Reasoning on Web Data Semantics

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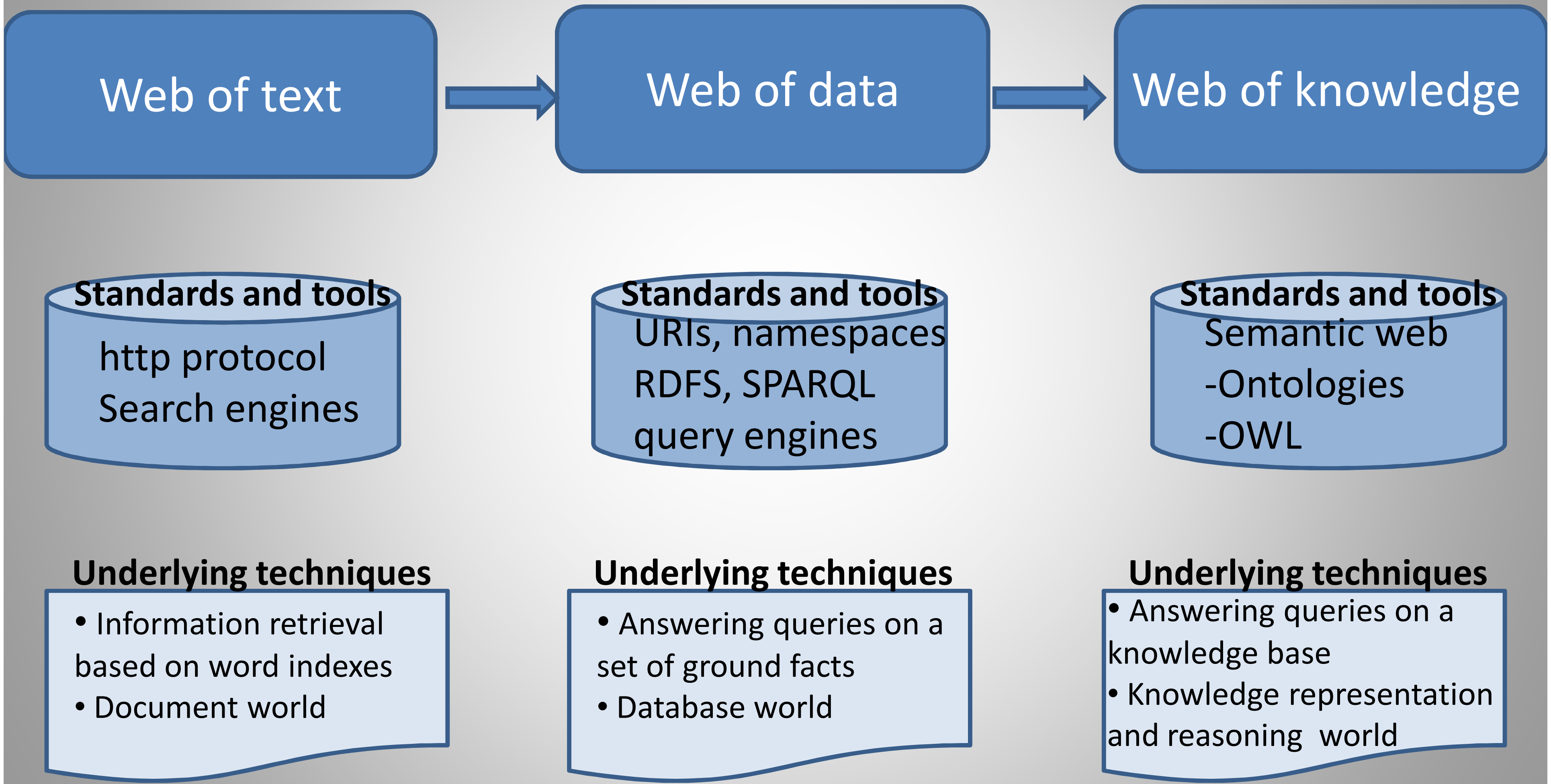
Evolution of the Web



