Semantic Technologies & Triplestores for BI

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Marin Dimitrov (Ontotext)

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- Semantic Databases – advantages, features and benchmarks
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INTRODUCTION TO SEMANTIC TECHNOLOGIES

The need for a smarter Web

- *"The Semantic Web is an extension of the current web in which information is given <u>well-defined</u> meaning, better enabling computers and people to work in cooperation."* (Tim Berners-Lee, 2001)

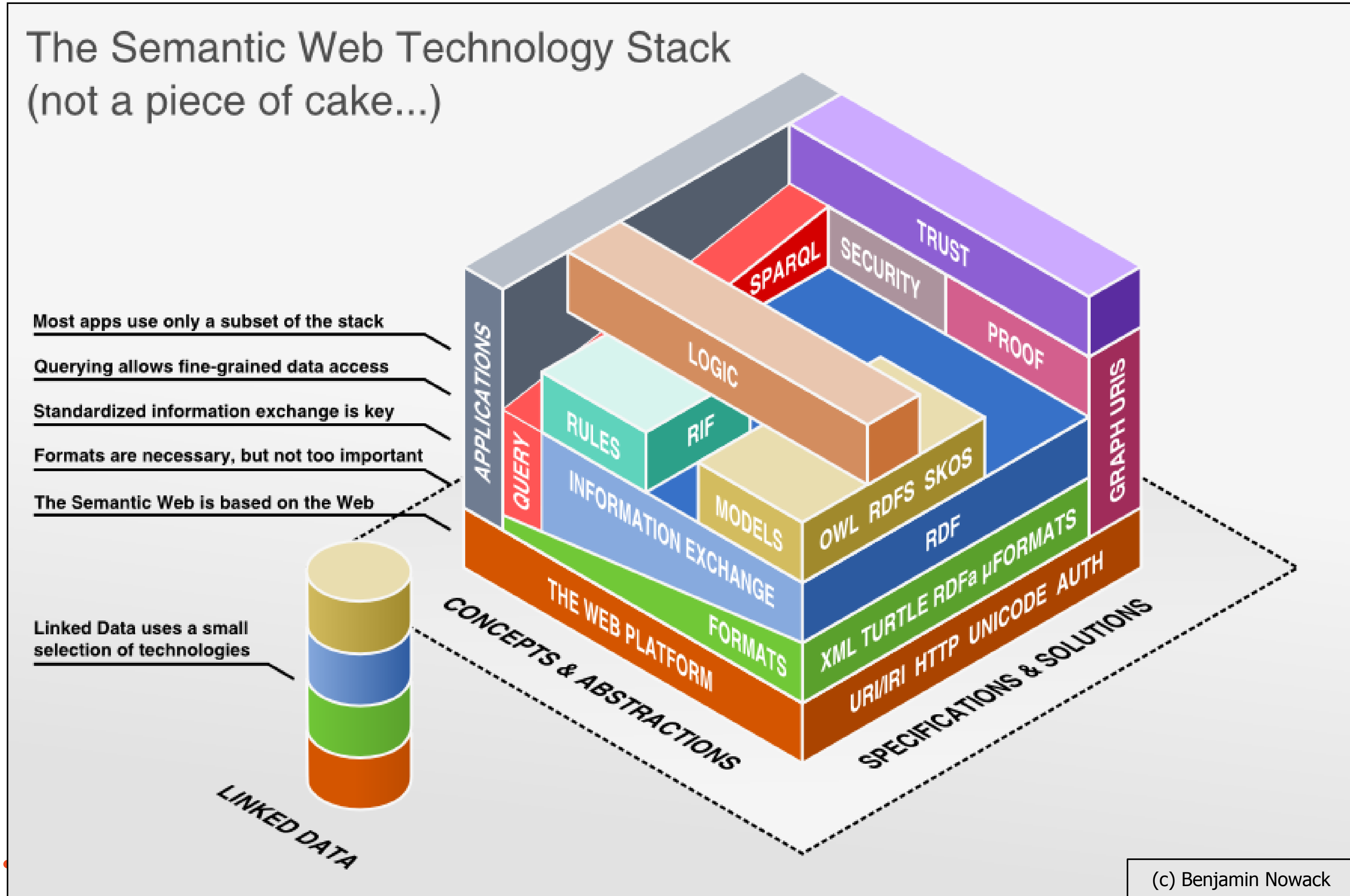
The need for a smarter Web (2)

- *"PricewaterhouseCoopers believes a Web of data will develop that fully augments the document Web of today. You'll be able to find and take **pieces of data** sets **from different places**, aggregate them without warehousing, and **analyze them in a more straightforward, powerful way** than you can now." (PWC, May 2009)*

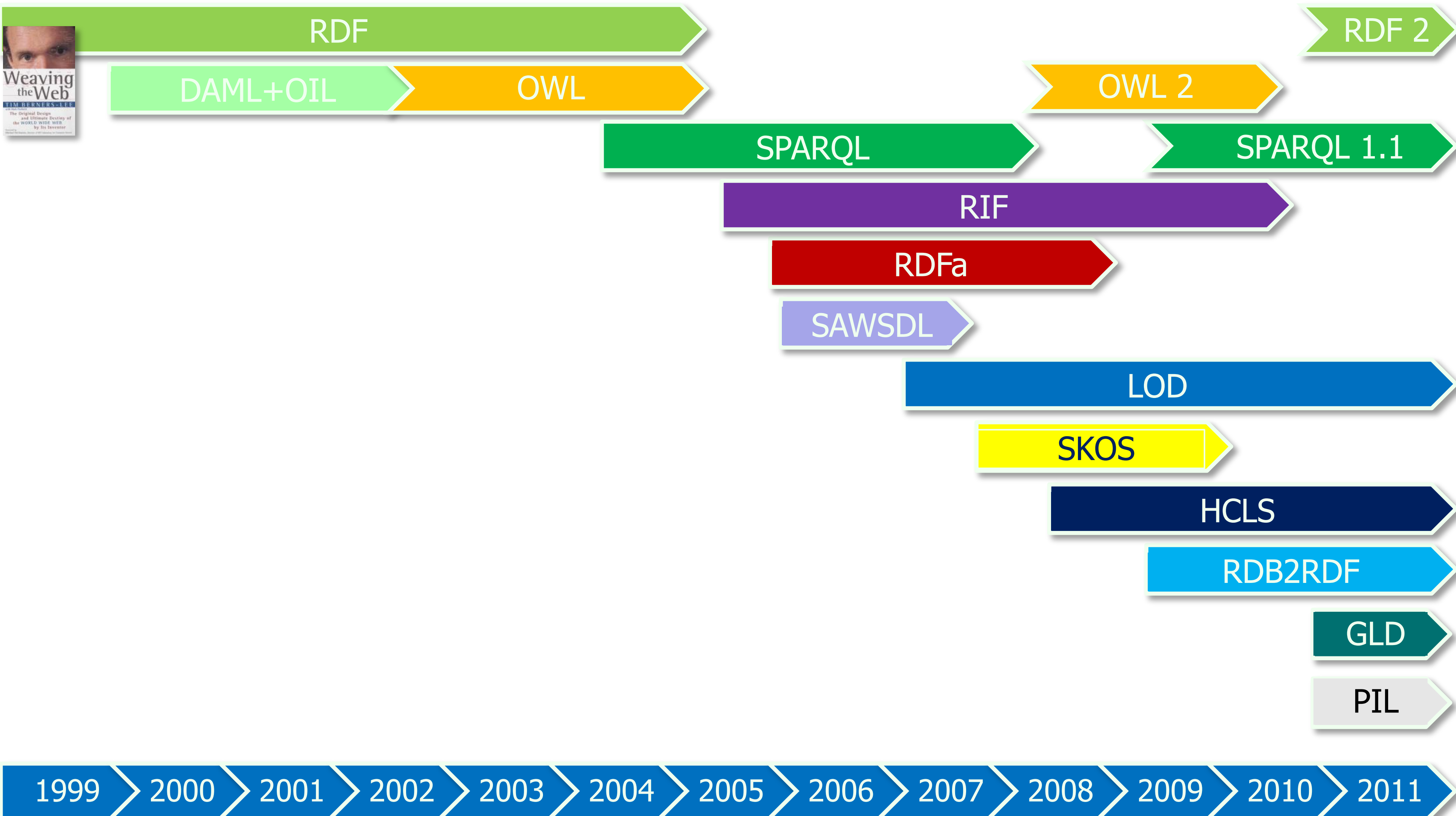
The Semantic Web vision (W3C)

