SQUALL: a Controlled Natural Language for Querying and Updating RDF Graphs

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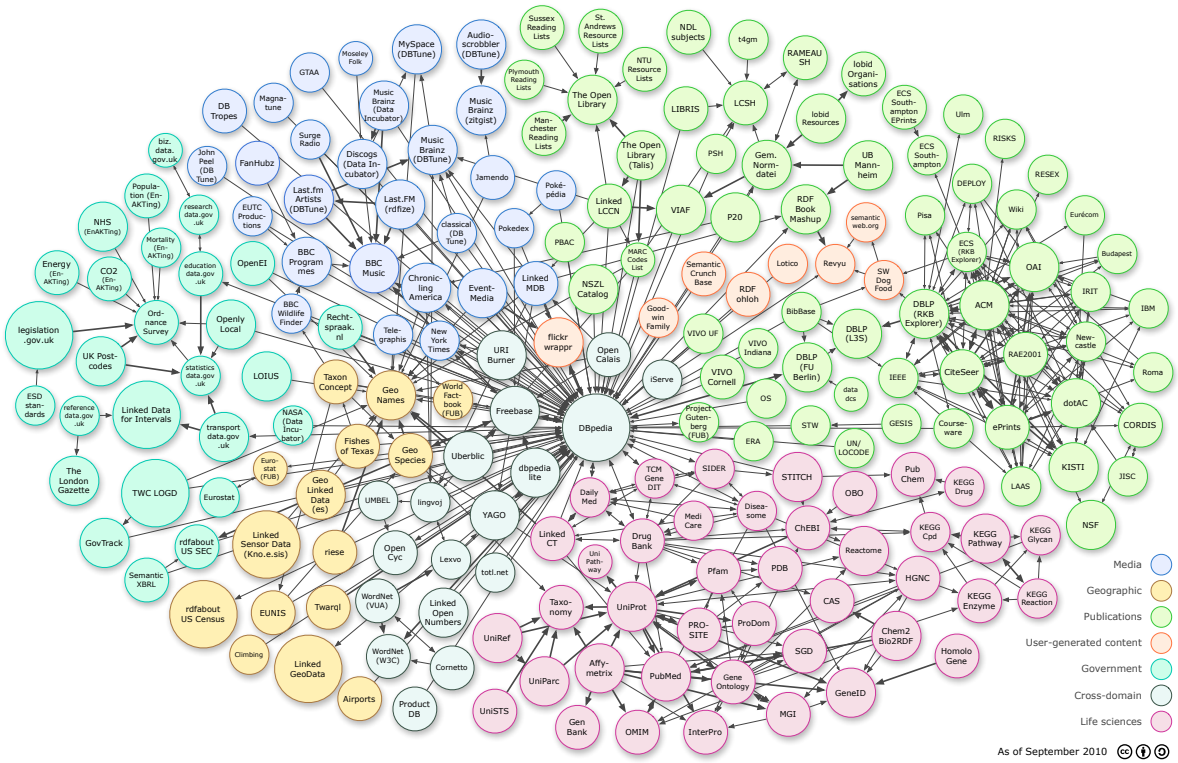
The Web of Data

- How to search and explore the Web of data (RDF graphs) ?
- How to fill the gap between end users and formal languages (RDF, OWL, SPARQL) ?



Linking Open Data cloud diagram, by Richard Cyganiak and Anja Jentzsch. http://lod-cloud.net/

Formal vs Natural Languages

- SPARQL: a formal language *à la* SQL
  - very expressive and precise for querying and updating RDF graphs
  - requires understanding of low-level notions: relational algebra and logic
- natural language interfaces (ex., Aqualog, FREyA)
  - good usability through NL
  - difficult problems: ambiguity and adequacy w.r.t. the underlying system
  - in practice, generally limited to simple questions (much less expressive than SPARQL)
    - ex., Aqualog queries are limited to 2-triples queries

Controlled Natural Languages (CNL)

- on the natural/formal continuum [Kaufmann&Bernstein 2010]
- combine natural syntax and formal semantics
- *"There is no important theoretical difference between natural languages and the artificial languages of logicians."* (Montague)
- a few CNLs:
  - ACE [Fuchs *et al*]: a general purpose CNL
  - SOS, Rabbit: CNLs for verbalizing OWL axioms
  - *SQUALL*: the first CNL for SPARQL queries *and* updates

What SQUALL is *not*...