Evolution of the Web

Current web

Web of text

Billions of web pages

→

Is emerging

Web of data

YAGO, DBPedia, Linked Data
Billions of RDF triples

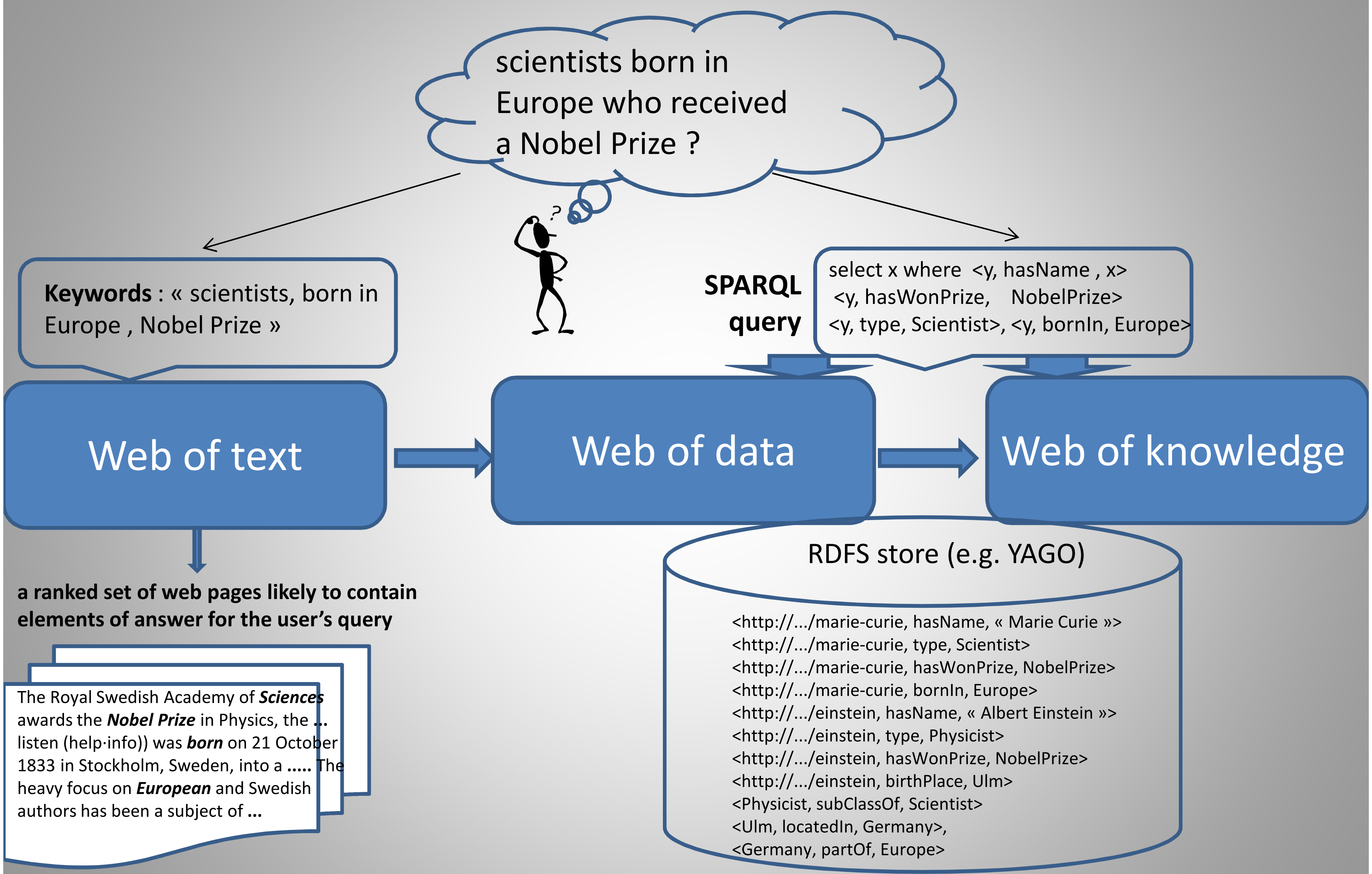
→

Very next step

Web of knowledge