- Extend principles of the Web from documents to data
- Data should be accessed using the general Web architecture (e.g., URI-s, protocols, …)
- Data should be related to one another just as documents are already
- Creation of a common framework that allows:
  - Data to be shared and reused across applications
  - Data to be processed automatically
  - New relationships between pieces of data to be inferred

The Semantic Web stack



The Semantic Web timeline



Ontologies as data models on the Semantic Web

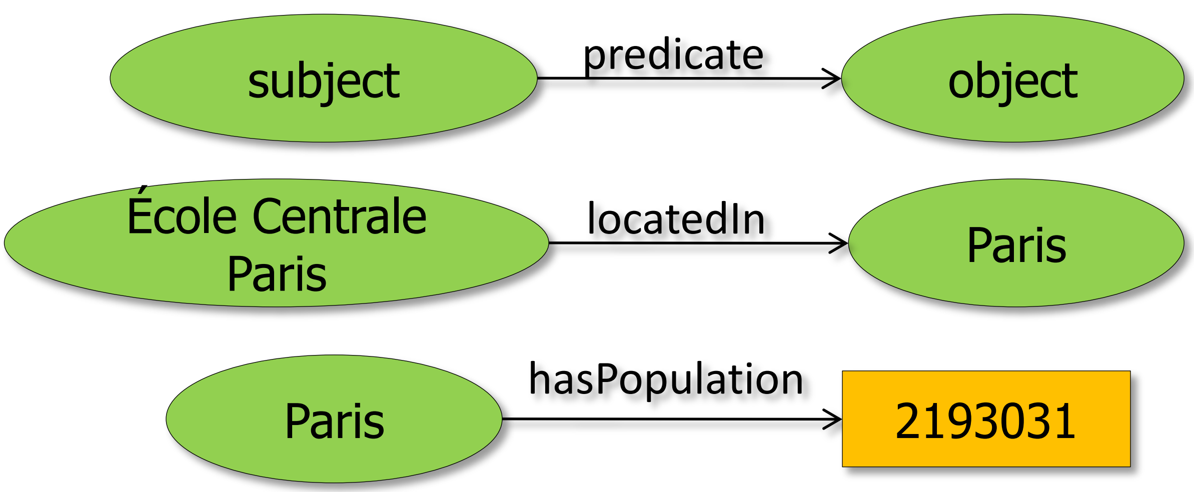
- An ontology is a *formal* specification that provides sharable and reusable knowledge representation
  - Examples – taxonomies, thesauri, topic maps, formal ontologies
- An ontology specification includes
  - Description of the *concepts* in some domain and their properties
  - Description of the possible *relationships* between concepts and the *constraints* on how the relationships can be used
  - Sometimes, the *individuals* (members of concepts)

Resource Description Framework (RDF)

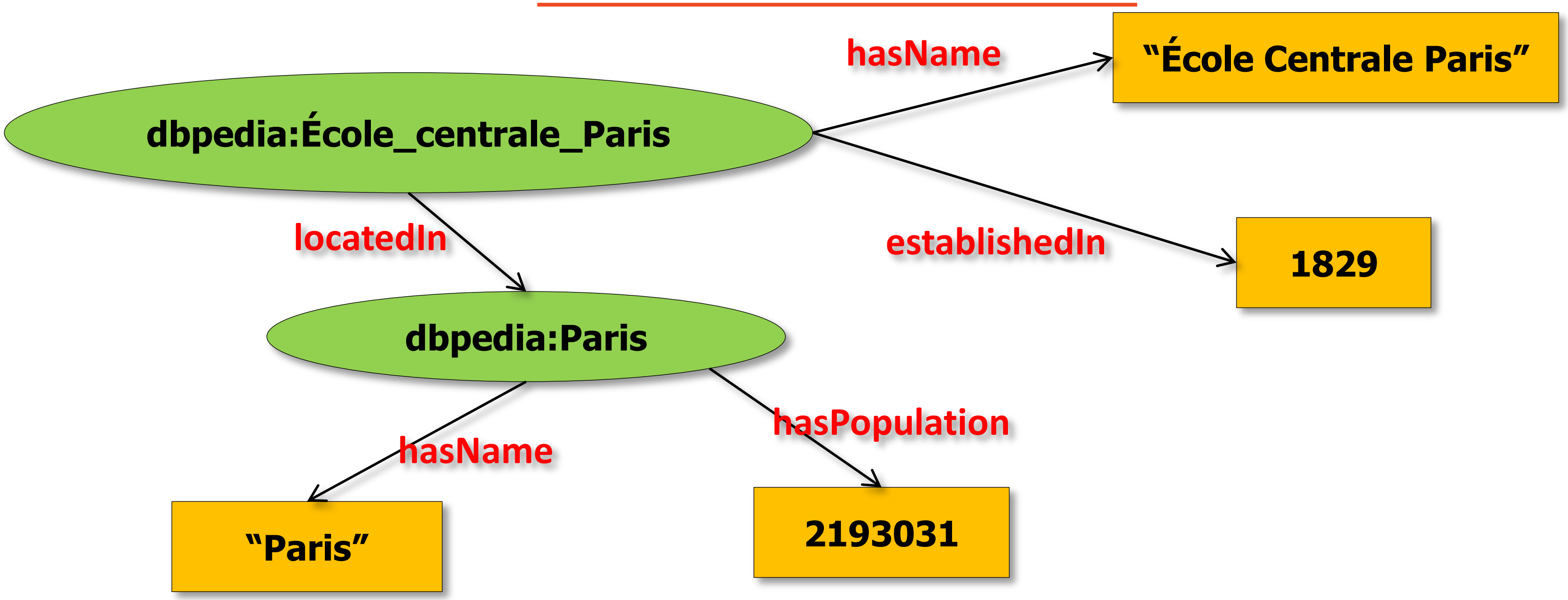
- A simple data model for
  - Formally describing the *semantics* of information
  - representing meta-data (data about data)
- A set of representation syntaxes
  - RDF/XML (standard), N-Triples, N3
- Building blocks
  - *Resources* (with unique identifiers)
  - *Literals*
  - Named *relations* between pairs of resources (or a resource and a literal)

RDF (2)

- Everything is a triple
  - **Subject** (resource), **Predicate** (relation), **Object** (resource or literal)
- The RDF graph is a collection of triples



RDF graph example (3)



Subject	Predicate	Object
http://dbpedia.org/resource/Paris	hasName	"Paris"
http://dbpedia.org/resource/Paris	hasPopulation	2193031
http://dbpedia.org/resource/École_centrale_Paris	locatedIn	http://dbpedia.org/resource/Paris
http://dbpedia.org/resource/École_centrale_Paris	hasName	"École Centrale Paris"
http://dbpedia.org/resource/École_centrale_Paris	establishedIn	1829