1. a pure (grammatically correct) subset of English
   - natural languages are a source of inspiration for flexibility, expressiveness, concision, high-level forms
   - I think that CNLs should be more regular than NLs because they have to be learnt anyway
2. concerned with morphology (lexicon, agreements, etc.)
   - should have the same requirements as SPARQL w.r.t. data
   - should be able to refer to every resource without preprocess
   - shares non-ambiguous notations with SPARQL
     - author → `hackcraft:authoredBy` or `purl:author` ... ?
3. a user interface
   - querying is difficult, whatever the language
     - syntax errors, empty results, preferences
   - syntactic guided input (e.g., Ginseng) is not enough
   - the objective is *semantic* guided input (done to a limited extent in previous work with Sewelis)

What SQUALL is...?

- an alternative CNL syntax for SPARQL
  - hence, same expressiveness as SPARQL
  - hence, full adequacy to RDF data
  - with natural high-level syntax
- its implementation is a compiler (3 phases)
  1. parsing of the source sentence (SQUALL)
  2. generation of an intermediate representation (Montague λ-terms)
  3. production of the target code (SPARQL)

RDF Graphs

- a RDF graph is a set of triples (labeled edges)
- a triple (of resources) has a subject, a predicate, and an object
  - a triple is a basic sentence
  - ex., `ex:John ex:loves ex:Mary .`
- a resource denotes an entity or a concept or a literal value (e.g., numbers, dates, strings)
- a property denotes a binary relation between resources
  - a property can be a transitive verb (ex., `ex:loves`) or a relational noun (ex., `ex:author`)
- a class denotes a set of resources
  - a class can be a noun (ex., `ex:woman`) or an intransitive verb (ex., `ex:works`)
- properties and classes are resources themselves

SPARQL 1.1: querying and updating RDF graphs

- SPARQL forms
  - closed question: `ASK` *`graph pattern`*
  - open question: `SELECT` *`vars`* `WHERE` *`graph pattern`*
  - update: `DELETE` *`graph`* `INSERT` *`graph`* `WHERE` *`graph pattern`*
- graph patterns
  - relational algebra: joins, unions, complements, selections, projections
  - constraints: logic, arithmetic, built-ins
  - named graphs
  - subqueries
  - aggregations

SPARQL query example

```
SELECT ?r
WHERE {
    ?r rdf:type :researcher .
    BIND (?r AS ?X)
    GRAPH :DBLP {
        FILTER NOT EXISTS {
            ?p rdf:type :publication .
            ?p :author ?X .
            ?p :year ?y .
            FILTER (?y >= 2000)
            FILTER NOT EXISTS {
                { SELECT COUNT(?a) AS ?n
                  WHERE { ?p :author ?a . } }
                FILTER (?n >= 2) } } } }
```

A Montague grammar of SQUALL

- Syntax and semantics
- Modules:
  1. lexical conventions
  2. triples as sentences
  3. relational algebra as coordinations
  4. natural constructs (headed NPs, relatives, ...)
  5. queries with *wh*-words
  6. quantifiers as determiners
  7. subordination and n-ary predicates with reification
  8. built-in predicates and aggregations
  9. resolving syntactic ambiguities

Lexical conventions

The same as in well-known notations (Turtle, SPARQL, N3)

- proper nouns, nouns, and verbs (URIs)
  - `<http://dbpedia.org/resource/Berlin>`: a full URI for the Berlin city
  - `dbpedia:Berlin`: an abbreviated URI with DBpedia namespace
  - `:Berlin`: an abbreviated URI with default namespace
  - `Berlin`: a bare URI (default namespace)
- literals
  - `"Hello world!"`: a plain literal
  - `"42"^^xsd:integer`: a typed literal
  - `42`: a bare integer
- variables: `?X`
- grammatical words (SQUALL reserved keywords)
  - `is`, `a`, `which`, `every`, ...