a flourishing of ontologies and of algorithms for ontology-based data access

Main differences illustrated by example



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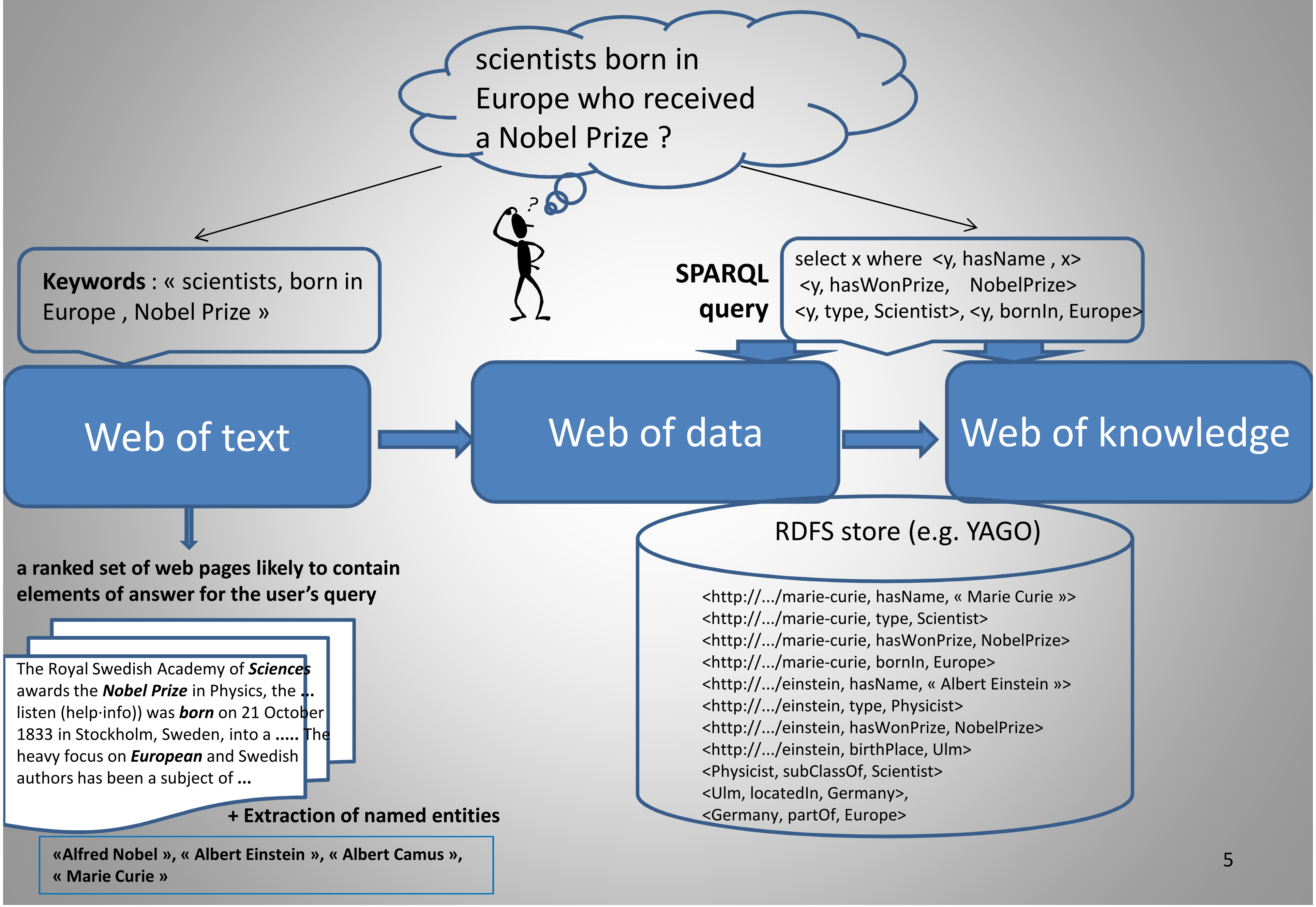