RDF advantages

- Global identifiers of all resources (URIs)
  - Reduces ambiguity
  - Makes incremental data integration easier
- Graph data model
  - Suitable for sparse, unstructured and semi-structured data
- Inference of implicit facts
- Schema agility
  - Lowers the cost of schema evolution

RDF Schema (RDFS)

- RDFS provides means for:
  - Defining *Classes* and *Properties*
  - Defining hierarchies (of classes and properties)
  - Domain/range of a property
- Entailment rules (axioms)
  - Infer new triples from existing ones

RDFS entailment rules

1:	$s\ p\ o$ (if o is a literal)		$\Rightarrow$ _:n rdf:type rdfs:Literal
2:	p rdfs:domain x	& $s\ p\ o$	$\Rightarrow$ s rdf:type x
3:	p rdfs:range x	& $s\ p\ o$	$\Rightarrow$ o rdf:type x
4a:	$s\ p\ o$		$\Rightarrow$ s rdf:type rdfs:Resource
4b:	$s\ p\ o$		$\Rightarrow$ o rdf:type rdfs:Resource
5:	p rdfs:subPropertyOf q	& q rdfs:subPropertyOf r	$\Rightarrow$ p rdfs:subPropertyOf r
6:	p rdf:type rdf:Property		$\Rightarrow$ p rdfs:subPropertyOf p
7:	$s\ p\ o$	& p rdfs:subPropertyOf q	$\Rightarrow$ $s\ q\ o$
8:	s rdf:type rdfs:Class		$\Rightarrow$ s rdfs:subClassOf rdfs:Resource
9:	s rdf:type x	& x rdfs:subClassOf y	$\Rightarrow$ s rdf:type y
10:	s rdf:type rdfs:Class		$\Rightarrow$ s rdfs:subClassOf s
11:	x rdfs:subClassOf y	& y rdfs:subClassof z	$\Rightarrow$ x rdfs:subClassOf z
12:	p rdf:type rdfs:ContainerMembershipProperty		$\Rightarrow$ p rdfs:subPropertyOf rdfs:member
13:	o rdf:type rdfs:Datatype		$\Rightarrow$ o rdfs:subClassOf rdfs:Literal

RDF entailment rules (2)

- Class/Property hierarchies
  - R5, R7, R9, R11

```
:human rdfs:subClassOf :mammal .
:man rdfs:subClassOf :human .
➔ :man rdfs:subClassOf :mammal .
```

```
:John a :man .
➔ :John a :human .
➔ :John a :mammal .
```

```
:hasSpouse rdfs:subPropertyOf :hasRelative .
:John :hasSpouse :Merry .
➔ :John :hasRelative :Merry .
```

- Inferring types (domain/range restrictions)
  - R2, R3

```
:hasSpouse rdfs:domain :human ;
           rdfs:range :human .
:Adam :hasSpouse :Eve .
➔:Adam a :human .
➔:Eve a :human .
```

Web Ontology Language (OWL)

- More expressive than RDFS
  - Identity equivalence/difference
    - *sameAs, differentFrom, equivalentClass/Property*
- Complex class expressions
  - Class intersection, union, complement, disjointness
- More expressive property definitions
  - Object/Datatype properties
  - Cardinality restrictions
  - Transitive, functional, symmetric, inverse properties

OWL (2)

- Identity equivalence

```
db1:Paris :hasPopulation 2913031.
db1:Paris = db2:Paris .
➔ db2:Paris :hasPopulation 2193031 .
```

- Transitive properties

```
:locatedIn a owl:TransitiveProperty .
:ECP :locatedIn :Paris .
:Paris :locatedIn :France .
➔ :ECP :locatedIn :France .
```

- Symmetric properties

```
:hasSpouse a owl:SymmetricProperty .
:John :hasSpouse :Merry .
➔ :Merry :hasSpouse :John .
```

- Inverse properties

```
:hasParent owl:inverseOf :hasChild .
:John :hasChild :Jane .
➔ :Jane :hasParent :John .
```

- Functional properties

```
:hasSpouse a owl:FunctionalPropety .
:Merry :hasSpouse :John .
:Merry :hasSpouse :JohnSmith .
➔ :JohnSmith = :John .
```

OWL sublanguages

- OWL Lite
  - low expressivity / low formal complexity
  - Logical decidability & completeness
  - All RDFS features
  - *sameAs/differentFrom*, equivalent class/property
  - inverse/symmetric/transitive/functional properties
  - cardinality restriction (only 0 or 1)
  - class intersection

OWL sublanguages (2)

- OWL DL
  - high expressivity / efficient DL reasoning
  - Logical decidability & completeness
  - All OWL Lite features
  - Class disjointness
  - Complex class expressions
  - Class union & complement
- OWL Full
  - max expressivity / no efficient reasoning
  - No guarantees for completeness & decidability

