Quelo: an ontology-driven query interface

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Abstract. In this paper we present a formal framework and tool supporting the user in the task of formulating a precise query – which best captures their information needs – even in the case of complete ignorance of the vocabulary of the underlying information system holding the data. Our intelligent interface is driven by means of appropriate automated reasoning techniques over an ontology describing the domain of the data in the information system.
We will define what a query is and how it is internally represented, which operations are available to the user in order to modify the query and how contextual feedback is provided about it presenting only relevant pieces of information. We will then describe the elements that constitute the query interface available to the user, providing visual access to the underlying reasoning services and operations for query manipulation. Lastly, we will define a suitable representation in "linear form", starting from which the query can be more easily expressed in natural language.

1 Introduction

Recent research showed that adopting formal ontologies as a means for accessing heterogeneous data sources has many benefits, in that not only does it provide a uniform and flexible approach to integrating and describing such sources, but it can also support the final user in querying them, thus improving the usability of the integrated system.

We introduce a framework that enables access to heterogeneous data sources by means of a conceptual schema and supports the users in the task of formulating a precise query over it. In describing a specific domain, the ontology defines a vocabulary which is often richer than the logical schema of the underlying data and usually closer to the user's own vocabulary. The ontology can thus be effectively exploited by the user in order to formulate a query that best captures their information need. The user is constantly guided and assisted in this task by an intuitive visual interface, whose intelligence is dynamically driven by reasoning over the ontology. The inferences drawn on the conceptual schema help the user in choosing what is more appropriate with respect to their information need, restricting the possible choices to only those parts of the ontology which are relevant and meaningful in a given context.

The most powerful and innovative feature of our framework lies in the fact that not only do not users need to be aware of the underlying organisation of the data, but they are also not required to have any specific knowledge of the vocabulary used in the ontology. In fact, such knowledge can be gradually acquired by using the tool itself, gaining confidence with both the vocabulary and the ontology. Users may also decide to just explore the ontology without actually querying the information system, with the aim of discovering general information about the modelled domain.

Another important aspect is that only queries that are logically consistent with the context and the constraints imposed by the ontology can be formulated, since contradictory or redundant pieces of information are not presented to the user at all. This makes user's choices clearer and simpler, by ruling out irrelevant information that might be distracting and even generate confusion. Furthermore, it also eliminates the often frustrating and time-consuming process of finding the right combination of parts that together constitute a meaningful query. For this reason, the user is free to explore the ontology without the worry of

making a "wrong" choice at some point and can thus concentrate on expressing their information need at best.

Queries can be specified through a refinement process consisting in the iteration of few basic operations: the user first specifies an initial request starting with generic terms, then refines or deletes some of the previously added terms or introduces new ones, and iterates the process until the resulting query satisfies their information need. The available operations on the current query include addition, substitution and deletion of pieces of information, and all of them are supported by the reasoning services running over the ontology.

In this paper we present a complete and coherent view of the **Quelo** tool, whose basic ideas have been already sketched in the past ([4; 1; 2; 3; 6]). Quelo relies on a web-based client-server architecture consisting of three components:

1. the tool logic, responsible of "reasoning" over the ontology in order to provide only relevant information w.r.t. the current query;
2. the natural language generation (NLG) engine, that given a query and a lexicalisation map for the ontology produces an English sentence; the lexicon is automatically generated from the ontology;
3. the user interface (GUI), that provides visual access to the query and editing facilities for it, allowing to interact with the reasoning sub-system while benefiting from the services of the NLG engine.

2 The Abstract Functionality

In this section we describe the behaviour of the tool using a generic representation based on an abstract user interface. Consider a scenario in which we have a conceptual schema, say an OWL ontology, we know nothing about. In such situation, the tool reveals to be particularly useful in that it allows to discover information about the ontology and the modelled domain, even when its vocabulary is completely ignored. What we call *intensional navigation* of the ontology is the process of building a query, starting from a very general request which is then refined by adding or deleting constraints according to the user's information need. In our abstract representation, the default initial query generically asks for some "thing". Four operations are available for manipulating the query: *add* for the addition of new terms and relations; *substitute* for replacing a portion of the query with a more general, equivalent or more specific term; *delete* for discarding parts of the query; and *weaken* for making a portion of the query as general as possible.