Triples as sentences

S	$\rightarrow$	$NP\ VP\ \{\ np\ vp\ \}$	"[$_{NP}$A] [$_{VP}$know-s B]"
NP	$\rightarrow$	$Term\ \{\ \lambda d.(d\ term)\ \}$	"A"
VP	$\rightarrow$	$P1\ \{\ \lambda x.(p1\ x)\ \}$	"[$_{P1}$work-s]"
	$\mid$	$P2\ NP\ \{\ \lambda x.(np\ \lambda y.(p2\ x\ y))\ \}$	"[$_{P2}$know-s] [$_{NP}$B]"
$P1$	$\rightarrow$	$ClassURI\ \{\ \lambda x.(\mathbf{type}\ x\ uri)\ \}$	"work"
$P2$	$\rightarrow$	$PropertyURI\ \{\ \lambda x.\lambda y.(\mathbf{stat}\ x\ uri\ y)\ \}$	"know"

Relational algebra as coordinations

They apply to most syntagms Δ: *S*, *NP*, *VP*, *P1*, *P2*, (next: *Rel*, *AP*, *PP*).

Δ	$\rightarrow$	**not** Δ_1 $\{$ **not** δ_1 $\}$	"not [$_{VP}$know-s B]"
	$\mid$	Δ_1 **and** Δ_2 $\{$ **and** δ_1 δ_2 $\}$	"[$_{VP}$work-s] and [$_{VP}$cite-s X]"
	$\mid$	Δ_1 **or** Δ_2 $\{$ **or** δ_1 δ_2 $\}$	"[$_{NP}$A] or [$_{NP}$B]"
	$\mid$	**maybe** Δ_1 $\{$ **option** δ_1 $\}$	"maybe [$_{VP}$know-s B]"

Headed NPs

NP	→	*Det NG1* { $\lambda d.(det\ (\textbf{init}\ ng1)\ d)$ }	"[$_{Det}$a] [$_{NG1}$woman]"
	|	*Det NG2* **of** *NP* { $\lambda d.(np\ \lambda x.(det\ (\textbf{init}\ (ng2\ x))\ d))$ }	
			"[$_{Det}$the] [$_{NG2}$author-s] of [$_{NP}$X]"
Det	→	**a**(**n**) { $\lambda d_1.\lambda d_2.(\textbf{exists}\ (\textbf{and}\ d_1\ d_2))$ }	
	|	**the** { $\lambda d_1.\lambda d_2.(\textbf{the}\ d_1\ d_2)$ }	
NG1	→	**thing** *AR* { **and thing** *ar* }	"thing [$_{AR}$that cite-s A]"
	|	*P1 AR* { **and** *p1 ar* }	"[$_{P1}$woman] [$_{AR}$?A]"
NG2	→	*P2 AR* { $\lambda x.\lambda y.(\textbf{and}\ (p2\ x\ y)\ (ar\ y))$ }	
			"[$_{P2}$author] [$_{AR}$?A]"
AR	→	*App Rel* { **and** *app rel* }	"[$_{App}$?A] [$_{Rel}$that X cite-s]"
	|	*App* { *app* }	
App	→	*URI* { $\lambda x.(\textbf{eq}\ x\ uri)$ }	"A"
	|	*Var* { $\lambda x.(\textbf{bind}\ x\ var)$ }	"?X"
	|	ϵ { $\lambda x.\textbf{true}$ }	