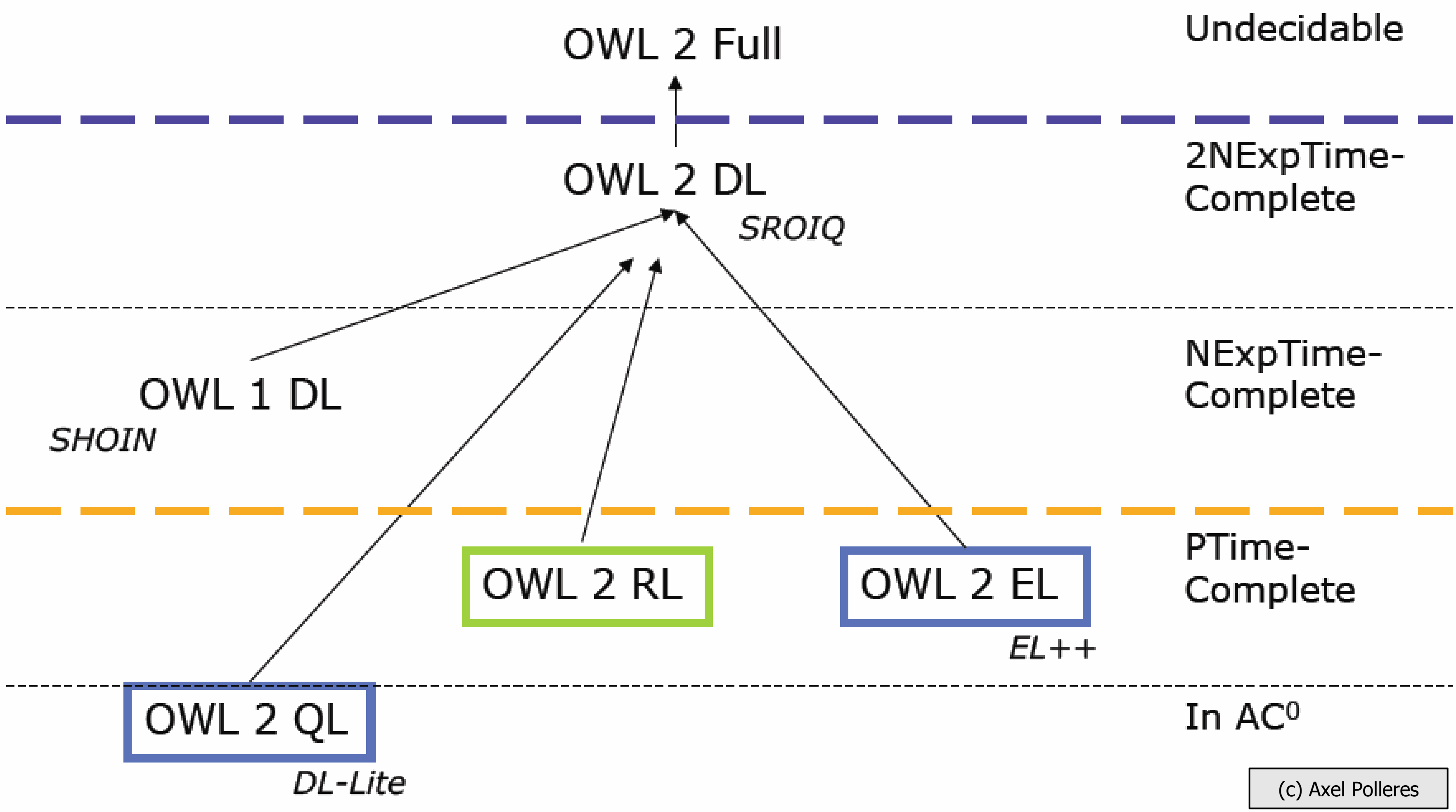
OWL 2 profiles

- Goals
  - sublanguages that trade expressiveness for efficiency of reasoning
  - Cover specific important application areas
  - Easier to understand by non-experts
- ***OWL 2 EL***
  - Best for large ontologies / small instance data (TBox reasoning)
  - Computationally optimal
    - PTime reasoning complexity

OWL 2 profiles (2)

- ***OWL 2 QL***
  - Quite limited expressive power, but very efficient for query answering with large instance data
  - Can exploit query rewriting techniques
    - Data storage & query evaluation can be delegated to a RDBMS
- ***OWL 2 RL***
  - Balance between scalable reasoning and expressive power
  - Suitable for rule-based reasoning

OWL 2 profiles (3)



SPARQL Protocol and RDF Query Language (SPARQL)

- SQL-like query language for RDF data
- Simple protocol for querying remote databases over HTTP
- Query types
  - *select* – query data by complex graph patterns
  - *ask* – whether a query returns results (result is true/false)
  - *describe* – returns all triples about a particular resource
  - *construct* – create new triples based on query results

Graph patterns

- Whitespace separated list of *Subject, Predicate, Object*
  - *?x dbp-ont:city dbpedia:Paris*
  - *dbpedia:École_centrale_Paris db-ont:city ?y*
- *Group Graph Pattern*
  - A group of 1+ graph patterns
  - FILTERs can constrain the whole group

```
{
   ?uni a dbpedia:University ;
        dbp-ont:city dbpedia:Paris ;
        dbp-ont:numberOfStudents ?students .
   FILTER (?students > 5000)
}
```

Graph Patterns (2)

- *Optional Graph Pattern*
  - Optional parts of a pattern
  - *pattern OPTIONAL {pattern}*

```
SELECT ?uni ?students
WHERE {
   ?uni a dbpedia:University ;
        dbp-ont:city dbpedia:Paris .
   OPTIONAL {
      ?uni dbp-ont:numberOfStudents ?students
   }
}
```

Graph Patterns (3)

- *Alternative Graph Pattern*
  - Combine results of several alternative patterns
  - *{pattern} UNION {pattern}*

```
SELECT ?uni
WHERE {
  ?uni a dbpedia:University .
  {
     { ?uni dbp-ont:city dbpedia:Paris }
     UNION
     { ?uni dbp-ont:city dbpedia:Lyon }
  }
}
```

Anatomy of a SPARQL query

- List of namespace prefixes
  - PREFIX xyz: <URI>
- Query result clause (variables)
  - ?x, $y
- Datasets
- Graph patterns + filters
  - Simple / group / alternative / optional
- Modifiers
  - ORDER BY, DISTINCT, OFFSET/LIMIT

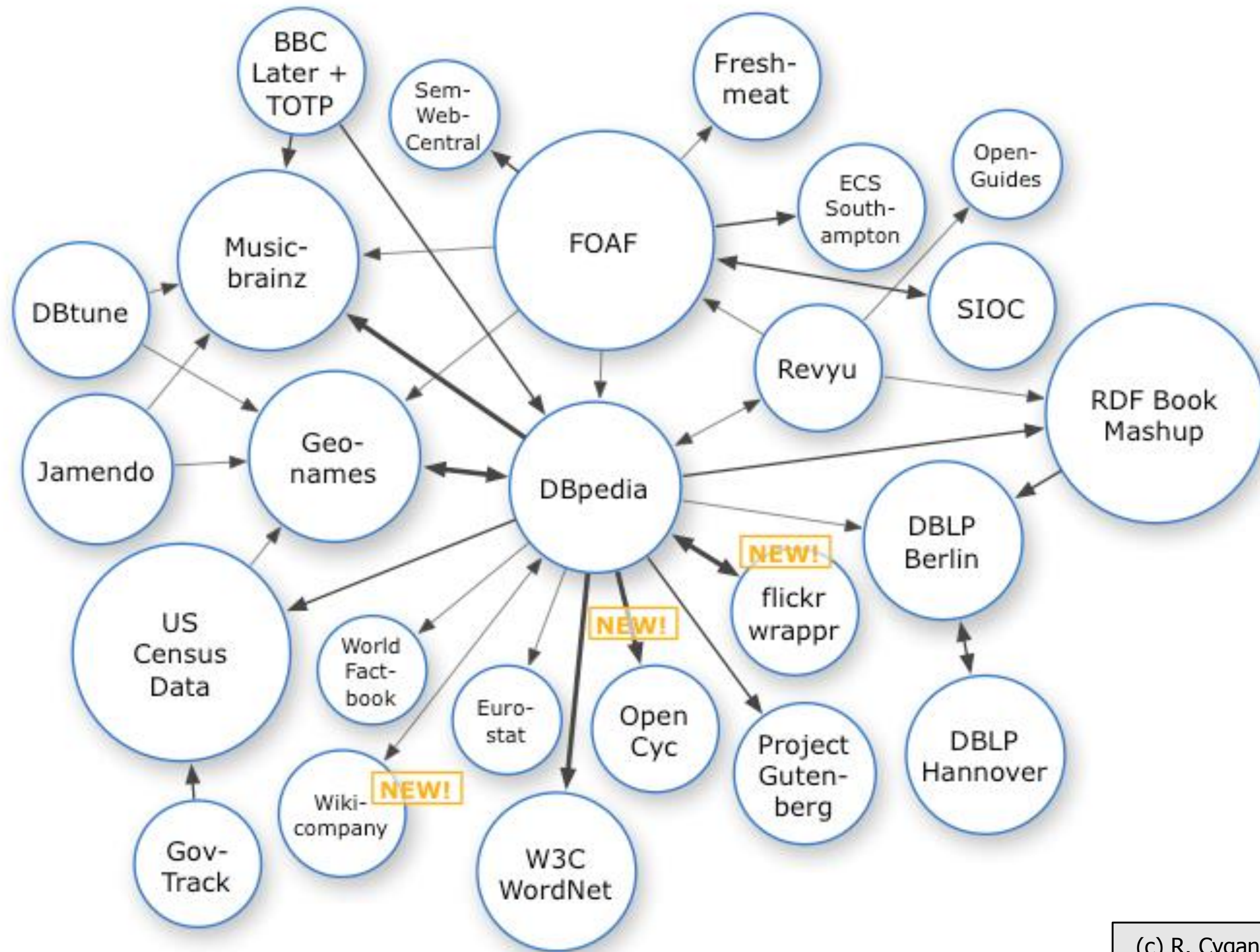
Linked Data

- *“To make the Semantic Web a reality, it is necessary to have a large volume of data available on the Web in a standard, reachable and manageable format. In addition the relationships among data also need to be made available. This collection of interrelated data on the Web can also be referred to as **Linked Data**. Linked Data lies at the heart of the Semantic Web: large scale integration of, and reasoning on, data on the Web.”* (W3C)
- *Linked Data* is a set of principles that allows publishing, querying and browsing of RDF data, distributed across different servers
  - similar to the way HTML is currently published & consumed