The first step in the refinement of our query consists in being more specific about what we are looking for. This can be achieved by selecting something within the query and asking for a substitution. In our example, we tick the check-box associated with the term **Thing** and then press the **Substitute** button. As shown in Figure 1, we are presented with a three-part menu listing all the possible substitutions available for the selected portion of the query: terms that appear at the top are more general than the selection, the ones in the middle are equivalent, while those at the bottom are more specific. Moreover, these terms are organised in sub-menus according to the taxonomic information defined in the ontology. Thus, we

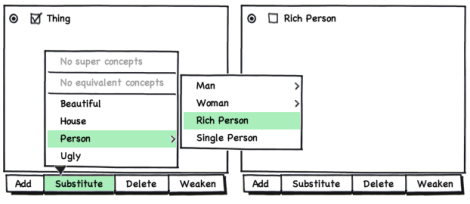
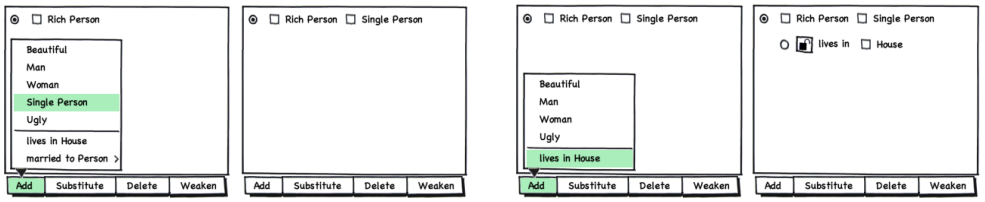


Fig. 1: Example of specialisation



(a) **(b)**

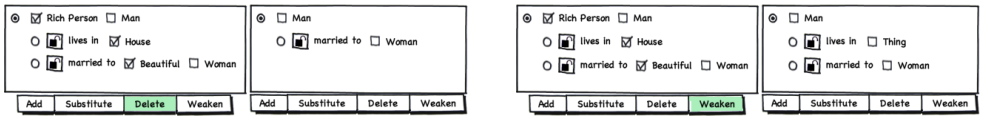
Fig. 2: Addition of (a) a new term and (b) a new relation

can easily navigate the different options choosing the desired level of detail for the substitution. In our case, instead of **Person** we choose the further specific term **Rich Person** as a replacement for the selection, resulting in the query visible on the right side of Figure 1.

Another way of modifying a query is to add constraints in the form of new terms or relations. As shown in Figure 2, upon clicking on the add button a two-part menu is displayed, containing suitable terms and relations that can be safely added to the query. Terms are shown in the upper part of the menu, while relations in the lower one. The chosen item is inserted in a specific place of the query, that can be selected by means of the radio button present in each line. Figure 2a shows how the new term **Single Person** is added to the first (and only) line of the query, while Figure 2b shows how adding a relation results in the creation of a new line, indented w.r.t. the first one and consisting of the name of the relation **lives in** followed by the label **House** associated with its range. Observe that the menu of Figure 2b, compared to that of Figure 2a, does not include the term **Single Person** and the relation **married to Person** as possible options. In fact, the former is already present in the query, thus it would be redundant to propose it again; the latter became incompatible with the query due to the addition of the previous term, and this means that in our ontology a person who is rich and single (or perhaps just single) cannot be married to anyone.

A query can be made more general or "weaker" in a variety of ways, one of which is the substitution with a more general term. Other possibilities are given by deletion and weakening, both of which remove selected elements from the query but with distinct approaches and outcomes. The difference between them is shown in Figure 3: while in Figure 3a deleting the selected portion causes the second row of the query to disappear, in Figure 3b weakening the same portion preserves the row, although the term **House** is replaced with the generic term **Thing**.

Suppose that our ontology states that a rich man who is married to a beautiful woman and lives in a beautiful house is indeed a lucky person. As a result of the substitution shown in Figure 4, where the whole query is replaced with the (more general) term **Lucky Person**, the second line disappears. In some situations this "side-effect" is undesired, because we would perhaps like to operate on that part of the query later on. The closed padlock icon visible in the third line of the query indicates that that line is protected against such an "accidental" deletion and would not inadvertently disappear as the result of the substitution. However, note that locked portions of the query are still fully affected by explicit deletion.



