Classical DB Questions on New Kinds of Data

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Evolution of data models

80s $\rightarrow$ early 90s

Overcome expressiveness limitations of the relational model

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Overcome expressiveness limitations of the relational model

- Logical data model
- OODB
- Active databases
- Disjunctive databases
- Temporal databases
- Constraint databases
- ...

Evolution of data models

The 90s on:

Flexibility, easy integration, topology (sometimes)

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- Graphs
- XML
- RDF
- JSON
- CSV
- ...

Classical DB questions on new kind of data

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- Data design
- Languages (markup, querying)
- Optimization
- Updates

Classical questions that gain renewed interest

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- Uncertainty
- Distribution
- Ranking
- Query workloads

New questions on new kind of data

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- Access
- Schema extraction
- Trust
- Variety

In this talk

We talk about Graph DBs, RDF and tabular data (CSV)

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Bottomline:

Despite similarities with old DB problems, new applications require:

- understanding the nature of their problems
- refining old/developing new techniques

Graph Databases

The need for a standard graph QL in practice

Recognized by major graph DB engines

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- Neo4J $\rightarrow$ Cypher

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Not all of them are declarative

LDBC GraphQL task force

Formed by researchers/practitioners
(Neo4J, Sparksee, IBM, Oracle, SAP, HP)

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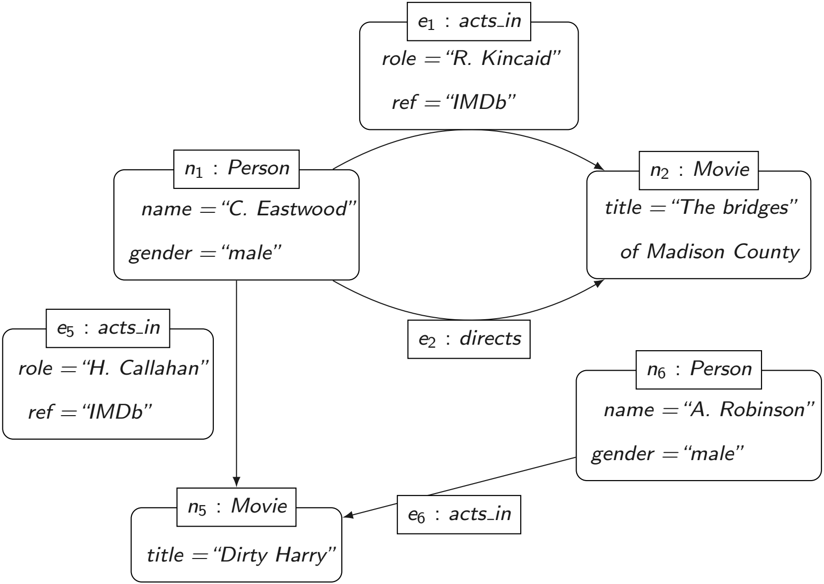
3. Identify features needed in a graph QL (ongoing)
4. Design a standard declarative graph QL (2017?)

A property graph by example



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Definition (Property graph)

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3. $\rho : E \rightarrow (V \times V)$ is a total function
   - $\rho(e) = (v_1, v_2)$ means that e is of the form $v_1 \rightarrow v_2$

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5. $\sigma : (V \cup E) \times Prop \to Val$ is a partial function with $Prop$ a finite set of properties and Val a set of values
   - $\sigma(v, p) = s$ means that s is the value of property p for v in G

In existing query languages

Basic unit for querying the structure:

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- MATCH (x) -[directs]-> (y) <-[acts_in]- (x)
  RETURN (x)

Dealing with paths is fundamental

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Reasonable data complexity so far: NLogspace

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Data complexity still reasonable: NLogspace

- For a semantics based on arbitrary paths

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Is there a simple path from x to y labeled in $(aa)^*$?

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A simple path semantics already tried/discarded in SPARQL 1.1

- [Losseman & Martens, 2012; Arenas, Conca & Pérez, 2012]

They also return paths...

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Example

MATCH $p = (x)$ -[acts_in*0..5]-> (y)
RETURN p, length(p)

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Example

MATCH $p = (x)$ -[$\mathrm{acts\_in}$*0..5]-> (y)
RETURN p, length(p)

A single path, a simple path, all paths, all simple paths?

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From a theoretical point of view:

- Return a single shortest path (complexity in NLogspace)

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From a theoretical point of view:

- Return a single shortest path (complexity in NLogspace)
- Return others, one by one, if needed

A representation problem

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- As a tuple in a table?
- As a graph?
- As a new “path” data type?