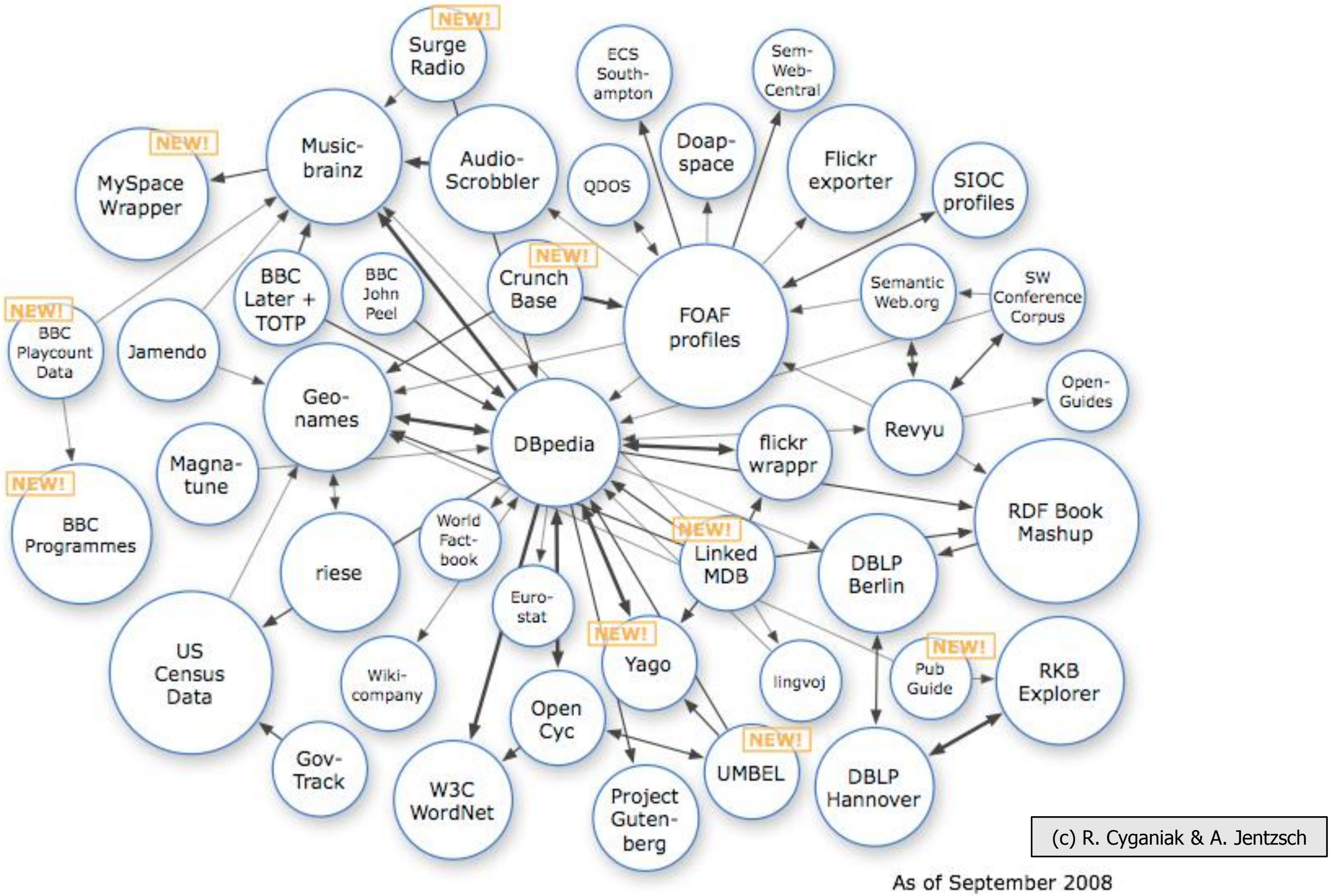
Linked Data design principles

1. Unambiguous identifiers for objects (resources)
   – Use URIs as names for things
2. Use the structure of the web
   – Use HTTP URIs so that people can look up the names
3. Make is easy to discover information about an object (resource)
   – When someone lookups a URI, provide useful information
4. Link the object (resource) to related objects
   – Include links to other URIs

