surprise people in whatever language we translate it to. This "complementary polysemy ", as he calls it, can be explained by classifying contextual expressions into relatively few, languageneutral categories ("quales"). When a user selects a relationship term and a value, we use a similar mechanism to disambiguate the term as a further help to the user: The term is interpreted according to the selected FC and the FC the value is instance of, rather than forbidding "illegal values". Of course the user may also filter values by the FC.

A good example is the term *from,* a very natural relationship term describing a sort of origin or provenance. For instance, in good museum practice and intuition "Things *from* New Guinea" may mean things found, produced, or used in New Guinea or things with parts from there. It may also mean things produced by people coming from New Guinea. This interpretation is common for all Place values. Museum metadata frequently contain the term "provenance" in this sense. However, "Things *from* J.W. Goethe" (an Actor) has a different interpretation: It could mean things created, produced, modified, said, acquired, owned, kept or used by him or his household, gifts he gave or received, or awards he received. "Things *from* the Parthenon" (a Thing) may mean parts or pieces of the Parthenon, but it may also comprise inscriptions found on it. Quite differently, we would interpret "Actors (people) *from* New Guinea", a sort of nationality concept, whereas "Actors (people) *from* Siemens Company" (Actor) would pertain to membership. "Places *from* Time" make no sense. All interpretations correspond to composite path expressions in the CIDOC CRM. Constrained to a particular combination of FCs, it is feasible to find all relevant expressions in the ontology for this interpretation.

Our empirical sources for the FR are "simple" metadata schemata, such as Dublin

Core and VRA, but also the Europeana EDM model, experiences from structuring museum information [22], generalizations of the CRM itself and intuition. We divide the relationships into those describing (1) how and what something is (classification, part-whole structure), (2) what an item has undergone gone in its history, and (3) what it may "show", say or refer to. We have not looked at relationships of intention, motivation or cause, because they are rarely documented. In our current implementation, we have selected:

1. *has type:* denotes relations of an item11 to a classification, category, type, essential role or other unary property, such as a format, material, color. It generalizes over dc:type, dc:classification, dc:format, dc:language. The relationship is applicable to all FCs and has always range Concept.

2. *is part of*: denotes structural relations of an item to a wider unit it is contained in. The relationship is applicable to all FCs, except for Concept. In case of Actors, one would rather speak of "*is member of*", and persons are the minimal elements. Domain and range must be identical.

3. *is similar or the same with*: denotes the symmetric relation between items that share features or are possibly identical. It is only usual for Things to document similarity manually. There exist enough comparison algorithms that deduce degrees of similarity automatically. We do not deal with these in this work.

4. *has met:* denotes the symmetric relation between items that were present in the same event, including time intervals and places. Applicable to any combination of FCs, except for Concepts.

5. *from, has founder* or *has parent:* denotes the relations of an item to constituants of a context in its history which is either significant for the item, or the item is significant for the context, "provenance" in the widest sense, including time intervals and places. In case of genealogy or group formation,

natural language prefers the terms parent and founder respectively in order to refer to Actors. The relationship is a special case of *has met*.

6. Conclusion

I proposed here a methodology for constructing a new framework for querying semantic networks: For formulating queries, the user is presented a small list of configurable "Fundamental Relationships" and relevant specializations, easy to comprehend, that abstract by rich deductions from an underlying semantic network of much more specialized metadata comprising explicit event descriptions. These FRs simulate to the user a much simpler semantic network, which covers as many generic questions as possible with a high recall. The specializations of the FRs allow for systematically increasing the precision of queries on demand, down to the level of detail of the underlying network.

7. Future Work

With this method, it can be believed that we can overcome the recall-precision gap between keyword and semantic search, the problems of formulating powerful queries in complex semantic networks and the problems of simplifying the metadata themselves, but, of course, rely on an efficient database technology. Future work will consist of further testing, consolidating and refining the FRs with respect to real user questions, including practical 3D data management and scholarly queries. It is planned to upload complete museum collection data to the RI and to deploy it for massive 3D model production, but other large-scale information integrators may take up the method as well.

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