Relatives

$$
\begin{array}{lcl}
\textit{Rel} & \rightarrow & \textbf{that } \textit{VP} \ \{ \textbf{ init } \textit{vp} \} \qquad \text{“that } [_{VP}\text{know-s B]”} \\
& | & \textbf{that } \textit{NP P2} \ \{ \textbf{ init } \lambda x.(np\ \lambda y.(p2\ y\ x)) \} \\
& & \qquad \text{“that } [_{NP}\text{X}]\ [_{P2}\text{cite-s]”} \\
& | & \textbf{such that } S \ \{ \textbf{ init } \lambda x.s \} \qquad \text{“such that } [_{S}\text{?A work-s]”} \\
& | & \textit{Det NG2} \textbf{ of which } \textit{VP} \ \{ \textbf{ init } \lambda x.(det\ (ng2\ x)\ vp) \} \\
& & \qquad \text{“}[_{Det}\text{an}]\ [_{NG2}\text{author}] \text{ of which } [_{VP}\text{know-s B]”} \\
& | & \textbf{whose } \textit{NG2 VP} \equiv \textbf{the } \textit{NG2} \textbf{ of which } \textit{VP} \\
& & \quad \text{“whose } [_{NG2}\text{author ?A}]\ [_{VP}\text{cites-s a colleague of ?A]”} \\
& | & \textbf{whose } \textit{P2} \textbf{ is/are } \textit{NP} \ \{ \lambda x.(np\ \lambda y.(p2\ x\ y)) \} \\
& & \qquad \text{“whose } [_{P2}\text{author}]\ [_{VP}\text{is a woman]”}
\end{array}
$$

Auxiliary verbs

$$
\begin{array}{lcll}
VP & \rightarrow & \textbf{is}/\textbf{are}\ AP\ \{\ ap\ \} & \text{“is [}_{AP}\text{a woman]”} \\
 & | & \textbf{is}/\textbf{are}\ Rel\ \{\ rel\ \} & \text{“is [}_{Rel}\text{such that ?A work-s]”} \\
 & | & \textbf{has}/\textbf{have}\ Det\ P2\ AR\ \{\ \lambda x.(det\ (p2\ x)\ ar)\ \} & \\
 & & & \text{“have [}_{Det}\text{an] [}_{P2}\text{author] [}_{AR}\text{that X cite-s]”} \\
AP & \rightarrow & Term\ \{\ \lambda x.(\textbf{eq}\ x\ term)\ \} & \text{“A”} \\
 & | & \textbf{a}(\textbf{n})/\textbf{the}\ NG1\ \{\ ng1\ \} & \text{“a [}_{NG1}\text{woman]”} \\
 & | & \textbf{a}(\textbf{n})/\textbf{the}\ NG2\ \textbf{of}\ NP\ \{\ \lambda x.(np\ \lambda y.(ng2\ y\ x))\ \} & \\
 & & & \text{“the [}_{NG2}\text{author] of [}_{NP}\text{X]”}
\end{array}
$$

Queries with *wh*-words

$S \rightarrow$ **whether** S_1 { **ask** s_1 } "whether [$_S$A know-s a woman]"

$NP \rightarrow$ **what** $\equiv$ **which thing**

$\mid$ **whose** *NG2* $\equiv$ **the** *NG2* **of what**

"whose [$_{NG2}$author ?A]"

$Det \rightarrow$ **which** { $\lambda d_1.\lambda d_2.$(**select** (**and** d_1 d_2)) }

$\mid$ **how many** { $\lambda d_1.\lambda d_2.$(**count** (**and** d_1 d_2)) }

Quantifiers as determiners

Not present as such in SPARQL.

$$
\begin{array}{lcl}
\mathit{Det} & \rightarrow & \textbf{some}\ \{\ \lambda d_1.\lambda d_2.(\textbf{exists}\ (\textbf{and}\ d_1\ d_2))\ \} \\
 & | & \textbf{every}\ \{\ \lambda d_1.\lambda d_2.(\textbf{forall}\ d_1\ d_2)\ \} \\
 & | & \textbf{no}\ \{\ \lambda d_1.\lambda d_2.(\textbf{not}\ (\textbf{exists}\ (\textbf{and}\ d_1\ d_2)))\ \} \\
 & | & \textbf{at least}\ i\ \{\ \lambda d_1.\lambda d_2.(\textbf{atleast}\ i\ (\textbf{and}\ d_1\ d_2))\ \} \\
S & \rightarrow & \textbf{for}\ \mathit{NP}\ ,\ S\ \{\ np\ \lambda x.s\ \}
\end{array}
$$