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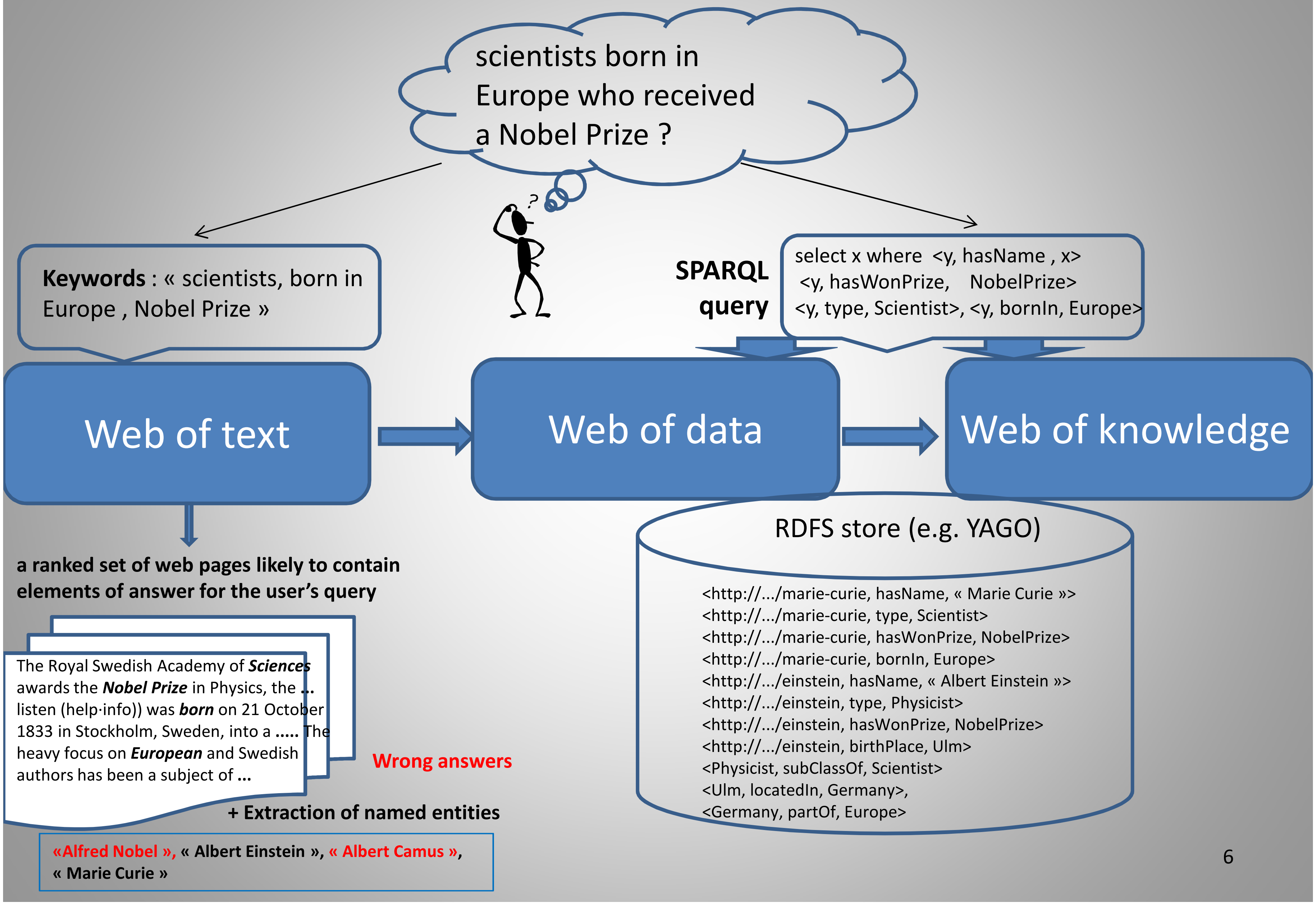