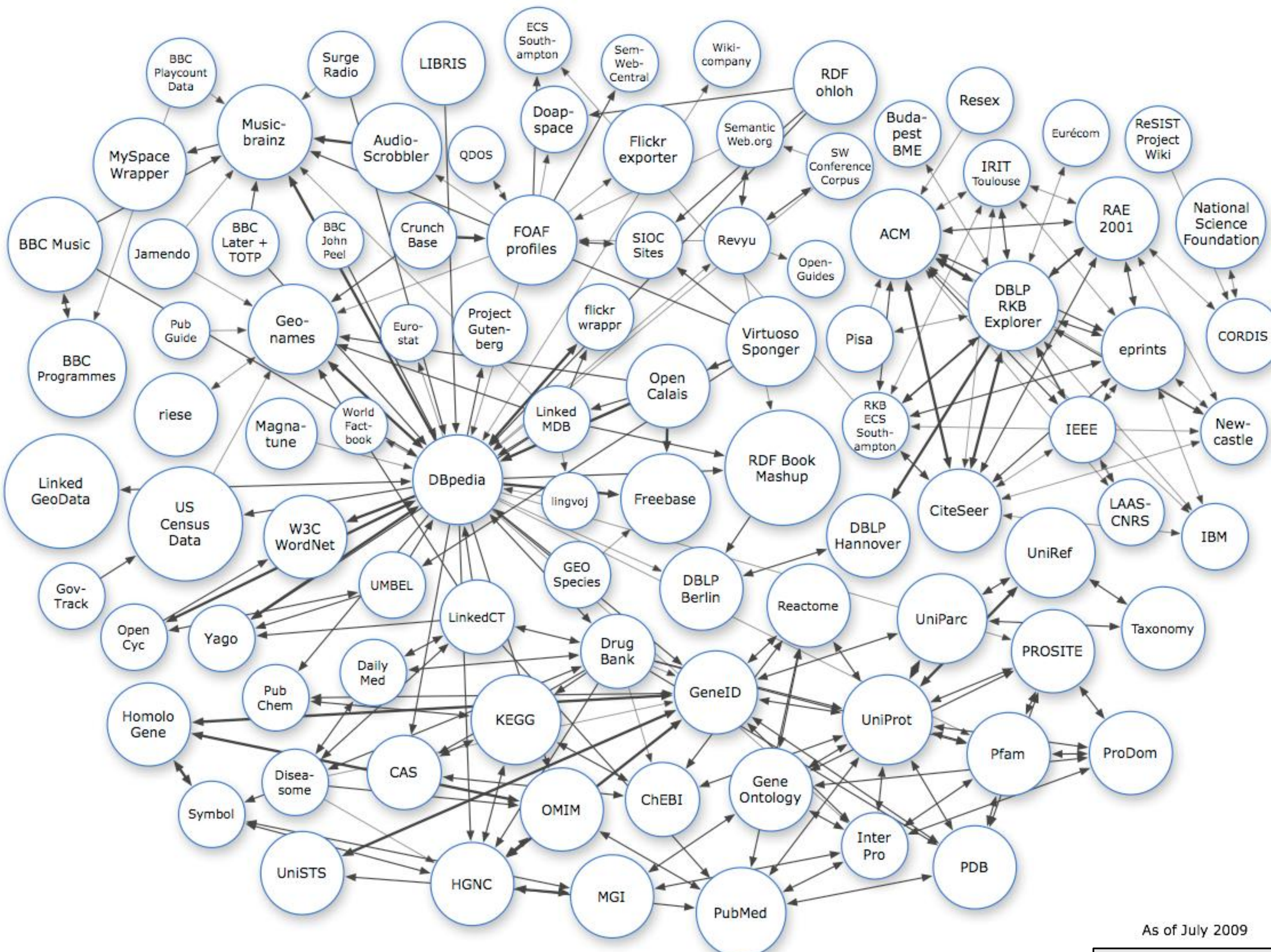
Linked Data evolution – Oct 2007



Linked Data evolution – Sep 2008

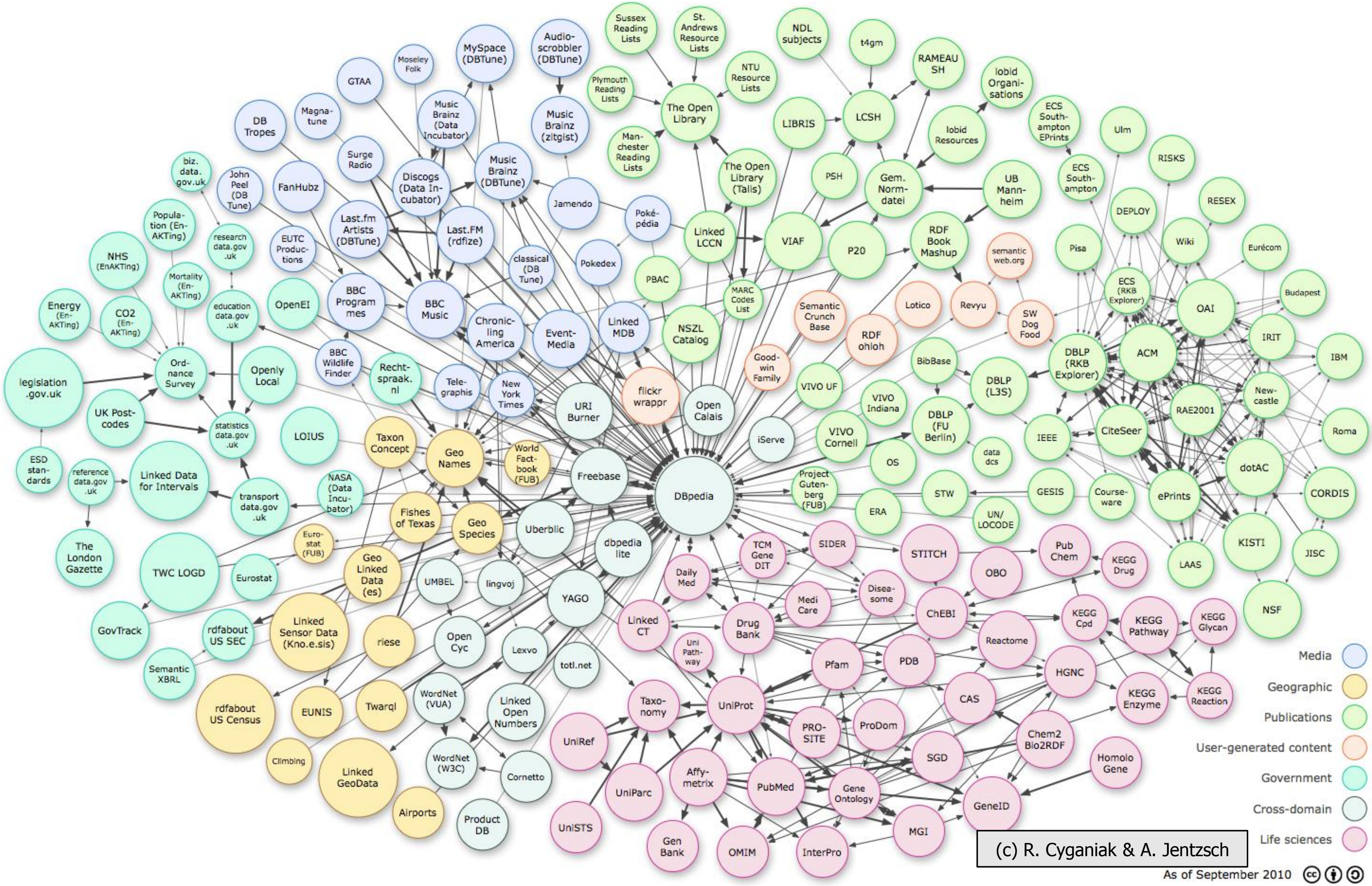


Linked Data evolution – Jul 2010



As of July 2009

Linked Data evolution – Sep 2010



Why use Linked Data?

- Facilitate data integration
  - Use LOD as an “interlingua” for EDI
    - Additional public information can help alignment and linking
- Add value to proprietary data
  - Public data can allow enhanced content and more analytics on top of proprietary data
    - E.g. linking to spatial data from GeoNames, search for images
  - Better description and access to content
- Make enterprise data more open & accessible
  - Public identifiers and vocabularies can be used to access them

SEMANTIC DATABASES (TRIPLESTORES)

Triplestores

- RDF databases
  - Store data according to the RDF data model
  - Provide inference of implicit triples (either at data loading time, or at query time)
  - SPARQL as a query language
- Many similarities to traditional DBMS approaches
  - … and many differences too

Triplestores vs. traditional DBMS

	Triplestore	OLTP	OLAP	NoSQL	Graph
Update performance	+/-	+	+/-	++	+
Complex Queries	+	+/-	+	-	+/-
inference	+	-	+/-	-	-
Sparse data	+	-	+/-	+	+
Semi-structured / unstructured data	+	-	-	+/-	+
Dynamic schema	+	-	-	+/-	+/-

Triplestore advantages

- Global identifiers of resources (entities)
  - Lowers the cost of data integration
- Inference of implicit facts
- Graph data model
  - Suitable for sparse, semi-structured and unstructured data
- Agile schema
  - New relations between entities may be easily added
- Exploratory queries against unknown schema
  - Query and data vocabulary may differ
- Compliance to standards (RDF, SPARQL)

Design & Implementation

- Storage engine
  - Native
  - on top of a RDBMS
  - on top of NoSQL engine
- Triple density
  - The in-memory "footprint" per triple may differ x10 between different triplestores
  - Impact on TCO
- Compression
  - Improves I/O on multi-core systems

Design & Implementation (2)

- Reasoning strategy
  - *Forward-chaining* – at data loading time, start from the explicit facts and apply the inference rules until the complete closure is inferred
  - *Backward-chaining* – at runtime, start with a query and decompose recursively into smaller requests that can be matched to explicit facts
  - *Hybrid strategy* – partial materialization at data loading time + partial query pattern matching at runtime