To complicate things more

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- List set (bag) of nodes that belong to a path

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The power of ungrouping:

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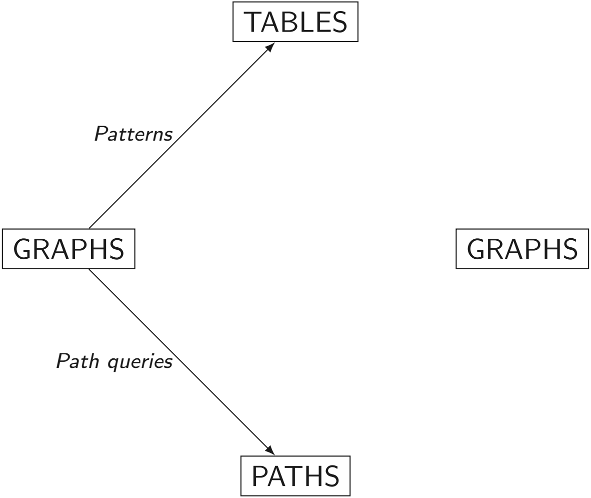
Theory: Graph QLs for data

- Complexity is astronomical [Barceló, Fontaine & Lin, 2013]
- Tractability conditions are delicate [Libkin & Vrgoč, 2012]

Type transformations



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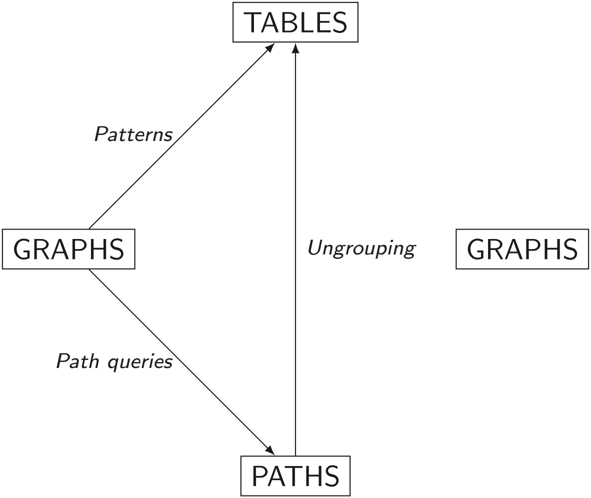

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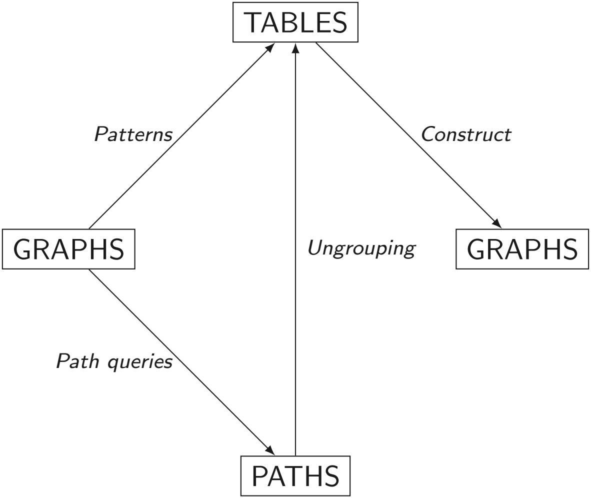

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- Real need from graph DBs to have a standard declarative QL
- Design is non-trivial due to efficiency/expressiveness trade-off
- Theory is not so much far away from practice
- It requires a political effort to "close the gap"

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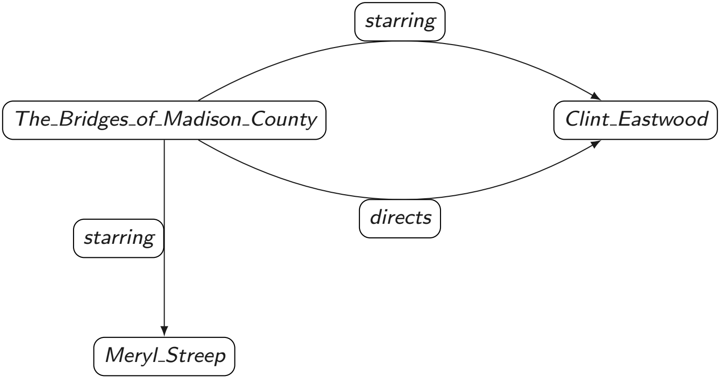
W3C proposals: Resource Description Framework (RDF) and SPARQL

