Querying the Semantic Web with Racer + nRQL

Applications on Description Logics ’04

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Overview of Talk

- Introducing nRQL

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  - Introductory Example
  - Overview of Features
  - Query Processing Modes
  - Syntax & Semantics

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  - The Lehigh University Benchmark (LUBM)
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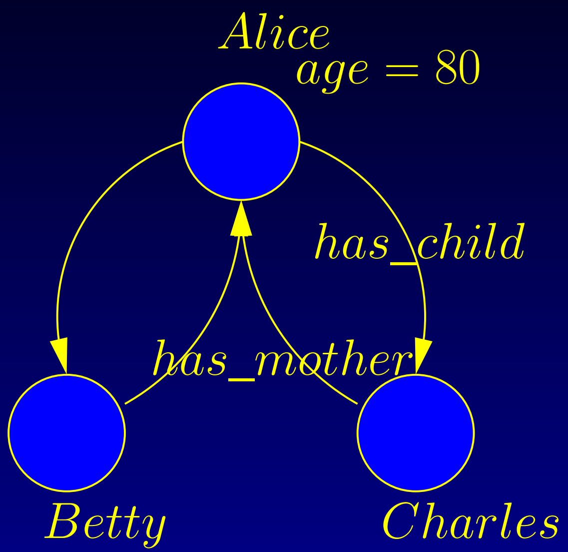
- Conclusion & Future Work

Motivating Simple Example



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$has\_mother(charles, alice),$
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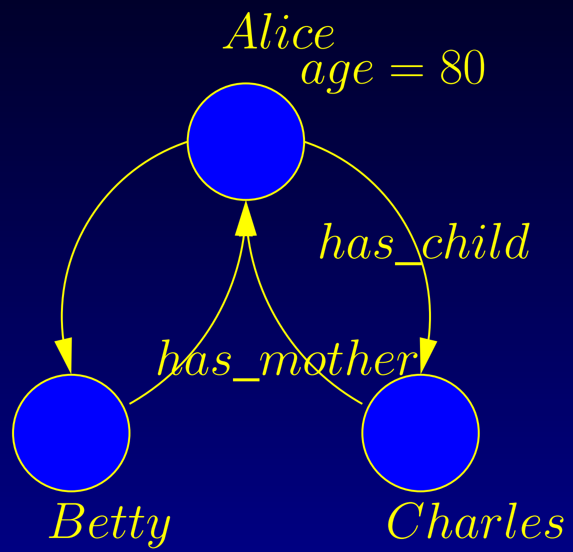

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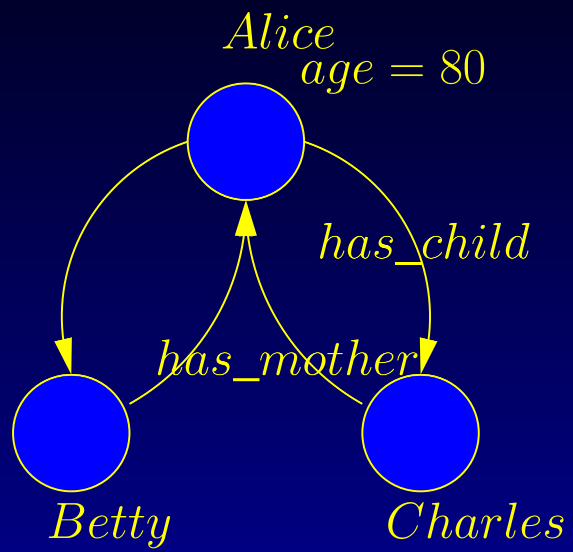

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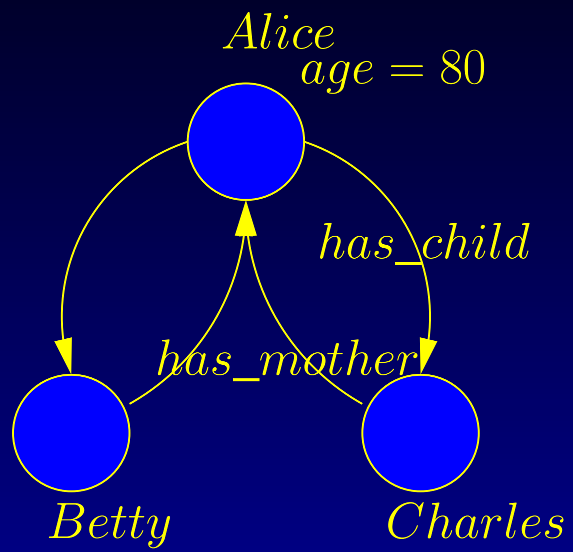

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⊕ use nRQL:

```
(retrieve (?x ?y)
          (and (has-child ?z ?x)
               (has-child ?z ?y)))
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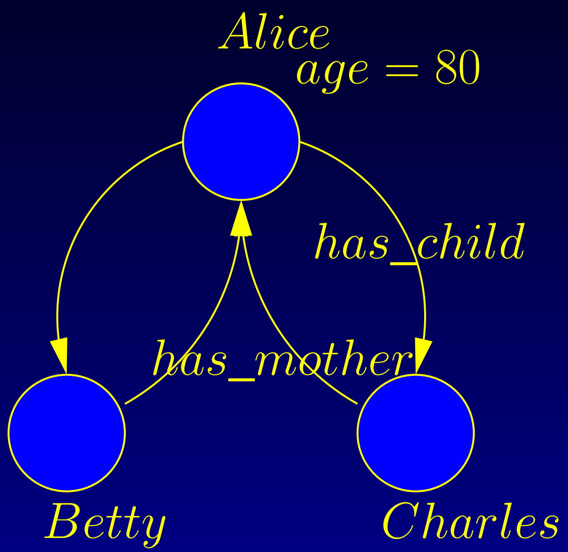

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$\Rightarrow$
```
(((?X CHARLES) (?Y BETTY))
 ((?X BETTY) (?Y CHARLES)))
```

nRQL Language – Features

- Concept and role query atoms

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  - With variables:
    ```
    (retrieve (?x) (?x woman))
    ```
  - Without variables:
    ```
    (retrieve () (betty woman))
    ```
  - With individuals:
    ```
    (retrieve (betty) (betty woman))
    =
    (retrieve (?betty-var)
        (and (?betty-var woman)
             (same-as ?betty-var betty)))
    ```

nRQL Language – Features

- Concept and role query atoms
  - ```
    (retrieve (?x ?y)
              (?x ?y has-child))
    ```
  - ```
    (retrieve (betty ?y)
              (betty ?y has-child))
    ```
  - ...

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  - ```
    (retrieve (?x)
        (?x ?x (:constraint
            (has-child has-father age)
            (has-child has-mother age)
            (> age-1 (+ 10 age-2)))))
    ```
    ```

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  - `(retrieve (?x) (neg (?x woman)))`
  - `(retrieve (?x ?y)`
    `(neg (?x ?y has-child)))`

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    - NAF for atoms with individuals can be tricky:

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(retrieve (betty)
          (neg (betty woman)))
=
(retrieve (?betty-var)