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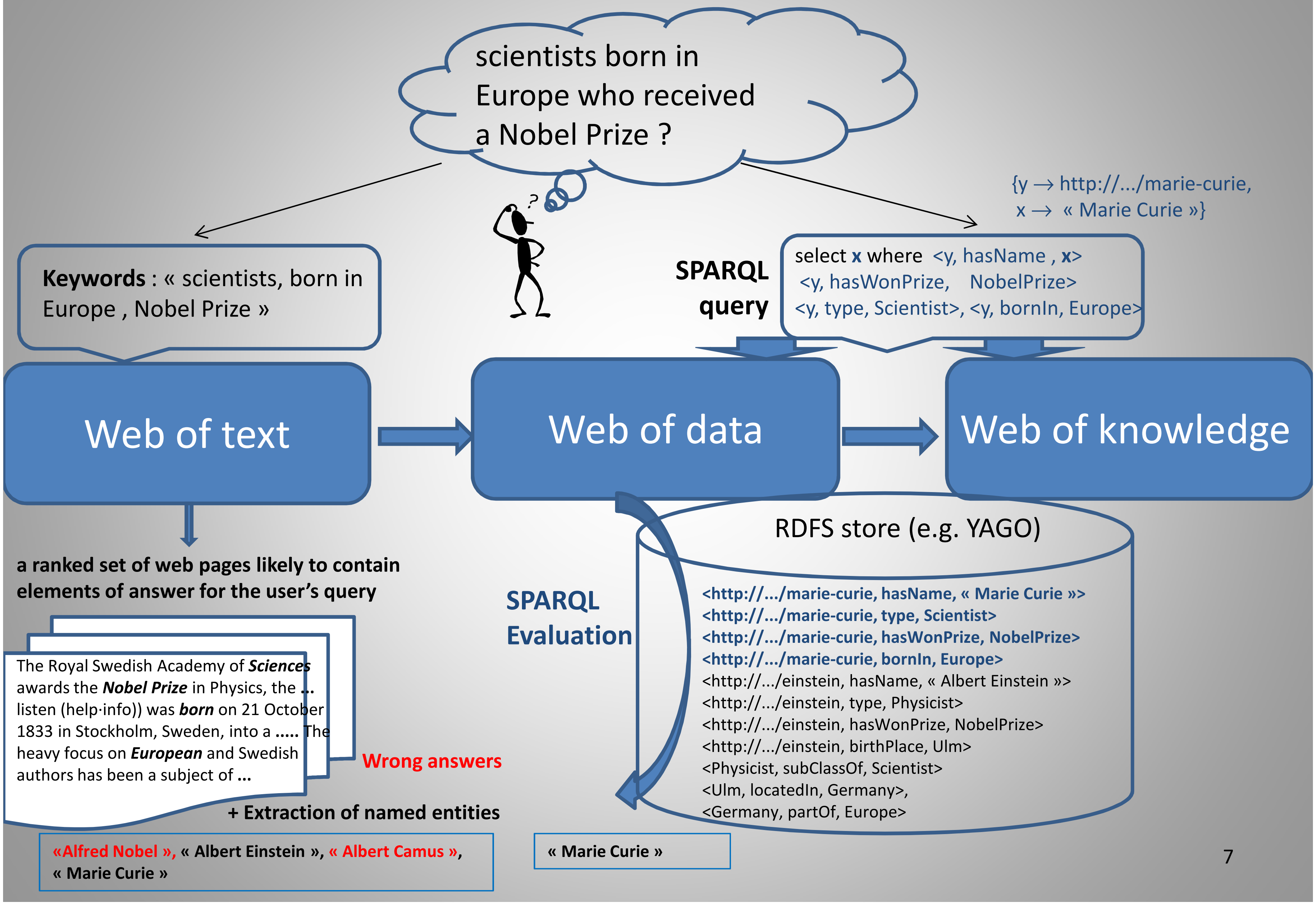