RDF in a nutshell

- RDF is the W3C proposal framework for representing information in the Web
- Abstract syntax based on directed labeled graph
- Extensible URI-based vocabulary

An RDF graph



starring
The_Bridges_of_Madison_County
Clint_Eastwood
directs
starring
Meryl_Streep

An RDF graph in real life: DBpedia

```
http://dbpedia.org/resource/The_Bridges_of_Madison_County_(film)
http://dbpedia.org/property/director
http://dbpedia.org/resource/Clint_Eastwood .

http://dbpedia.org/resource/The_Bridges_of_Madison_County_(film)
http://dbpedia.org/property/starring
http://dbpedia.org/resource/Clint_Eastwood .

http://dbpedia.org/resource/The_Bridges_of_Madison_County_(film)
http://dbpedia.org/property/starring
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Prefixes simplify the notation

Prefixes can be defined in an RDF graph to simplify notation

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We can include in an RDF graph the following triples:

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@prefix owl: <http://www.w3.org/2002/07/owl#> .
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@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
```

Then `<http://www.w3.org/1999/02/22-rdf-syntax-ns#type>` can be replaced by `rdf:type`

How are URIs created and assigned?

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There is no centralized mechanism

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A key component to deal with this issue: `owl:sameAs`

```
http://dbpedia.org/resource/Meryl_Streep   owl:sameAs
http://cs.dbpedia.org/resource/Meryl_Streepová .

http://dbpedia.org/resource/Meryl_Streep   owl:sameAs
http://yago-knowledge.org/resource/Meryl_Streep .

http://dbpedia.org/resource/Meryl_Streep   owl:sameAs
http://data.nytimes.com/32250484050106278413 .
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Reasoning capabilities are needed to deal with `owl:sameAs`

Querying RDF: SPARQL

- SPARQL is the W3C recommendation query language for RDF (January 2008)
- Originally it was a graph-matching query language
- SPARQL 1.1 is the new version of this language, its was released in March 2013

An example of a SPARQL query

Retrieve all the movies in DBpedia

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```
?movie  rdf:type  <http://schema.org/Movie> .
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WHERE
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}
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An example of a SPARQL query

Retrieve all the movies in DBpedia

```
SELECT ?movie
WHERE
{
   ?movie  rdf:type  <http://schema.org/Movie> .
}
```

Important problems when querying RDF

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- Reasoning with ontologies
- Dealing with incomplete information
- Exploiting the graph structure of RDF
- Working with highly distributed data

Returning as much information as possible

RDF follows an open world assumption

Users may be unaware of the structure of the data

Returning as much information as possible

RDF follows an open world assumption

Users may be unaware of the structure of the data

Thus, the possibility of obtaining additional information if possible is important in this scenario

- In fact, this feature was present from the very beginning in SPARQL

An optional operator

Retrieve each movie in DBpedia and its gross if this information is available

```
SELECT ?movie ?gross
WHERE
{
   ?movie  rdf:type  <http://schema.org/Movie> .
   OPTIONAL
   {
      ?movie  <http://dbpedia.org/property/gross>  ?gross .
   }
}
```

Part of the answer to the query

?movie	?gross
http://dbpedia.org/resource/Frozen_(2013_film)	"1.274E9"
http://dbpedia.org/resource/Amazon_Souls	

What is new?

The `OPTIONAL` operator essentially corresponds to a left-outer join in relational algebra

But ...

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But ...

- The fragments of SPARQL that are natural to study are different than for the case of relational algebra
  - The complexity of evaluating these fragments was not known [Pérez, A. & Gutierrez 2009; Schmidt, Meier & Lausen 2010]
- New notions of safeness are needed to avoid a counterintuitive behavior [Pérez, A. & Gutierrez 2009]
- New optimization techniques are needed [Pérez, A. & Gutierrez 2009; Letelier, Pérez, Pichler & Skritek 2013; Pichler & Skritek 2014]

Openness influences other operators