(a) **(b)**

Fig. 3: Example of (a) deletion and (b) weakening

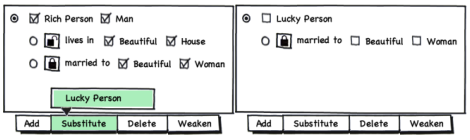


Fig. 4: Preventing side-effects of substitution

3 The Reasoning module

The framework and its functional API are defined in a formal way; here, we concisely summarise the main definitions introduced in [7] and formally prove the most important of tool's properties, namely that it generates only "meaningful" queries.

3.1 Formal framework

From the point of view of the reasoning sub-system, a query is a labelled tree where each node corresponds to a variable and is associated with a set of concept names from the ontology, while each edge is labelled with a role name.

Let **N** be a countably infinite set of node names, **C** be a finite set of concept names and **R** a finite set of role names, and let **N**, **C** and **R** be pairwise disjoint. A *query* Q is a quintuple $\langle V, E, o, \mathcal{V}, \mathcal{E} \rangle$ in which (V, E) is a directed tree rooted in $o \in V$, with set of nodes $V \subseteq \mathbf{N}$ and with set of edges $E \subseteq V \times V$; $\mathcal{V}$ is a total function, called *node-labelling function*, associating each node with either a non-empty set of concept names or with the singleton $\{\top\}$; and $\mathcal{E}$ is called the *edge-labelling function* that associates each edge with a role name. A query consisting of exactly one node, whose set of labels is a singleton, is called *atomic*. For an edge $e = \langle x, y \rangle$, we indicate its initial node x with $\mathsf{init}(e)$ and its terminal node with $\mathsf{ter}(e)$. Given queries S and Q, we say that S is a *subquery* of Q, and write $S \subseteq Q$, iff $V(S) \subseteq V(Q)$, $E(S) \subseteq E(Q)$, each node $n \in V(S)$ is s.t. $\mathcal{V}_S(n) \subseteq \mathcal{V}_Q(n)$ and every edge $e \in E(S)$ is such that $\mathcal{E}_S(e) = \mathcal{E}_Q(e)$. We say that S is a *complete subquery* of Q (in symbols $S \subseteqq Q$) if it also holds that, for every $n \in V(S)$, $\mathcal{V}_S(n) \supseteq \mathcal{V}_Q(n)$ and every descendant of o_S in Q is a node in S. A *selection* within a query Q is a subquery S of Q, which is called *simple* if $S \subseteqq Q$ or S consists of exactly one node, namely its root o_S, such that $\mathcal{V}_S(o_S)$ is a singleton or is equal to $\mathcal{V}_Q(o_S)$. Every selection S within a query Q partitions the nodes of Q into *selected*, which belong to $V(S)$, and *unselected*, belonging to $V(Q) \setminus V(S)$. The selected nodes can be further partitioned into *totally selected*, having all of their labels selected, and *partially selected*, which have some, but not all, of their labels selected. An example of query as represented is shown in Figure 5, which also shows the compact graphical notation we use for representing a selection within a query: selected nodes are drawn using a double circle and selected labels within each of them are underlined.

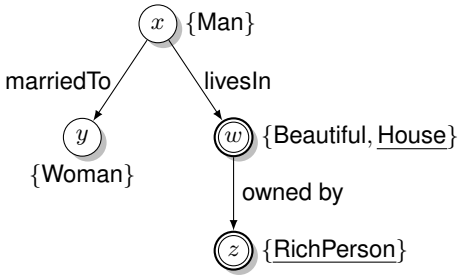


Fig. 5: Example of query and a selection within it

The *weakening* of a query Q w.r.t. a selection S within Q is the query $Q \ominus S$ obtained from Q by replacing its node-labelling function $\mathcal{V}_Q$ with a function that associates each totally selected node with $\{\top\}$, each partially selected node n with $\mathcal{V}_Q(n) \setminus \mathcal{V}_S(n)$ and each unselected node m with $\mathcal{V}_Q(m)$.