     (neg (and (?betty-var woman)
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(retrieve (betty)
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=
(retrieve (?betty-var)
    (UNION (neg (?betty-var woman))
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    (retrieve (?x (AGE ?x))
        (?x (and human (an age))))
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  - `(retrieve ((fillers (OWL-DTP ?x))) (?x (MIN OWL-DTP 10)))`

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    - Lazy: compute next tuple if requested
    - Eager: precompute next tuples (proactive)

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- Additional index structures for Racer ABoxes, suitable for mass-data processing

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  - Phase 1: deliver cheap tuples (incomplete)
  - Warn user; then, if next tuple requested, start
  - Phase 2: use full ABox reasoning to deliver remaining tuples (complete)

Incremental Query Processing

TBox:

$$\begin{aligned} person &\sqsubseteq \top \\ man &\sqsubseteq person \\ woman &\sqsubseteq person \\ spouse &\doteq woman \sqcap \\ & \quad (\exists married\_to.man) \end{aligned}$$

ABox :

$$spouse(doris)$$
$$spouse(betty)$$
$$man(adam)$$
$$woman(eve)$$
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- `(retrieve (?x) (?x spouse))`

$\Rightarrow$ `(:QUERY-1 :RUNNING)`

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$\Rightarrow$ `:EXHAUSTED`

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- `(get-answer :query-1)`

$\Rightarrow$ `(((?X DORIS)) ((?X BETTY)) ((?X EVE)))`

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- Reasoning with Queries
  - Incomplete for full nRQL, but still useful
  - Complete for restricted nRQL
  - Query consistency check
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  $\Rightarrow$ maintenance of a "Query repository" lattice (similar to a TBox)

  $\Rightarrow$ use cached tuples of queries in repository for optimization purposes ("materialized views")
  - Semantic optimization: query "realization" (similar to ABox realization)

    $\Rightarrow$ add implied conjuncts to enhance informdness of backtracking search

nRQL Engine – Features (4)

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  - ```
    (defquery mother
              (?x ?y)
              (and (?x woman)
                   (?x ?y has-child)))

    (defquery mother-with-male-child
              (?x ?child)
              (and (:substitute
                         (mother ?x ?child))
                   (?child man)))
    ```