```
SELECT ?voice_actor ?film_actor
WHERE
{
   {
      ?voice_actor  rdf:type
      <http://dbpedia.org/class/yago/AmericanVoiceActors> .
   }
   UNION
   {
      ?film_actor  rdf:type
      <http://dbpedia.org/class/yago/AmericanFilmActors> .
   }
}
```

The answer to the query

?voice_actor	?film_actor
http://dbpedia.org/resource/Alec_Baldwin	
	http://dbpedia.org/resource/Meryl_Streep

Reasoning with ontologies

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Reasoning capabilities are needed

- We already mentioned owl:sameAs
- An RDF graph can use RDF Schema (RDFS) to establish hierarchies of classes and properties
- The Web Ontology Language (OWL) can be used to define more complex relations between classes and properties

The use of RDFS vocabulary

The following triples are included in DBpedia:

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```
http://dbpedia.org/class/yago/Professor110480730
rdfs:subClassOf
http://dbpedia.org/class/yago/Academician109759069 .

http://dbpedia.org/class/yago/Academician109759069
rdfs:subClassOf
http://dbpedia.org/class/yago/Educator110045713 .

http://dbpedia.org/ontology/championInDoubleFemale
rdfs:subPropertyOf
http://dbpedia.org/ontology/championInDouble .

http://dbpedia.org/ontology/championInDouble
rdfs:subPropertyOf
http://dbpedia.org/ontology/champion .
```

The use of RDFS vocabulary

Some numbers in DBpedia:

- triples with `rdfs:subClassOf` as predicate are at least 450K
- triples with `rdfs:subPropertyOf` as predicate are at least 1K

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We need reasoning capabilities to deal with:

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The use of RDFS vocabulary

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We need reasoning capabilities to deal with:

- `rdfs:subClassOf`, `rdfs:subPropertyOf`
- and other elements of RDFS such as `rdfs:domain` and `rdfs:range`

Answering a query with RDFS vocabulary

Retrieve all the educators in DBpedia

```
SELECT ?educator
WHERE
{
   ?educator  rdf:type
   <http://dbpedia.org/class/yago/Educator110045713> .
}
```

Answering a query with RDFS vocabulary

The answer to the previous query should be the same as for the following query:

```
SELECT ?educator
WHERE
{
   {  ?educator  rdf:type
        . }
   UNION
   {  ?educator  rdf:type
      <http://dbpedia.org/class/yago/Educator110045713> . }
}
```

Open issues about reasoning with ontologies

Two important problems:

- Development of efficient query answering algorithms over large RDF graphs with RDFS vocabulary
- Identification of fragments of OWL that have good expressive power and can be efficiently evaluated

Exploiting the graph structure of RDF

The structure of an RDF graph stores information

It is important to have operators that can deal with this structure

- In particular, navigating an RDF graph is an important functionality

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Properties paths in SPARQL allow to express reachability queries

Navigating RDF graphs

Get starring actors in the same movie:

```
SELECT ?actor1 ?actor2
WHERE
{
   ?movie  <http://dbpedia.org/property/starring>  ?actor1 .
   ?movie  <http://dbpedia.org/property/starring>  ?actor2 .
}
```

Navigating RDF graphs

Previous query can be rewritten by using navigation patterns:

Navigating RDF graphs

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```
SELECT ?actor1 ?actor2
WHERE
{
   ?actor1 ^<http://dbpedia.org/property/starring> ?movie .
   ?movie <http://dbpedia.org/property/starring> ?actor2 .
}
```

Navigating RDF graphs

Previous query can be rewritten by using navigation patterns:

```
SELECT ?actor1 ?actor2
WHERE
{
   ?actor1
   ^<http://dbpedia.org/property/starring>/

   ?actor2 .
}
```

Navigating RDF graphs

Previous query can be rewritten by using navigation patterns:

```
SELECT ?actor1 ?actor2
WHERE
{
   ?actor1
   ^<http://dbpedia.org/property/starring>/

   ?actor2 .
}
```

The expression in red is called a property path

Navigating RDF graphs

Get starring actors that are connected:

```
SELECT ?actor1 ?actor2
WHERE
{
   ?actor1
   (^<http://dbpedia.org/property/starring>/
     <http://dbpedia.org/property/starring>)+
   ?actor2 .
}
```

Navigating RDF graphs

Get starring actors that are connected:

```
SELECT ?actor1 ?actor2
WHERE
{
   ?actor1
   (^<http://dbpedia.org/property/starring>/
     <http://dbpedia.org/property/starring>)+
   ?actor2 .
}
```

Can this query be answered?

- Can it be answered starting from a specific node?

Open issues in exploiting the graph structure of RDF

Some important problems:

- Development of efficient evaluation algorithms for reachability queries over large RDF graphs
- Standardization of a query language where paths are first-class citizens

Web data is highly distributed

Data can be stored in different repositories

- Different pieces of data have to be collected to answer a query

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- A Web service that accepts a SPARQL query as input, and returns (part of) the result to the query

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SPARQL has an operator `SERVICE` to query an endpoint

The SPARQL endpoint of DBpedia

Querying DBpedia

We want to retrieve the list of American actors in DBpedia

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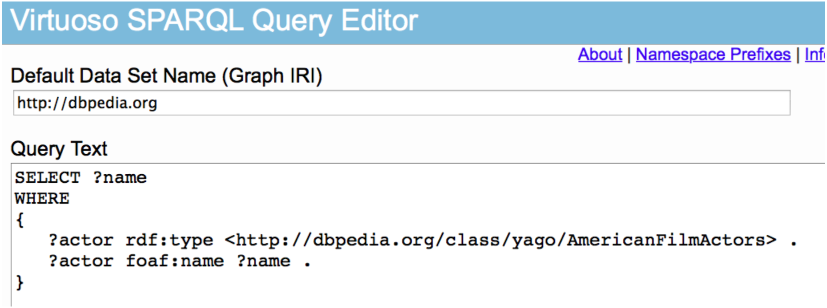

The answer to the query

name
"Courtenay Taylor"@en
"Taylor, Courtenay"@en
"Nakia Burrise"@en
"Burrise, Nakia"@en
"Alan Hale, Sr."@en
"Hale, Alan, Sr."@en
"Alec Baldwin"@en
"Baldwin, Alec"@en

...

The SPARQL endpoint of DBLP

We want to retrieve the list of authors in DBLP

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SPARQL:

```
PREFIX d2r: <http://sites.wiwiss.fu-berlin.de/suhl/bizer/d2r-server/config.rdf#>
PREFIX swrc: <http://swrc.ontoware.org/ontology#>
PREFIX dcterms: <http://purl.org/dc/terms/>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
PREFIX dc: <http://purl.org/dc/elements/1.1/>
PREFIX map: <file:///home/diederich/d2r-server-0.3.2/dblp-mapping.n3#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX foaf: <http://xmlns.com/foaf/0.1/>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
```

```
SELECT ?name
WHERE
{
  ?paper  dc:creator  ?author .
  ?author  foaf:name  ?name .
}
```

Results: Browse | Go! | Reset

The answer to the query

SPARQL results:

name
"Sanjeev Saxena"
"Hans-Ulrich Simon"
"Nathan Goodman"
"Oded Shmueli"
"Norbert Blum"
"Arnold Schönhage"
"Juha Honkala"
"Chua-Huang Huang"
"Christian Lengauer"

...

We would like to combine the previous results . . .

```
SELECT ?name
WHERE
{
  ?actor rdf:type <http://dbpedia.org/class/yago/AmericanActors> .
  ?actor foaf:name ?name .
  SERVICE <http://dblp.l3s.de/d2r/sparql>
  {
     SELECT ?name
     WHERE
     {
        ?paper dc:creator ?author .
        ?author foaf:name ?name .
     }
  }
}
```

Open issues when dealing with distribution

Some important problems:

- The notion of SPARQL endpoint needs to be formalized
  - What queries are accepted?
  - How is the time distributed between them?
  - Should a pricing model be used?
  - What is the protocol to return the answer to a query?

- A more general notion of endpoint should be formalized and studied

Open issues when dealing with distribution (cont'd)

- Usability needs to be hugely improved
  - schema/structure extraction and visualization play a fundamental role here
- Approaches for discovering relevant data should be studied
- Operators to distribute the execution of queries should be studied in more depth

A first issue about the SERVICE operator

SERVICE operators can be nested

```
SELECT ...
WHERE
{
   ...
   SERVICE <uri1>
   {
      ...
      SERVICE <uri2>
   }
}
```

A second issue about the SERVICE operator

SERVICE can be used not only with a URI but also with a variable

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SERVICE can be used not only with a URI but also with a variable

```
SELECT ...
WHERE
{
   ...
   ?address rdf:type <http://example.org/SparqlEndpoint> .
   SERVICE ?address
   {
      ...
   }
}
```

A second issue about the SERVICE operator

SERVICE can be used not only with a URI but also with a variable