The last notion we introduce is that of *sticky edges*, which are edges that can only be deleted explicitly (that is, when performing a deletion), but never implicitly (e.g., as the consequence of a substitution). Sticky edges are closed w.r.t. the tree structure of the query, that is, when an edge e is sticky, then all the edges in the path from the root of the query to $\mathsf{ter}(e)$ are such. The meaning and importance of sticky edges will become more clear in the next section, where we introduce and describe the two operations delete and substitute. For the moment, sticky edges can be simply understood as immutable (to some extent) pieces of information within a query, which are not modified as a "side effect" of an operation not directly intended to do so.

3.2 Functional API

To draw the inferences that are at the basis of the query formulation tasks, we express a query as a concept of some description logic (DL) language, for which the containment test of two conjunctive queries is decidable and available as a reasoning service. In what follows, we assume the existence of an underlying knowledge base $\mathcal{K}$ in such a DL language $\mathcal{L}$ over $\mathbf{C}$ and $\mathbf{R}$. We say that C is a sub-concept of (or *subsumes*) D in $\mathcal{K}$, and write $C \sqsubseteq_\mathcal{K} D$, iff $\mathcal{K} \models C \sqsubseteq D$, in which case we also say that D is a super-concept of (or *is subsumed by*) C. Two concepts C and D are *equivalent* in $\mathcal{K}$, written $C \equiv_\mathcal{K} D$, iff one subsumes the other and vice versa. For two concept names c_1 and c_2 we say that c_1 is a *direct sub-concept* of c_2 (and that c_2 is a *direct super-concept* of c_1) iff c_1 subsumes c_2 and there is no $c \in \mathbf{C}$ equivalent to neither c_1 nor c_2 and such that $c_1 \sqsubseteq_\mathcal{K} c \sqsubseteq_\mathcal{K} c_2$.

Before introducing the functional API, let us first give some preliminary definitions. Given a query Q and $n \in V(Q)$, the operation $\mathsf{roll\text{-}up}(Q, n)$ translates Q into an $\mathcal{L}$-concept w.r.t. n and it is defined as $\mathsf{enc\text{-}rollup}(Q, n, n)$, where enc-rollup is the recursive procedure described in Algorithm 1. We use $\mathsf{roll\text{-}up}(Q)$ as an abbreviation for $\mathsf{roll\text{-}up}(Q, o)$, where o is the root of Q. The concept $\mathsf{roll\text{-}up}(Q, n)$ is called the *context* of Q w.r.t. n, expressing the informative content of Q from the point of view of a specific node, which we call the *focus*. Queries Q_1 and Q_2 are *equivalent*, in symbols $Q_1 \equiv Q_2$, iff $\mathsf{roll\text{-}up}(Q_1) \equiv_\mathcal{K} \mathsf{roll\text{-}up}(Q_2)$. We say that a query Q over a consistent knowledge base $\mathcal{K}$ is *satisfiable* iff its roll-up is such in $\mathcal{K}$ (that is, $\mathcal{K} \not\models \mathsf{roll\text{-}up}(Q) \sqsubseteq \bot$).

The functional API of the tool is structured in two main parts:

- the underlying reasoning services, consisting of the operations getComp, getRel, getSupers, getEquiv, getSubs;
- the operations for query manipulation, including addRel, addComp, weaken, substitute and delete.

Given a query Q and a node n, we say that a concept name c is *compatible* with Q focused in n iff $c \sqcap \mathsf{roll\text{-}up}(Q, n) \not\sqsubseteq \bot$, while a role name r is such iff $\exists r^-.\, \mathsf{roll\text{-}up}(Q, n) \not\sqsubseteq \bot$. The operation $\mathsf{getComp}(Q, n)$ returns a directed acyclic graph (DAG) G, whose nodes are all the concept names that are compatible with Q focused in n and that are neither sub- nor super-concepts of $\mathsf{roll\text{-}up}(Q, n)$, and whose edges are all the pairs of concept names $c_1, c_2 \in V(G)$ such that c_1 is a direct sub-concept of c_2. In other words, the output of getComp is a taxonomy of concept names which are compatible with the query and not in hierarchy with the context. The operation $\mathsf{getRel}(Q, n)$ returns a DAG G, whose nodes are all the pairs $\langle r, c\rangle$ of role names and concept names such that r is compatible with Q focused in n and c is a sub- or a super-concept of $\exists r^-.\, \mathsf{roll\text{-}up}(Q, n)$, and whose edges are the pairs $\langle\langle r, c_1\rangle, \langle r, c_2\rangle\rangle \in V(G) \times V(G)$ such that c_1 is a direct super-concept of c_2.