Pros and cons of forward-chaining based materialization

- Relatively **slow addition** of new facts
  - inferred closure is extended after each transaction
- **Deletion** of facts is **slow**
  - facts that are no longer true are removed from the inferred closure
- The **maintenance of the inferred closure** requires more resources
- **Querying and retrieval are fast**
  - no reasoning is required at query time
  - RDBMS-like query evaluation & optimisation techniques are applicable

Design & Implementation (3)

- Invalidation strategy
  - Truth maintenance is not trivial
  - huge overhead for keeping meta-data about inference dependencies
  - Trivial approach: just re-compute the complete inferred closure after a deletion
  - Advanced approach: detect which parts of the inferred closure are invalid and need to be deleted as well

Design & Implementation (4)

- *owl:sameAs* optimization
  - It is a transitive, reflexive and symmetric relationship
  - *owl:sameAs* induced inference can "inflate" the number of statements and deteriorate inference/query performance
  - Specific optimizations allow that a compact representation of equivalent resources is used
  - Query results can be expanded through backward-chaining at query time

Popular triplestores

- 4store
  - http://4store.org
  - *Open source*, distributed cluster (up to 32 nodes), data fully partitioned, no inference (external reasoner, backward chaining)
- AllegroGraph
  - http://www.franz.com
  - ACID transactions, RDF and limited OWL reasoning, full-text indexing, compression, replication cluster, backward chaining

Popular triplestores (2)

- Bigdata
  - http://www.systap.com
  - Open source, data partitioning, hybrid materialization, RDF and limited OWL reasoning
- Dydra
  - http://dydra.com
  - SaaS, SPARQL endpoint + REST API, no reasoning
- Jena TDB
  - http://www.openjena.org/TDB
  - Open source, RDF and limited OWL reasoning

Popular triplestores (3)

- Oracle
  - RDF and limited OWL reasoning, data partitioning & compression (RAC), *owl:sameAs* optimization, security & versioning; geo-spatial extensions
- OWLIM
  - http://www.ontotext.com
  - Forward-chaining, RDF / OWL 2 RL / OWL 2 QL and limited OWL Lite / OWL DL reasoning; replication cluster; *owl:sameAs* optimization; full-text indexing; geo-spatial extensions; scalable RDF Rank

Popular triplestores (4)

- Sesame
  - http://www.openrdf.org
  - Open source; plugable storage & inference layer
- StarDog
  - http://stardog.com
  - backward-chaining; OWL DL and all OWL 2 profiles; full-text indexing; compression
- Virtuoso
  - http://virtuoso.openlinksw.com
  - Universal server (RDF, XML, RDBMS); backward chaining; geo-spatial extensions; full-text indexing

Benchmarking

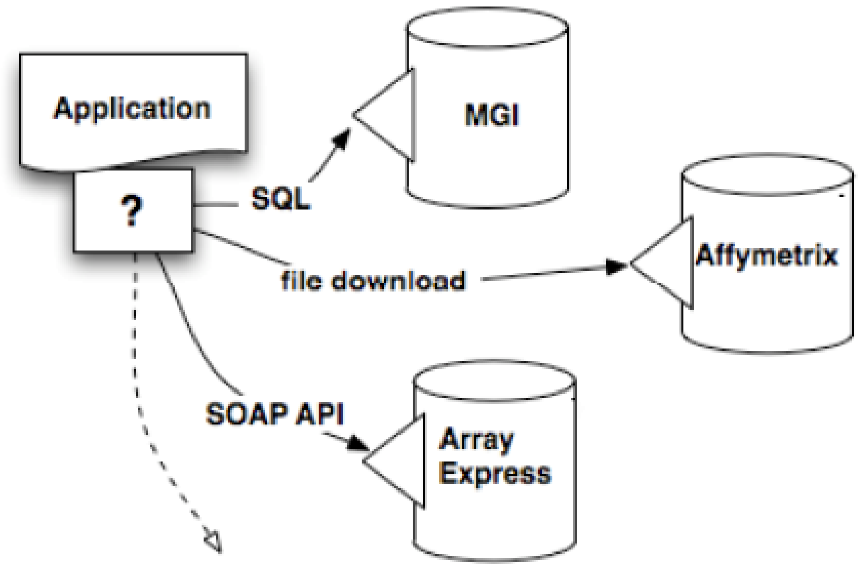
- Tasks
  - Data loading
  - Query evaluation
  - Data modification
- Performance factors
  - Forward-chaining vs. backward-chaining
  - Data model complexity
  - Query complexity
  - Result set size
  - Number of concurrent clients

Popular benchmarks for triplestores

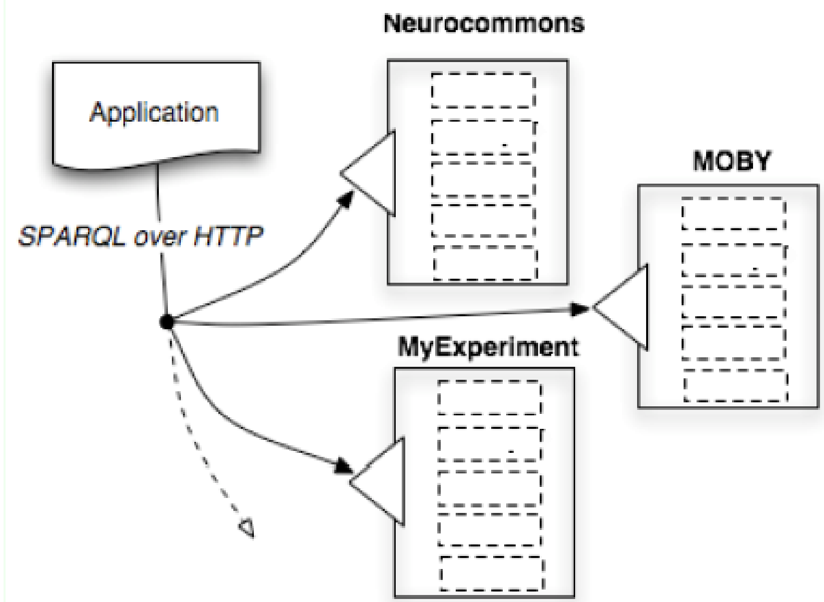
- LUBM
  - Storing & query performance benchmark
  - 14 predefined queries + data generator tool
- BSBM
  - SPARQL benchmark
  - 3 use cases (12/17/8 distinct queries)
- SP²Bench
  - SPARQL benchmark
  - 12 queries for most common SPARQL constructs & access patterns

SEMANTIC TECHNOLOGIES & TRIPLESTORES FOR BI

Data integration & querying (HCLS)