    ```

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  - ```
    (defrule
       ((instance (new-ind child-of ?x ?y) human)
        (instance ?x mother)
        (instance ?y father)
        (related (new-ind child-of ?x ?y) ?x
                 has-mother)
        (related (new-ind child-of ?x ?y) ?y
                 has-father))

       (and (?x woman) (?y man) (?x ?y married))
            (neg (?x (:has-known-successor has-child))))
    ```
    ```

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  - ```
    (tbox-query (?x ?y)
         (and (?x woman)
              (?x ?y has-descendant)))
    ```
    ```

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  - “Rolling up”?
  - Approach OWL-QL?
  - Connect to real DB

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- . . . for more nRQL peculiarities: see manual

nRQL - Syntax (1)

Let $a, b \in \mathcal{O}$; C be an $\mathcal{ALCQHI}_{\mathcal{R}^+}(\mathcal{D}^-)$ concept expression, R a nRQL role expression (a nRQL role expression is either a $\mathcal{ALCQHI}_{\mathcal{R}^+}(\mathcal{D}^-)$ role expression, or a <u>negated</u> $\mathcal{ALCQHI}_{\mathcal{R}^+}(\mathcal{D}^-)$ role expression); P one of the concrete domain expressions offered by Racer; and f, g be so-called attributes (whose range is defined to be one of the available concrete domains offered by Racer). Then, the set of <u>nRQL atoms</u> is given as follows:

- Unary concept query atoms: $C(a)$
- Binary role query atoms: $R(a, b)$
- Binary constraint query atoms: $P(f(a), g(b))$
- Binary same-as atoms: $same\_as(a, i)$
- Unary has-known-successor atoms: $has\_known\_successor(a, R)$
- Negated atoms: If A is a nRQL atom, then so is $\backslash(A)$, a so-called <u>negation as failure atom</u> or simply <u>negated atom.</u>

nRQL - Syntax (2)

A nRQL Query has a head and a body. Query bodies are defined inductively as follows:

- Each nRQL atom A is a body; and
- If $b_1 \dots b_n$ are bodies, then the following are also bodies:
  - $b_1 \wedge \dots \wedge b_n$, $b_1 \vee \dots \vee b_n$, $\backslash(b_i)$

We use the syntax $body(a_1, \dots, a_n)$ to indicate that $a_1, \dots, a_n$ are all the object names ($a_i \in \mathcal{O}$) mentioned in $body$. A nRQL Query is then an expression of the form

$$ans(a_{i_1}, \dots, a_{i_m}) \leftarrow body(a_1, \dots, a_n),$$

The expression $ans(a_{i_1}, \dots, a_{i_m})$ is also called the head, and $(i_1, \dots, i_m)$ is an index vector with $i_j \in 1 \dots n$. A conjunctive nRQL query is a query which does not contain any $\vee$ and $\backslash$ operators.