"for [$_{NP}$every publication ?X], [$_{S}$an author of ?X work-s]"

$$
\begin{array}{lcl}
 & | & \textbf{there is/are}\ \mathit{NP}\ \{\ np\ \lambda x.\textbf{true}\ \}
\end{array}
$$

"there are [$_{NP}$at least 3 person-s that know A]"

Subordination and n-ary predicates with reification

$$
\begin{array}{lcl}
\textit{NP} & \rightarrow & \textbf{that}\ \textit{S}\ \ \{\ \lambda d.\lambda \overline{a}.\lambda g.(s\ ()\ \lambda t.(d\ t\ \overline{a}\ g))\ \} \\
 & & \text{“that } [_{S}\text{A know-s B]”} \\
\textit{PP} & \rightarrow & \textbf{at}/\textbf{in}\ \textit{Prep NP}\ \ \{\ \lambda s.(np\ \lambda z.(prep\ z\ s))\ \} \\
 & & \text{“at } [_{Prep}\text{place] } [_{NP}\text{the city Rennes]”} \\
 & \mid & \textbf{at}/\textbf{in}\ \textit{Det Prep AR} \equiv \textbf{at}\ \textit{Prep Det}\ \textbf{thing}\ \textit{AR} \\
 & & \text{“at } [_{Det}\text{some] } [_{Prep}\text{venue] } [_{AR}\text{whose place is Rennes]”} \\
\textit{Rel} & \rightarrow & \textbf{at}/\textbf{in}\ \textbf{which}\ \textit{Prep AR S} \\
 & & \{\ \textbf{init}\ \lambda x.(\textbf{and}\ (ar\ x)\ (prep\ x\ s))\ \} \\
 & & \text{“in which } [_{Prep}\text{graph] } [_{S}\text{A work-s]”} \\
\textit{Prep} & \rightarrow & \textbf{graph}\ \ \{\ \textbf{graph}\ \}\ \mid\ \textit{URI}\ \ \{\ \textbf{arg}\ \textit{uri}\ \}
\end{array}
$$

- Prepositional phrases (PP) can occur at any position of a sentence among the subject, verb, and object.

Built-in predicates and aggregations

$$
\begin{array}{lcll}
\textit{P1} & \rightarrow & \textit{Pred1URI}\ \{\ \lambda x.(\textbf{pred1}\ \textit{uri}\ x)\ \} & \text{“Monday”} \\
\textit{P2} & \rightarrow & \textit{Pred2URI}\ \{\ \lambda x.\lambda y.(\textbf{pred2}\ \textit{uri}\ x\ y)\ \} & \text{“match”} \\
\textit{NG1} & \rightarrow & \textit{AggregURI}\ \textbf{of}\ \textit{AP}\ (\textbf{per}\ \textit{AP}_i^+)? & \\
 & & \{\ \lambda x.(\textbf{aggreg}\ \textit{uri}\ x\ \textit{ap}\ (\textit{ap}_i)_i)\ \} & \\
 & & \text{“count of [}_{AP}\text{the publication ?P] per [}_{AP}\text{the year of ?P]”} &
\end{array}
$$

Translation to SPARQL (principle)

Starting with the λ-term produced when parsing a SQUALL sentence:

1. replace some constants by their definition
   - ex., **count** $= \lambda d.$(**select** $\lambda x.$(**aggreg** `COUNT` x d ()))
2. perform all β-reductions on the result
3. inductively generate SPARQL code
   - 4 generators for: sentences, updates, queries, and graph patterns
   - [**ask** f] $=$ `ASK` $\{$ $[f]_G$ $\}$
   - [**select** d] $= [?x \mid d\ ?x]_Q$
   - [**forall** d_1 d_2]$_G$ $=$ [**not** (**exists** (**and** d_1 (**not** d_2)))]$_G$
   - [**the** d_1 d_2]$_G$ $=$ [**exists** (**and** d_1 d_2)]$_G$
   - [**the** d_1 d_2]$_U$ $=$ [**forall** d_1 d_2]$_U$

Translation to SPARQL (example)