Let S be a selection within a query Q. Then, the operations getSupers, getEquiv and getSubs return the concept names that are more general than, equivalent to and more specific

Algorithm 1 Calculate $\mathsf{enc\text{-}rollup}(Q, n, m)$

Input: a query Q and two nodes $n, m \in V(Q)$
Output: a concept C expressing Q in the description logics language $\mathcal{L}$

$C \leftarrow c$, for some $c \in \mathcal{V}(n)$
for all $x \in \mathcal{V}(n)$ such that $x \neq c$ **do**
    $C \leftarrow C \sqcap x$
end for
for all children x of n in Q such that $x \neq m$ **do**
    $R \leftarrow \mathcal{E}(\langle n, x \rangle)$
    $C \leftarrow C \sqcap \exists R$. $\mathsf{enc\text{-}rollup}(Q, x, n)$
end for
if $n \neq o$ **then**
    Let p be the parent node of n in Q
    if $p \neq m$ **then**
        $R \leftarrow \mathcal{E}(\langle p, n \rangle)$
        $C \leftarrow C \sqcap \exists R^{-}$. $\mathsf{enc\text{-}rollup}(Q, p, n)$
    end if
end if
return C

than $\mathsf{roll\text{-}up}(S)$, respectively. Moreover, the concept names in the output of $\mathsf{getSubs}(Q, S)$ are additionally required to be compatible with Q focused in the root of S.

Let Q be a query and n a focus node. For a concept name c in the output of $\mathsf{getComp}(Q, n)$, the operation $\mathsf{addComp}$ adds c to $\mathcal{V}(n)$. More precisely, the result of $\mathsf{addComp}(Q, n, c)$ is the query Q' obtained from Q by replacing its node-labelling function $\mathcal{V}$ with $\mathcal{V}' := \mathcal{V}[n \mapsto \mathcal{V}(n) \cup \{c\}]$. For a pair $\langle r, c \rangle$ in the output of $\mathsf{getRel}(Q, n)$, the operation addRel creates a new node n' such that $\mathcal{V}(m) = \{c\}$ and an edge $e = \langle n, m \rangle$ with $\mathcal{E}(e) = r$.

Let Q and R be queries and $\widetilde{E}$ be a set of sticky edges. Then, the operation prune deletes from Q the maximal number of non-root nodes, having no incoming sticky edge (if any) and associated with the same concept names both in R and Q, such that the result is still a query.

Let S be a selection within a query Q and let $\widetilde{E}$ be a set of sticky edges. We define $\mathsf{weaken}(Q, S)$ as $Q \ominus S$ and

$$\mathsf{delete}(Q, S, \widetilde{E}) := \mathsf{prune}\big(\mathsf{weaken}(Q, S), R, \widetilde{E}\big) \ ,$$

where R is the query obtained from S by replacing $\mathcal{V}_S$ with the function on $V(S)$ associating each node n that is both in Q and S with $\mathcal{V}_Q(n) \cap \mathcal{V}_S(S)$ if such intersection is non-empty and with $\{\top\}$ otherwise, and each other node m of S with $\mathcal{V}_S(m)$. The last operation we introduce is "substitution" which, for a concept name c in the output of $\mathsf{getSupers}$ (*generalisation*) or $\mathsf{getEquiv}$ or $\mathsf{getSubs}$ (*specialisation*), is defined as follows:

$$\mathsf{substitute}(Q, S, \widetilde{E}, c) := \mathsf{delete}(Q', S, \widetilde{E}) \ ,$$

where Q' is the query obtained from Q by adding c to the set of concept names associated with the root of S.

3.3 Properties of the framework

We will now formally state that, starting from an atomic query that is satisfiable, the query obtained by means of the operations in the tool's functional API is satisfiable. In order to do that, we first prove that the operations for query manipulation preserve satisfiability, i.e., the application of each of them to a satisfiable query results in a query that is satisfiable.