nRQL - Semantics (1)

Let $\mathcal{K} = (\mathcal{T}, \mathcal{A})$ be an $\mathcal{ALCQHI}_{\mathcal{R}^+}(\mathcal{D}^-)$ knowledge base. A positive ground query atom A is logically entailed (or implied) by $\mathcal{K}$ iff every model $\mathcal{I}$ of $\mathcal{K}$ is also a model of A. In this case we write $\mathcal{K} \models A$. Moreover, if $\mathcal{I}$ is a model of $\mathcal{K}$ (A) we write $\mathcal{I} \models \mathcal{K}$ ($\mathcal{I} \models A$). We therefore have to specify when $\mathcal{I} \models A$ holds. In the following, if the atom A contains individuals i, j, it will always be the case that $i, j \in \mathsf{inds}(\mathcal{A})$. From this it follows that $i^{\mathcal{I}} \in \Delta^{\mathcal{I}}$ and $j^{\mathcal{I}} \in \Delta^{\mathcal{I}}$, for any $\mathcal{I} = (\Delta^{\mathcal{I}}, \cdot^{\mathcal{I}})$ with $\mathcal{I} \models \mathcal{K}$:

- If $A = C(i)$, then $\mathcal{I} \models A$ iff $i^{\mathcal{I}} \in C^{\mathcal{I}}$.
- If $A = R(i, j)$, then $\mathcal{I} \models A$ iff $(i^{\mathcal{I}}, j^{\mathcal{I}}) \in R^{\mathcal{I}}$.
- If $A = P(f(i), g(j))$, then $\mathcal{I} \models A$ iff $(f^{\mathcal{I}}(i^{\mathcal{I}}), g^{\mathcal{I}}(j^{\mathcal{I}})) \in P^{\mathcal{I}}$.
- If $A = same\_as(i, i)$, then $\mathcal{I} \models A$.
- If $A = same\_as(i, j)$, then $\mathcal{I} \not\models A$.
- If $A = has\_known\_successor(i, R)$, then $\mathcal{I} \models A$ iff for some $j \in \mathsf{inds}(\mathcal{A})$: $\mathcal{I} \models R(i, j)$.

nRQL - Semantics (2)

Let $ans(a_{i_1}, \ldots, a_{i_m}) \leftarrow body(a_1, \ldots, a_n)$ be a nRQL query q such that $body$ is in NNF. Let $\beta(a_i) =_{def} x_{a_i}$ if $a_i \in \mathcal{I}$, and a_i otherwise; i.e., if a_i is an individual we replace it with its representative unique variable which we denote by x_{a_i}. Let $\mathcal{K}$ be the knowledge base to be queried, and $\mathcal{A}$ be its ABox. The answer set of the query q is then the following set of tuples:

$$\{ (j_{i_1}, \ldots, j_{i_m}) \mid \exists j_1, \ldots, j_n \in \mathsf{inds}(\mathcal{A}), \forall m, n, m \neq n : j_m \neq j_n, \\ \mathcal{K} \models_{NF} \alpha(body)_{[\beta(a_1) \leftarrow j_1, \ldots, \beta(a_n) \leftarrow j_n]} \}$$

Finally, we state that $\{()\} =_{def}$ TRUE and $\{\} =_{def}$ FALSE.

The LUBM

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- See `http://www.lehigh.edu/~yug2/Research/SemanticWeb/LUBM/LUBM.htm`

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- Benchmark generator generates “ABoxes”
- 14 benchmarking queries

The LUBM

```
Query 9: (retrieve
           (?x ?y ?z)
           (and (?x Student)
                (?y Faculty)
                (?z Course)
                (?x ?y advisor)
                (?x ?z takesCourse)
                (?y ?z teacherOf)))
```

"Retrieve all triples `<?x,?y,?z>` such that `?x` is (bound to) a student undertaking a course `?z` whose teacher `?y` (from the faculty) happens to be his/her advisor"

The LUBM

```
Query 12: (retrieve
                (?x ?y www.University0.edu)
                (and (?x chair)
                     (?y Department)
                     (?x ?y memberOf)
                     (?y www.University0.edu
                         subOrganizationOf))
```

Cite LUBM: “The benchmark data do not produce any instances of class Chair. Instead, each Department individual is linked to the chair professor of that department by property headOf. Hence this query requires realization, i.e., inference that that professor is an instance of class Chair because he or she is the head of a department.”

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- How does Racer + nRQL perform (speed & completeness) compared to DLDB?