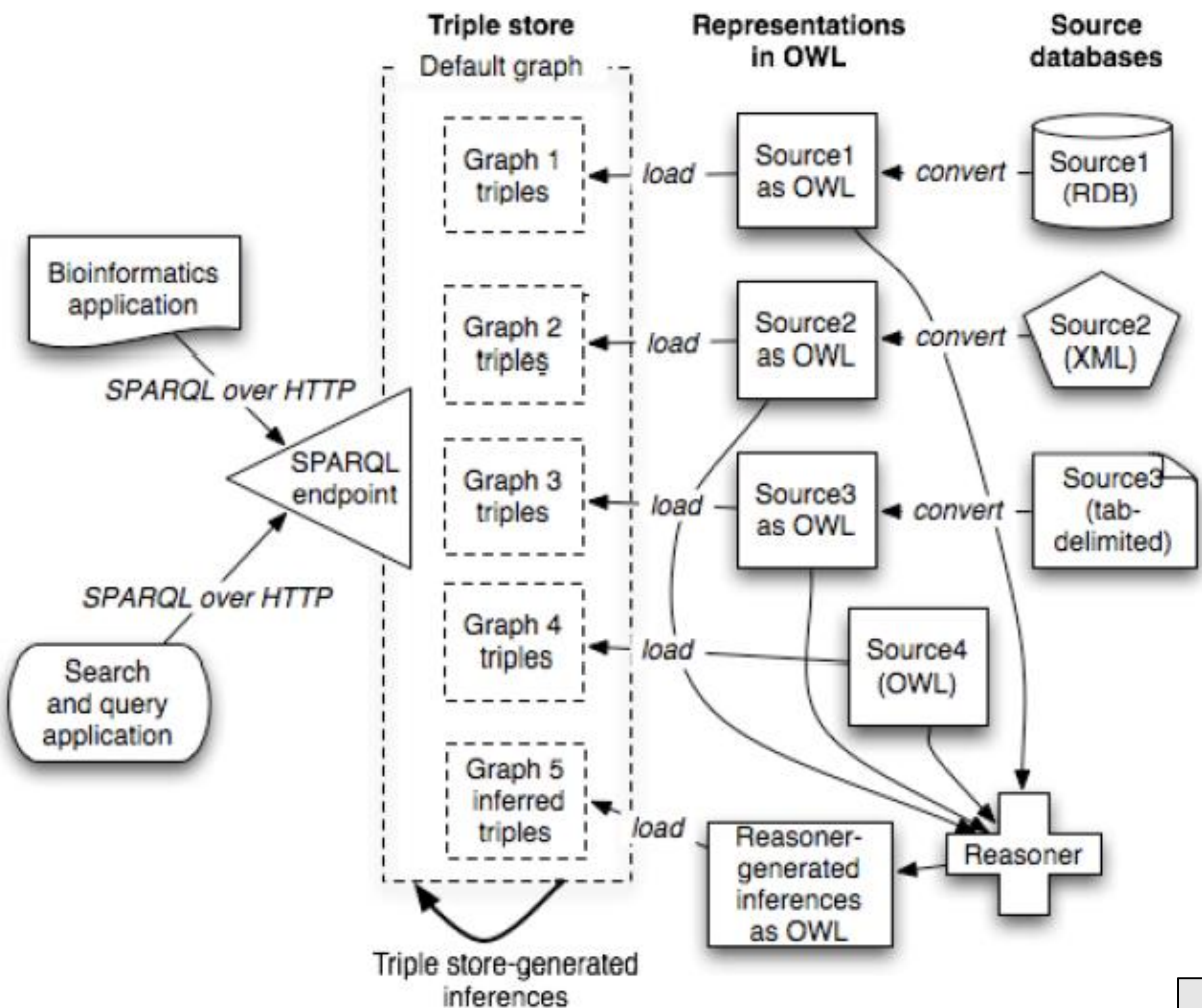
distributed querying at present



distributed querying with RDF and SPARQL

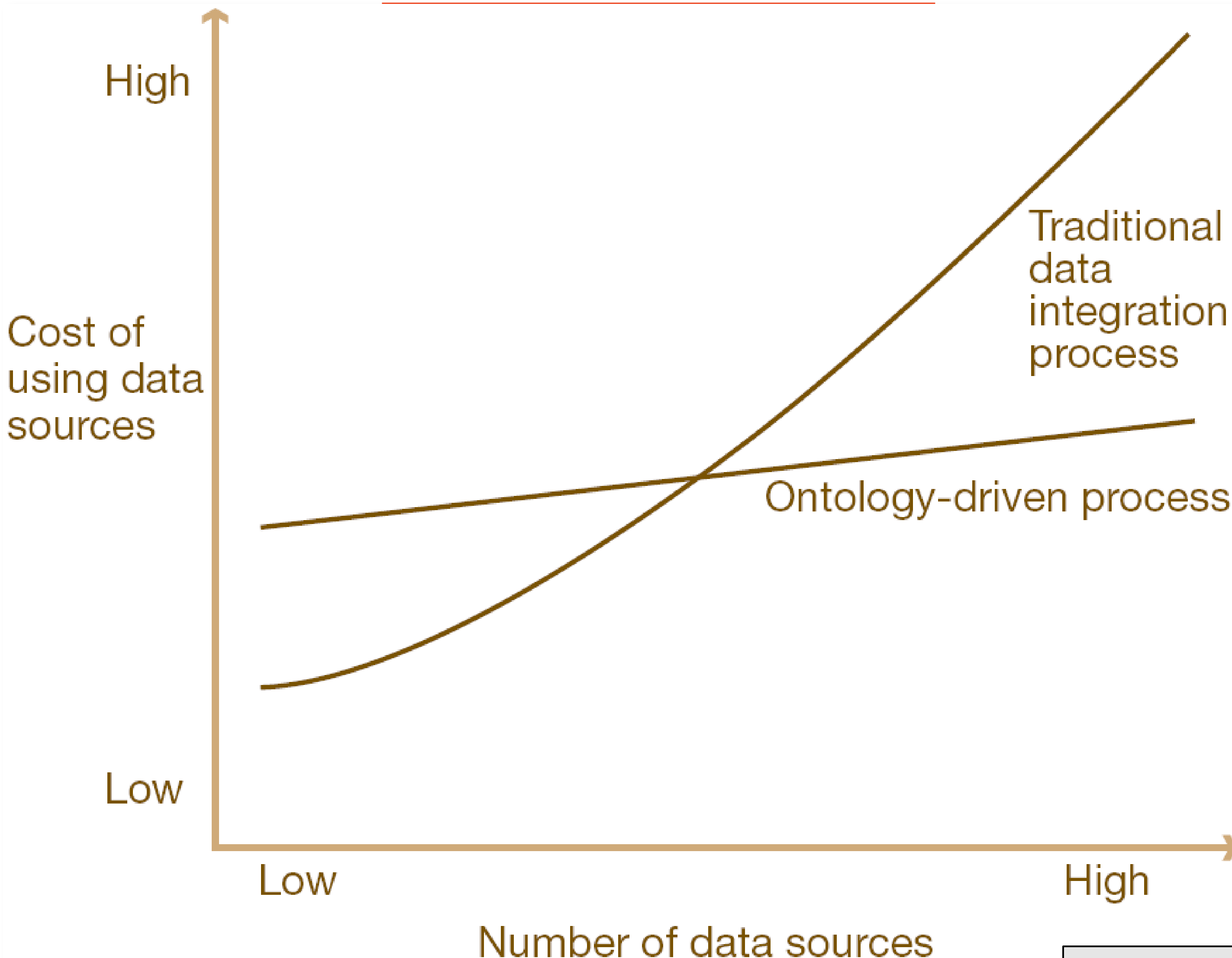
(c) HCLS @ W3C

Data integration & querying (HCLS)



(c) HCLS @ W3C

Data integration cost (PwC)



(c) PriceWaterhouseCooper

Semantic Technologies & Triplestores for BI

- Speed-up data integration
  - RDF based ETL is more agile
- Lower the cost of data integration
  - Initial cost of using ontologies is higher
  - But the cost of ad-hoc ETL will be higher in the long term (too many data sources)
- Align & integrate legacy data silos
  - Querying & consuming data from disparate sources is easier with SPARQL

Semantic Technologies & Triplestores for BI (2)

- Infer implicit & hidden knowledge
  - Custom, user-defined rules as well
- Efficiently manage unstructured & semi-structured data together
  - graph data model
- Improve the quality of query results
  - Inference of implicit facts
  - SPARQL query vocabulary may differ from data vocabulary
  - Exploratory queries

Q & A

Questions?

twitter @ontotext