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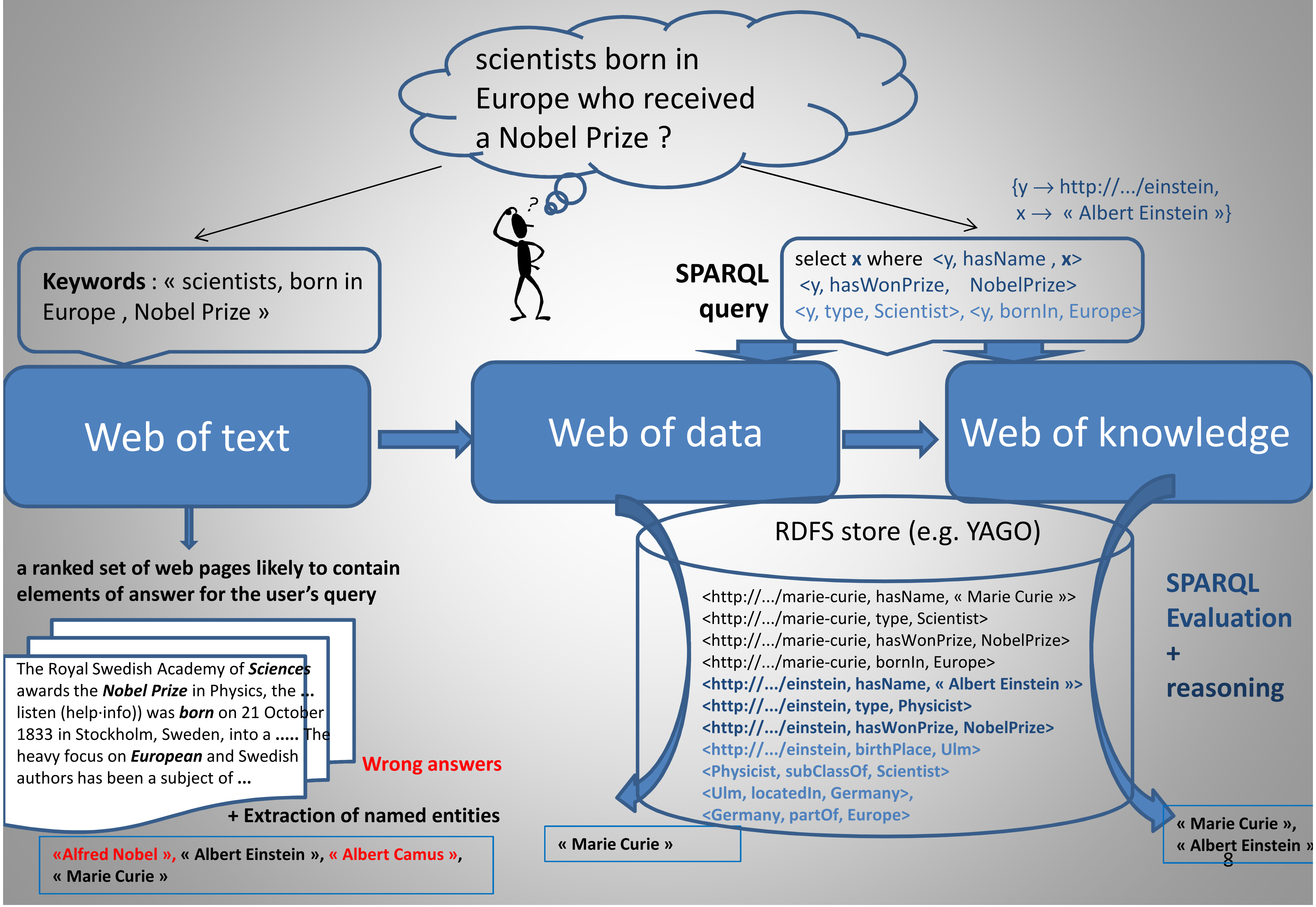
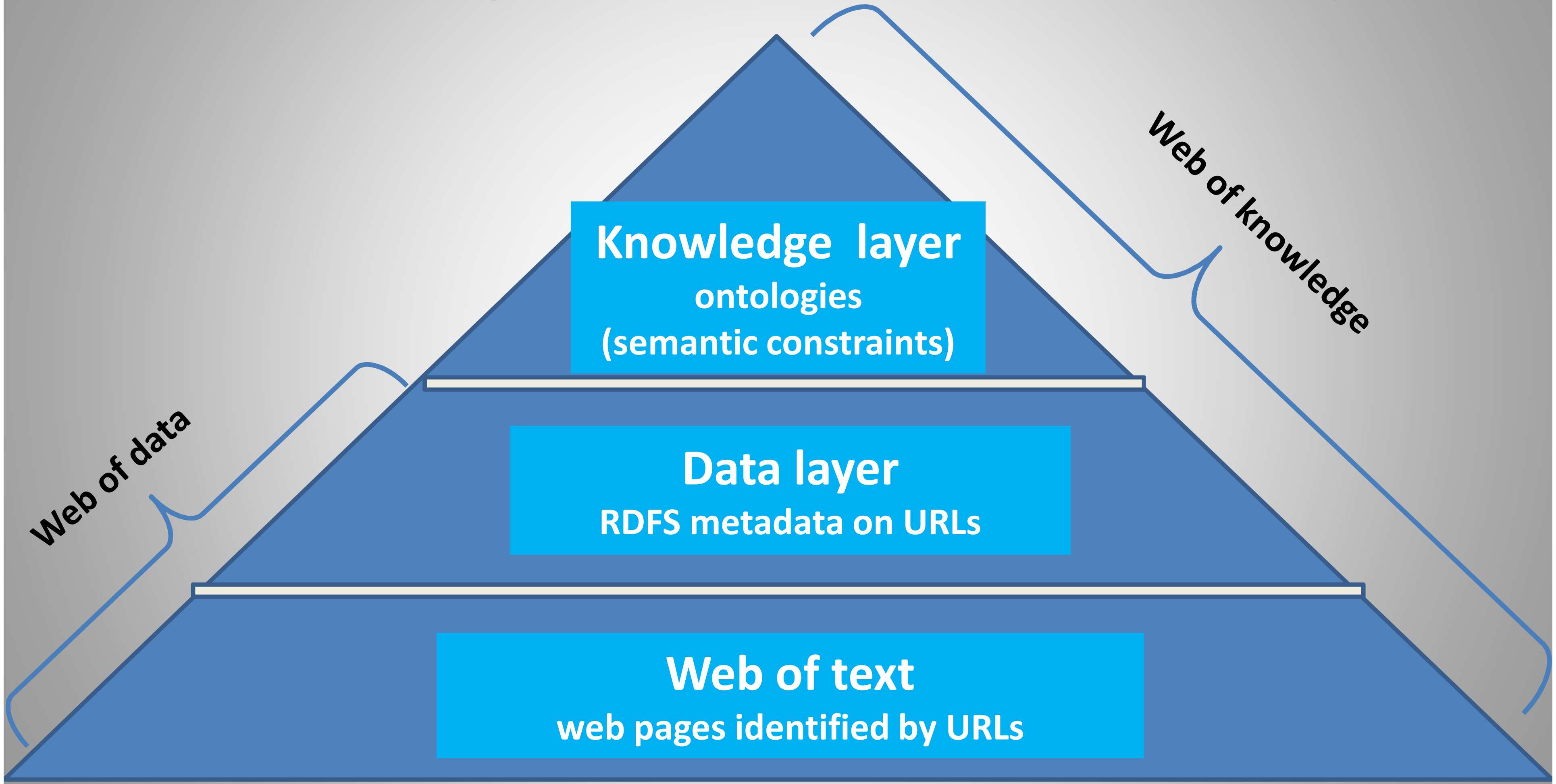