The SQUALL sentence

> *for which researcher-s ?X, in graph DBLP every publication whose author is ?X and whose year $\geq$ 2000 has at least 2 author-s*

is parsed as

> “[$_S$for [$_{NP}$[$_{Det}$which] [$_{NG1}$[$_{P1}$researcher-s] [$_{AR}$[$_{App}$?X]]]],
> [$_S$[$_{PP}$in [$_{Prep}$graph] [$_{NP}$DBLP]] [$_S$[$_{NP}$[$_{Det}$every]
> [$_{NG1}$[$_{P1}$publication] [$_{AR}$[$_{Rel}$[$_{Rel}$whose [$_{NG2}$[$_{P2}$author]] [$_{VP}$is
> [$_{AP}$?X]]] and [$_{Rel}$whose [$_{NG2}$[$_{P2}$year]] [$_{VP}$[$_{P2}\geq$] [$_{NP}$2000]]]]]]]
> [$_{VP}$has [$_{Det}$at least 2] [$_{P2}$author-s]]]]]”

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> [$_{NG1}$[$_{P1}$publication] [$_{AR}$[$_{Rel}$[$_{Rel}$whose [$_{NG2}$[$_{P2}$author]] [$_{VP}$is
> [$_{AP}$?X]]] and [$_{Rel}$whose [$_{NG2}$[$_{P2}$year]] [$_{VP}$[$_{P2}\geq$] [$_{NP}$2000]]]]]]]
> [$_{VP}$has [$_{Det}$at least 2] [$_{P2}$author-s]]]]]”

Translation to SPARQL (example)

...whose internal representation is:

(**select** X (**and**
(**triple** X rdf:type :researcher)
(**graph** :DBLP
(**forall** (**exists** x_3 x_5 (**and**
(**triple** x_3 rdf:type :publication) (**triple** x_3 :author X)
(**triple** x_3 :year x_5) (**pred2** $\geq$ x_5 2000)))
(**exists** x_6 (**and**
(**aggreg** COUNT x_6 x_8 x_3
(**exists** x_8 (**triple** x_3 :author x_8)))
(**pred2** $\geq$ x_6 2)))))))

Translation to SPARQL (example)

...which translates to the SPARQL query:

```
SELECT ?r
WHERE {
    ?r rdf:type :researcher .
    BIND (?r AS ?X)
    GRAPH :DBLP {
        FILTER NOT EXISTS {
            ?p rdf:type :publication .
            ?p :author ?X .
            ?p :year ?y .
            FILTER (?y >= 2000)
            FILTER NOT EXISTS {
                { SELECT COUNT(?a) AS ?n
                  WHERE { ?p :author ?a . } }
                FILTER (?n >= 2) } } } }
```

Implementation

- available as a Web form
  - See `http://www.irisa.fr/LIS/softwares/squall`
- developed in OCaml (functional, type safe, concise)
  - syntax (367 loc), semantics (295 loc), sparql (198 loc)
- extends the paper with
  - semantic validation: variable scope and binding, semantic restrictions (e.g., no built-ins in assertions)
  - arithmetic expressions and function calls (*NP*, *P2*, *AP*)
    - "what is the height * width of the rectangle-s whose color is red ?"
  - quoted NPs as verbs (P1, P2)
    - "a publication has author a person ?"
    - "a publication has 'which rdf:Property' a person ?"

Perspectives as a language

- covering 100% of SPARQL 1.1 (nothing hard)
  - `CONSTRUCT` and `DESCRIBE` forms
  - query modifiers (`ORDER BY`, `LIMIT`, `OFFSET`)
  - conditional expressions
  - concise notation of RDF collections (list) and membership test
  - + type checking in expressions
- adding more natural constructs
  - anaphoras: e.g., “some man ... this man” instead of “some man ?X ... ?X”
  - comparatives and superlatives
  - adjectives and adverbs (as RDF classes)
  - more forms of aggregations
    - e.g., “what is the average age of the researcher-s ?”

Perspectives as a user interface

- even a CNL is not simple enough
- need for guided input
  - syntax-based auto-completion (like in Ginseng)
  - query-based faceted search (like in Sewelis)

Thanks!

Questions ?