Lemma 1. *Each of the operations* $\mathsf{addComp}$, $\mathsf{substitute}$, addRel, weaken *and* delete *preserves query satisfiability.*

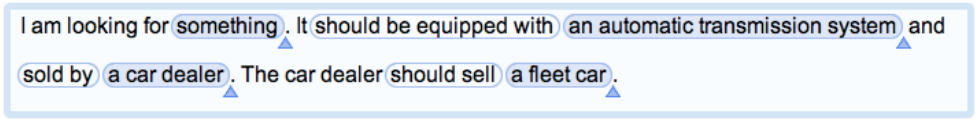
The fundamental property of the tool is then proved by means of a simple induction.

Theorem 1. *The query obtained from an initial satisfiable atomic query through a finite sequence of applications of the operations* addComp, addRel, substitute, weaken *and* delete *is satisfiable.*

4 The user interface

In this section we describe the basic elements of the concrete UI Quelo, based on natural language generation. In the UI, the query is represented as a continuous string of natural language text, composed of a sequence of coherent text constituents called *spans*. Each of the tags occurring in the query is associated with a span by means of an injective mapping. As for each edge there is one and only one corresponding edge tag, if a span is associated with the tag of an edge we simply say that the span is associated with that edge.

The English sentence representing the query in the UI is generated by the NLG subsystem, which will be described in the next section. Here is an example of the textual rendering of the query in natural language as displayed by the UI:

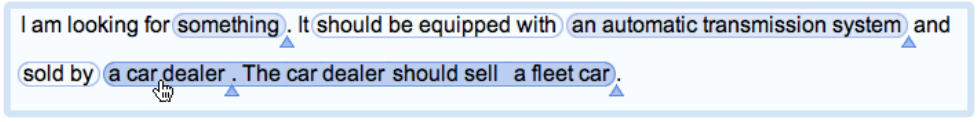


4.1 Hovering

In graphical user interfaces terminology, the user *hovers* on a graphic element whenever the mouse cursor moves from some point outside the element to some point inside the element. In normal conditions, as the user hovers on the query, the system gives visual hints about its structure:

- hovering on the span associated with a tag of some node n causes the span to become *lightly highlighted*, along with all the spans associated with the tags occurring in the complete subquery rooted in n;
- hovering on the span associated with the tag of some edge e causes that span and all the spans associated with the elements of $\mathsf{tags}(\mathsf{ter}(e))$ to become lightly highlighted.

The highlighting is such that spans associated with different tags are visualised as distinct, even when adjacent. One way of obtaining this kind of effect is, for instance, by rounding the corners of the highlighted rectangular area around each span. The only case in which highlighting on hovering does not trigger is when a menu is being displayed.



Associated with each node of the query is a button, called the *add-button*, which is located below the text baseline immediately after the rightmost span associated with a tag of that node. Hovering on the add-button of some node lightly highlights all the spans associated with tags of that node.

4.2 Selection

The UI provides facilities to easily select portions of the query. A simple selection can be directly specified by clicking on the span associated with a tag of some node n in one of the following ways:

– a single click results in an atomic selection, highlighting only the span on which the click occurred;
– a double click results in a node selection, highlighting all the spans associated with the elements of $\mathsf{tags}(n)$;
– a triple click results in a complete selection, highlighting all the spans in the complete subquery rooted in n.

A selection can be *cleared* by clicking on an area of the UI where clicking does not have any other effect (e.g., on the white space between the lines of text representing the query, or on a span that is not associated with any tag). Clearing a selection results in an *empty selection*.

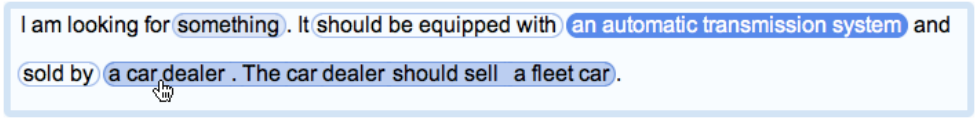
Observe that when a node has only one node label, an atomic selection on that node happens to be also a node selection, and when a node has no children, a node selection is also a complete selection. Thus, an atomic selection on a node having only one label and no children is also a node selection as well as a complete selection.