```
SELECT ...
WHERE
{
   ...
   SERVICE ?address
   {
      ...
      ?uri rdf:type <http://local_example.org/SparqlEndpoint> .
   }
   SERVICE ?uri
   {
      ...
   }
}
```

A second issue about the SERVICE operator

SERVICE can be used not only with a URI but also with a variable

Several specific issues have to be addressed [Buil-Aranda, A. & Corcho 2011]:

- If ?var does not have a value, how SERVICE ?var should be evaluated?
  - A notion of safeness is needed
- The situation gets more involved if we also have nested SERVICE operators
- The syntax of SPARQL 1.1 allows SERVICE ?var, but its semantics is not defined

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What have we learned?

- There are many interesting and challenging questions to be answered
- Most of these questions can be considered as classical DB questions
- But answering them require of a combination of classical and new techniques
- The Semantic Web community has been receptive to our ideas

Tabular Data (CSV)

Comma-separated values (CSV) documents

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The W3C recommendation for CSV documents (tabular data) was released on December 2015

Why such a recommendation is needed?

- This is just tabular data, what is new?

The main goals of the W3C recommendation

- Define a schema language for CSV
  - For example, it can be used to specify the name and the type of the elements of each column in a CSV document
- Develop a metadata vocabulary for CSV
  - It describes how the data should be interpreted
- Define mechanisms for transforming CSV into RDF, JSON and XML

CSV documents can be messy

A use case from `http://www.w3.org/TR/csvw-ucr`:

> The US National Institute of Standards and Technology has run various conferences on extracting information from text. The extracted information is submitted in a tab-separated format.

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An example document:

```
    ...
:e4 type         PER
:e4 mention      "Bart"  D00124 283-286
:e4 mention      "JoJo"  D00124 145-149 0.9
:e4 per:siblings :e7     D00124 283-286 173-179 274-281
:e4 per:age      "10"    D00124 180-181 173-179 182-191 0.9
    ...
```

A schema language for CSV

We describe an approach proposed by [Martens, Neven & Vansummeren 2015]

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The model for a CSV document:

	1	2	3	4	5	6
1	:e4	type	PER			
2	:e4	mention	"Bart"	D00124	283-286	
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Every cell has a coordinate (i, j)

- The cell with content `"Bart"` has coordinate $(2, 3)$

Checking conditions on regions

	1	2	3	4	5	6
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$[\mathtt{root}] \cdot \mathtt{right} \cdot \mathtt{right} \cdot \mathtt{right} \cdot \mathtt{right}^*$

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$[\mathtt{root}] \cdot \mathtt{right} \cdot \mathtt{right} \cdot \mathtt{right} \cdot \mathtt{right}^* \cdot \mathtt{down}^* \rightarrow R$

An annotation language

We describe our proposal in [A., Maturana, Riveros & Vrgoč 2016]

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```

is represented as:

```
: e 4 \t t y p e \t P E R \n : e 4 \t m e n t i o n \t ...
```

Annotation of regions

Let w be the string representing a CSV document

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- A region of w is a span (i, j) [Fagin, Kimelfeld, Reiss & Vansummeren 2013]

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Annotation of regions

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The main ingredients of our approach:

- A region of w is a span (i, j) [Fagin, Kimelfeld, Reiss & Vansummeren 2013]
- Regular expression with variables are used to extract spans from w
  - Fragments that can be evaluated very efficiently have been identified
- Datalog programs are used to combine the results of the extraction process and annotate spans [Shen, Doan, Naughton & Ramakrishnan 2007]

Annotation of regions

Recall that w is the string representation of:

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Assume that the alphabet of w is Σ and $\Delta = (\Sigma - \{\backslash\mathtt{t}, \backslash\mathtt{n}\})$

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$$
\begin{array}{rcl}
w.x\backslash\mathtt{t}\Sigma^* \;\wedge\; x.\Delta^* & \rightarrow & \mathrm{FC}(x) \\
w.\Sigma^*\backslash\mathtt{n}x\backslash\mathtt{t}\Sigma^* \;\wedge\; x.\Delta^* & \rightarrow & \mathrm{FC}(x)
\end{array}
$$

Open issues in the area

Many questions need to be answered:

- What is a good schema language for CSV?
- What is a good annotation language for CSV?
- How metadata should be specified for a CSV document?
- What is a good mapping language to specify the transformation of a CSV document to an RDF graph?
  - The same question needs to be answered for JSON and XML

Final remarks

Do not underestimate the theoretical interest behind new apps:

- Classical DB questions gain new flavors over new data models
- It might involve developing techniques of independent interest
- Some areas are in need of theoretical help
- It requires an effort to understand problems and transfer tools

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- It requires an effort to understand problems and transfer tools

Many problems are still in need of formalization

- structure extraction, access, trust, ...

Thank you!