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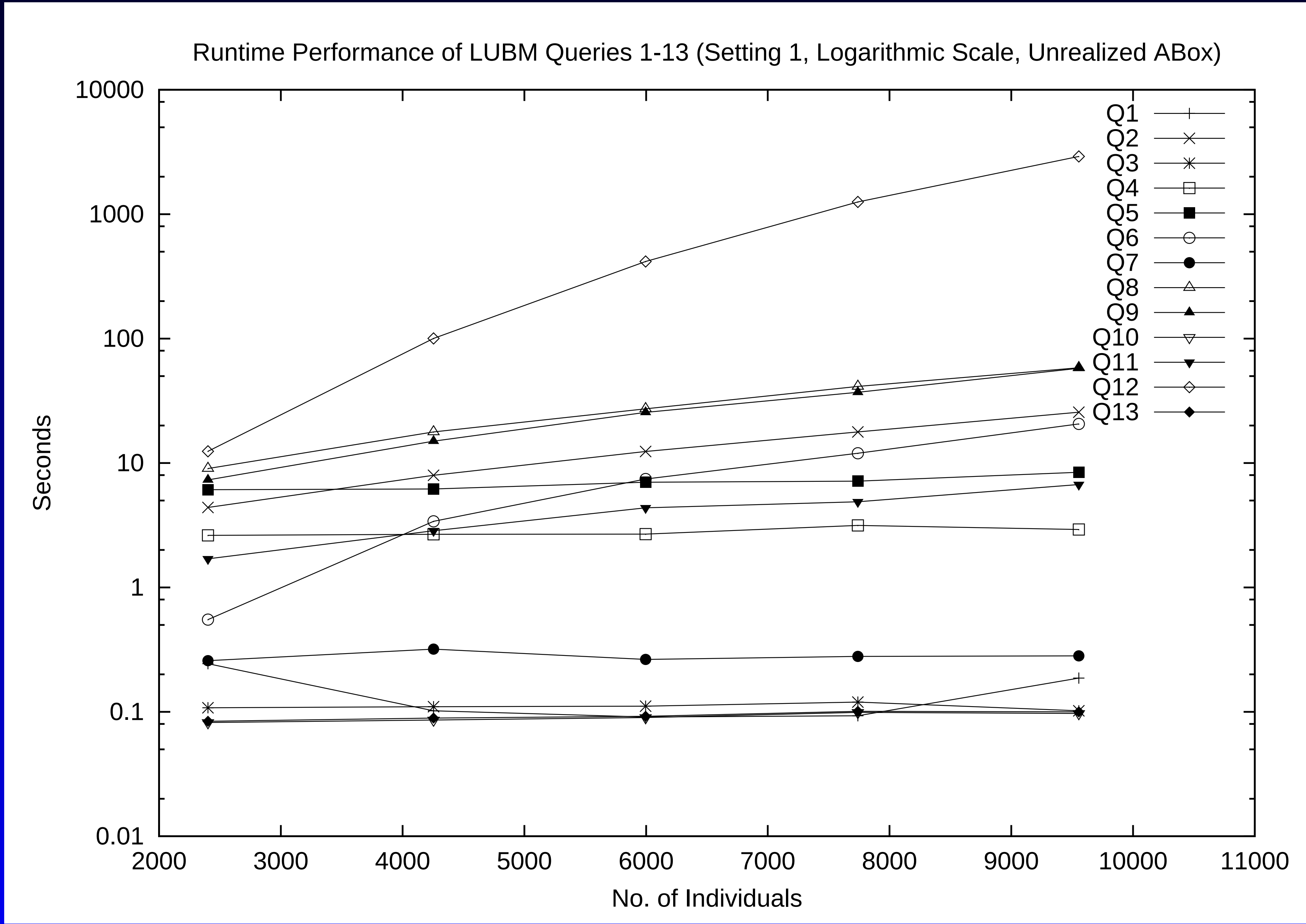
- Setting 2: complete ABox reasoning using a <u>realized</u> ABox
- Setting 3: "told information querying" enhanced with TBox information – "upward saturation":

  $\Rightarrow$ for each ABox axiom $C(i) \in \mathcal{A}$, for all $D \in \mathsf{concept\_ancestors}(C, TBox)$: put $D(i)$ into "ABox": $\mathcal{A} := \mathcal{A} \cup \{D(i)\}$

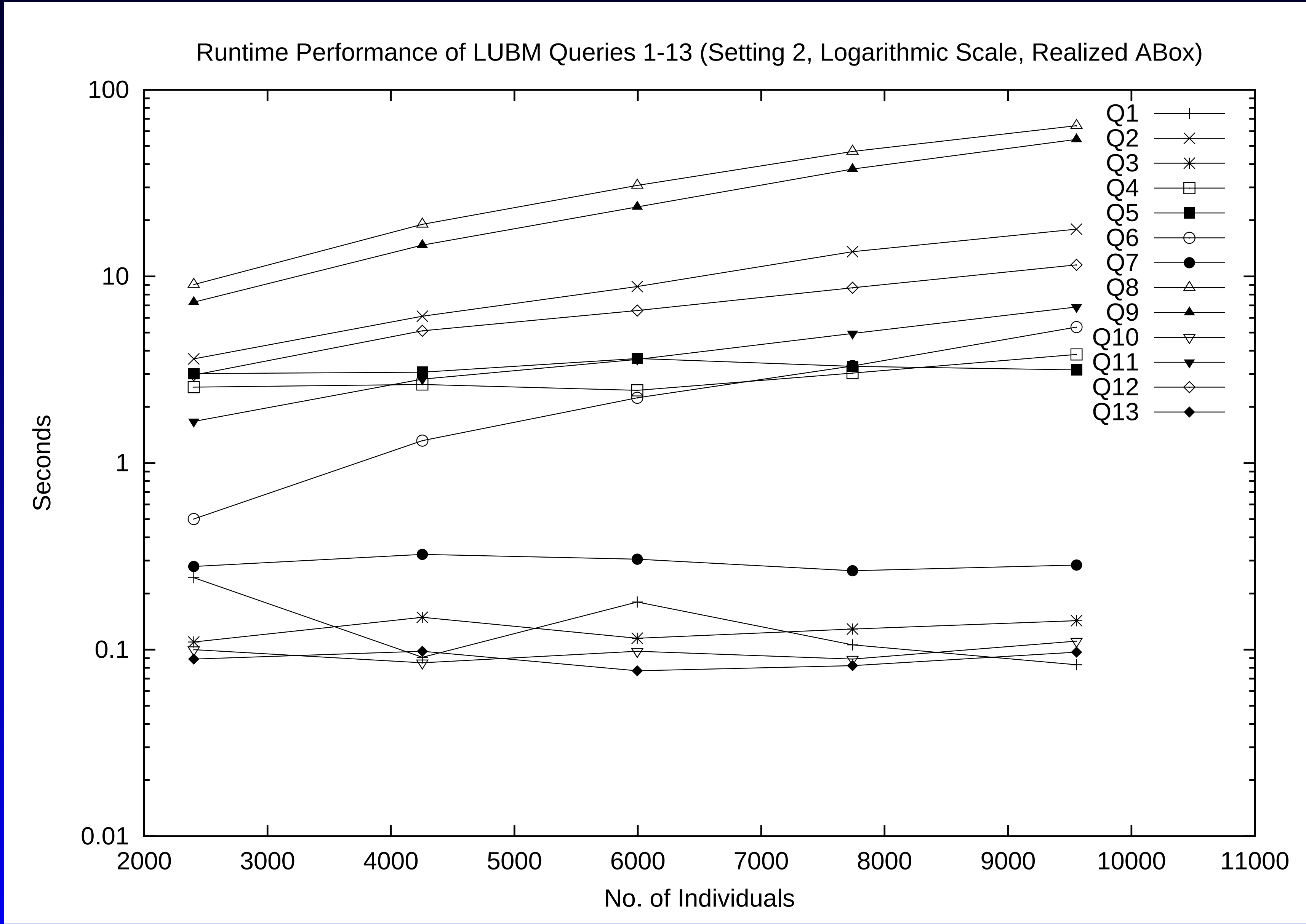
  $\Rightarrow$ same for role relationships due to role hierarchies

  - nRQL is always complete w.r.t. roles

Results - Setting 1



Results - Setting 2



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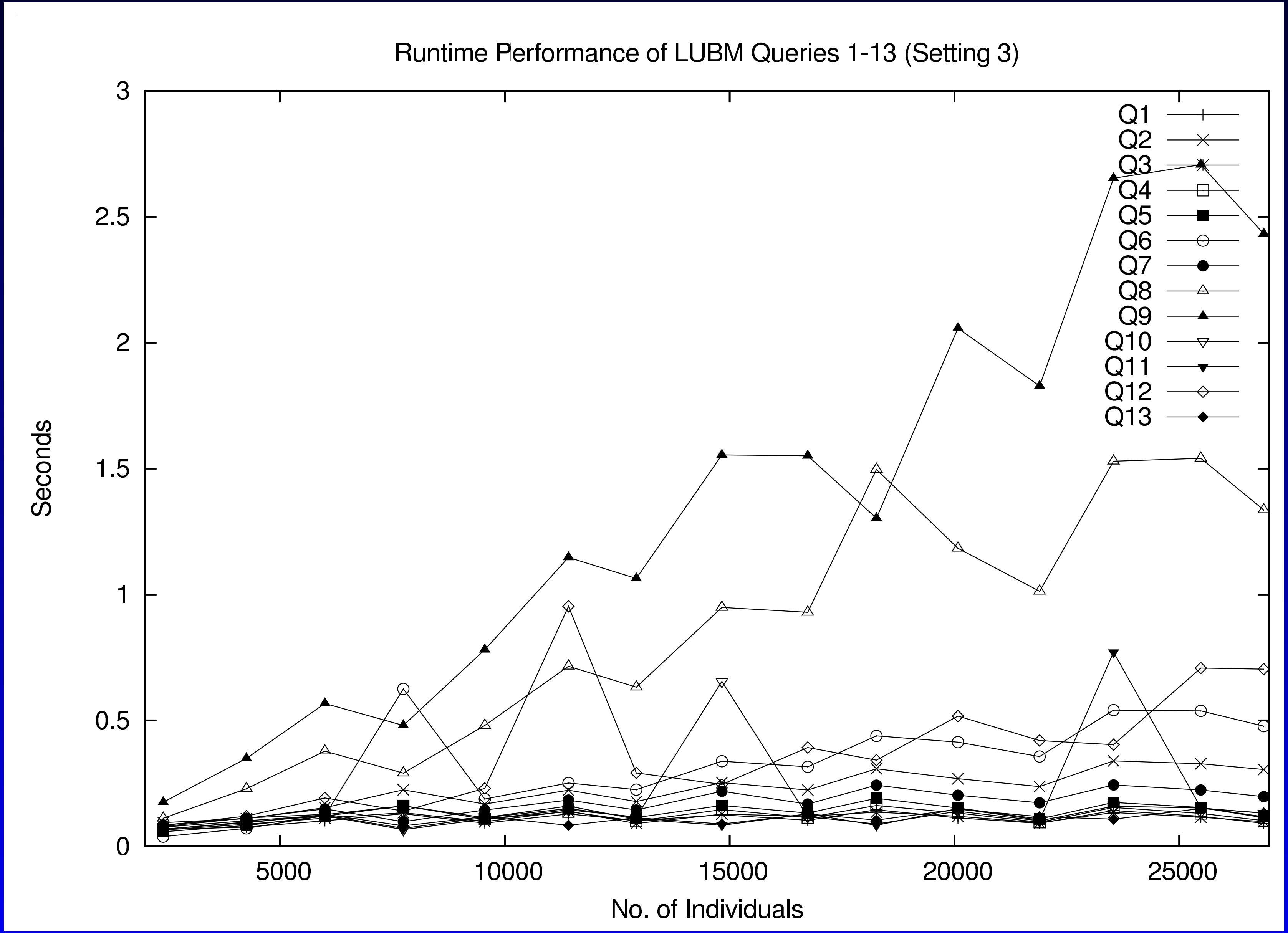

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$\Rightarrow$ in this scale, answering time is quite okay!

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$\Rightarrow$ the amount of data generated by the LUBM is demanding

$\Rightarrow$ hope: future versions of Racer will be able to process much bigger ABoxes

Thanks

for your

attention!