We consider atomic selections to have the lowest priority and complete selections the highest, and when a simple selection belongs to more than one class, it is considered to be only of the type with higher priority. Furthermore, whenever a double click would result in the same kind of selection a single click would, it yields a complete selection instead.

A *complex selection* (non-simple) is obtained from an empty or simple selection by control-clicking on additional spans associated with node tags, which are consequently included in the existing selection. Note that a complex selection can be *disconnected*, in the sense that it is not a well-formed subquery from the formal point of view, because there might be two selected nodes that are not connected by an edge.

From the graphic point of view, spans associated with tags in a selection are highlighted in a stronger way (e.g., a darker color) than they are when highlighted because of hovering and, unlike the highlighting effect triggered by hovering, it is not possible to distinguish between adjacent selected spans associated with the same node. When the selection includes one or more paths between nodes (that is, all of the nodes in a path within the query are selected), spans associated with edge tags are also highlighted.

The visual appearance of the spans associated with tags of selected nodes or edges does not change as the result of an hovering event, as shown here:



Moreover, as the reader might already have noticed, when a non-empty selection is present, the add-buttons become invisible without changing the layout of the text.

4.3 Addition

The query logic sub-system provides two operations, namely $\mathsf{addComp}$ and addRel, for refining a query through the addition of compatible terms and relations to a focus node. The UI makes these operations available to the user by means of a pop-up menu, activated by clicking on the add-button of a node which is set as the focus.

The menu contains a list of suitable arguments for the invocation of either $\mathsf{addComp}$ or addRel. The menu entries are concept names and pairs consisting of a role name and a concept name, which are obtained from the output of the Quelo operations $\mathsf{getComp}$ and getRel w.r.t. the current query and focus. In particular, for a query Q focused in n, the menu is populated with the nodes in the graph resulting from disjoint union of the output graphs of $\mathsf{getComp}(Q, n)$ and $\mathsf{getRel}(Q, n)$, arranged in the following way:

– nodes with no incoming edge populate a menu of level 0, which is the *topmost* menu, where entries corresponding to concept names are listed before entries associated with pairs of concept/role names.

– for each node n in a menu at level k, all the nodes that are reachable from n in one step populate a sub-menu at level $k + 1$ associated with entry n.

The actual items shown to the user in the above menu structure are natural language descriptions of the node-entries (either concept names or atomic concept/role pairs) generated by the NLG sub-system.

Some of the items come with an icon on their left: an upward-pointed (resp., downward-pointed) triangle is displayed for concept names (resp., role/concept pairs) indicating that the option is associated with a nested sub-menu containing more specific (resp., more generic) options of the same type. Hovering on any of these options opens the pop-up menu associated with that item and displayed next to it.

Clicking on any of the elements in the menu triggers the invocation of either addComp or addRel, according to whether the clicked item is associated with a concept name or a concept/role pair, respectively. Upon clicking, the menus disappear and the UI updates its representation of the query after the necessary changes are performed by the Quelo sub-system.

4.4 Weakening and Deletion

The user can *weaken* (respectively, *delete*) a selected portion of the query by pressing the backspace (resp., delete) key on the keyboard, which invokes the Quelo operation weaken (resp., delete) with the current query and selection as input arguments. Upon weakening (resp., deletion), the selection is cleared and the UI updates its representation to reflect the changes in the query.

Note that the operations weaken and delete, as defined in our functional API, cannot directly handle a disconnected complex selection. However, such a selection can be decomposed by the UI in a series of connected selections that are then suitable for the actual invocation of the two operations.

Observe that in some cases deletion produces the same result as weakening (e.g., for a node selection rooted in a non-leaf node).

4.5 Substitution

The Quelo sub-system provides the operation substitute in order to allow the substitution of a selection within the query with a more generic, equivalent or more specific term. The UI makes this operation available to the user: upon long-clicking on a selected portion (i.e., strongly highlighted) of the query a pop-up menu is displayed, listing all the possible terms with which the selection can be replaced.

Such a menu is populated with concept names that are more general than, equivalent to and more specific than the selection and that are retrieved from the Quelo sub-system by means of the operations getSupers, getEquiv and getSubs, respectively. More general terms are shown at the top of the list, equivalent terms in the middle and more specific terms at the bottom. At the left of each item an icon is shown: an upward-pointing triangle for more general terms, a square for equivalent terms and a downward-pointing triangle for more specific terms.

The substitution menu has a similar hierarchical structure as the menu for addition, reflecting the taxonomic information in the output graphs of the operations getSupers, getEquiv and getSubs. In particular, some (possibly none) of the more general terms might be further generalised, in which case hovering on one such item triggers a sub-menu containing its direct super-concepts; similarly, if some of the more specific terms can be further specialised, then hovering on one such item triggers a sub-menu containing its direct sub-concepts that are compatible with the query. The same rules for further generalisation/specialisation apply to the items in the sub-menus, while equivalent terms (if any) cannot be further generalised nor specialised.

As in the case of addition, the actual items shown to the user in the substitution menu are natural language descriptions generated by the NLG sub-system, rather than bare concept names. Clicking on any of given options triggers the invocation of substitute with the current selection and the concept name associated with the clicked item as input arguments. The selection is then cleared and the UI updates the representation of the query after the selected elements have been replaced with the chosen term.

Observe that the operation substitute, as defined in our functional API, cannot deal with disconnected complex selection and, unlike the case of weakening and deletion, the problem cannot be overcome by converting such selection in a series of connected ones. This is due to the fact that substitution relies on the roll-up of the input selection itself, which is thus required to be tree-shaped (i.e., connected). For this reason, in the presence of a disconnected selection, the substitution operation is disabled.

5 Natural language rendering

The natural language interface of the tool masks the composition of a precise query as the composition of English text describing the equivalent information needs. Interfaces following this paradigm are known as "menu-based natural language interfaces to databases" or"conceptual authoring" (see,most notably, [8]). As we have seen before, the users of such systems edit a query by composing fragments of generated natural language provided by the system through *contextual* menus. In [6] we describe how the natural language rendering of a query is achieved.

We start by defining a particular linear form of the query that satisfies certain constraints, necessary to represent the elements of the query using a linear medium, that is, text. The constraints are enforced at the API level to ensure that different graphical user interfaces represent the query in a homologous way. Moreover, a consistent ordering of the query elements needs to be preserved during the operations for query manipulation to avoid confusing the end user. The linearised version of the query is then used as a guide for the language generation performed by the tool's NLG engine.

The natural language interface (NLI) of the tool relies on a natural language generation (NLG) system to produce the textual representation of the query, following an idea first presented in [11] and lately refined in [8].

For the tool's NLI to work with a specific knowledge base (KB) a lexicon and a template map must be provided for it. Devising these resources requires an understanding of both the domain of interest and basic linguistic notions such as verb tenses, noun genders and countability. To ease the burden of developing these resources from scratch, we let the system generate them automatically. This technique follows an approach to domain independent generation proposed in [10], after the learning of a rich corpus of relations. The functionality we implemented allows to produce all the resources necessary to configure our NLI for use with a new KB, using as a source of data the ontology itself. It has to be noted that the process is not completely reliable, therefore system engineers must review the result and make the necessary corrections.

6 Future Work

The framework and functional API presented in this paper consider only the addition of new relations to the query, but they could be extended to deal with attributes (i.e., properties relating a concept to a datatype) as well. The only difference with the current framework would be that a node associated with a datatype (i.e., the "range" of the attribute) cannot be the focus of a query for operations other than deletion. This basically means that such a node is always a leaf of the query tree and the only operation allowed on it is deletion. Then, since a node of this kind cannot be refined by adding a compatible term or attaching a new property, the query is never rolled-up with respect to it, thus avoiding the nonsensical eventuality

that an edge associated with an attribute has to be inverted (going from the datatype to the subject). Though apparently simple, allowing for attributes poses some interesting questions, that we are currently investigating, in order to deal with concrete values from the point of view of reasoning.

Another direction we plan to pursue is that of continuing the series of experiments already carried on (see [1; 2]), in order to evaluate the usability of the tool and its complexity of use from the user's point of view. In particular, we are interested in determining how difficult it is for the user to formulate queries using the tool and to understand the results.

An online fully functional demonstrator of Quelo is freely accessible at:

`http://krdbapp.inf.unibz.it:8080/quelo/`

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