The real picture

The web is evolving from a web of text to a web of knowledge in a coherent and a smooth way



Lesson learnt from the example

- Answering queries over the web of knowledge requires **reasoning**
  - Ontological statements can be used to infer new facts and deduce answers that could not be obtained otherwise
  - They are constraints used as deductive rules that infer new facts
  - Subtlety: some inferred facts can be partially known

From the constraint “a professor teaches at least one master course”

$$\forall x\ (\mathbf{Professor(x) \Rightarrow \exists\ y\ Teaches(x,y),\ MasterCourse(y)})$$

and the fact:

Professor(dupond) (RDF syntax: **<dupond, type, Professor>**)

it can be inferred the two following incomplete “facts” :

Teaches(dupond, v) , MasterCourse(v)

i.e, in RDF notation, two RDF triples with blank nodes:

<dupond, Teaches, _v> , <_v, type, MasterCourse>

Finding inconsistent information on the Web

- **Reasoning**: a tool for checking consistency
  - Some ontological statements can be used as **integrity** constraints

    "a professor cannot be a lecturer" ; "a course must have a responsible"

    $\forall$x (Professor(x) => ¬ Lecturer(x))

    $\forall$x (Course(x) => $\exists$ y ResponsibleFor(y,x))

    "a master course is taught by a single teacher"

    "only professors can be responsible of the courses they have to teach"

    $\forall$x $\forall$y (Course(x), ResponsibleFor(y,x) => Professor(y), Teaches(y,x))
  - Subtlety: showing data inconsistency may require **intricate reasoning** on different rules, constraints and facts

    The facts: **Lecturer (jim), Teaches(jim, ue431) , MasterCourse(ue431)**

    + the above integrity constraints

    + the rule **$\forall$x (MasterCourse(x) => Course(x))** leads to an inconsistency

Automatic Reasoning

- Not a novel problem
  - Many decidability and complexity results coming from decades of research in the KR&R community
  - Several inference algorithms and implemented reasoners
- The key point
  - first-order-logic is appropriate for knowledge representation
  - but **full first-order-logic is not decidable**

    no general algorithm that, applied to two any FOL formula, determines whether the first one implies the second one

$\Rightarrow$ the game is to find restrictions to design:

- decidable fragments of first-order-logic
- expressive enough for modeling useful knowledge or constraints

Description Logics

- A family of class-based logical languages for which reasoning is decidable
  - Provides algorithms for reasoning on (possibly complex) logical constraints over unary and binary predicates
- This is exactly what is needed for handling ontologies
  - in fact, the OWL constructs come from Description Logics
- A fine-grained analysis of computational complexity with surprising complexity results
  - $\mathcal{ALC}$ is EXPTIME–complete

=>any sound and complete inference algorithm for reasoning on most of the subsets of constraints expressible in OWL may take an exponential time (in the worst-case)

"only professors or lecturers may teach to undergraduate students"

$\forall$x $\forall$y (TeachesTo(x,y), UndergraduateStudent(y) => Professor(x) $\vee$ Lecturer(x))

$$\exists TeachesTo.UndergraduateStudent \sqsubseteq Professor \sqcup Lecturer$$

The same game again…

- Find restrictions on the logical constructs and/or the allowed axioms in order to:
  - design sublanguages for which reasoning is in P

    EL, **DL-Lite**
  - expressive enough for modeling useful constraints over data
- **DL-Lite: a good trade-off**
  - captures the main constraints used in databases and in software engineering
  - extends **RDFS** (the formal basis of OWL2 QL profile)
  - specially designed for answering queries over ontologies to be **FOL-reducible**

FOL-reducibility

Query answering and data consistency checking can be performed in two separate steps:

- a **query reformulation step**
  - reasoning on the ontology (and the queries)
  - independent of the data

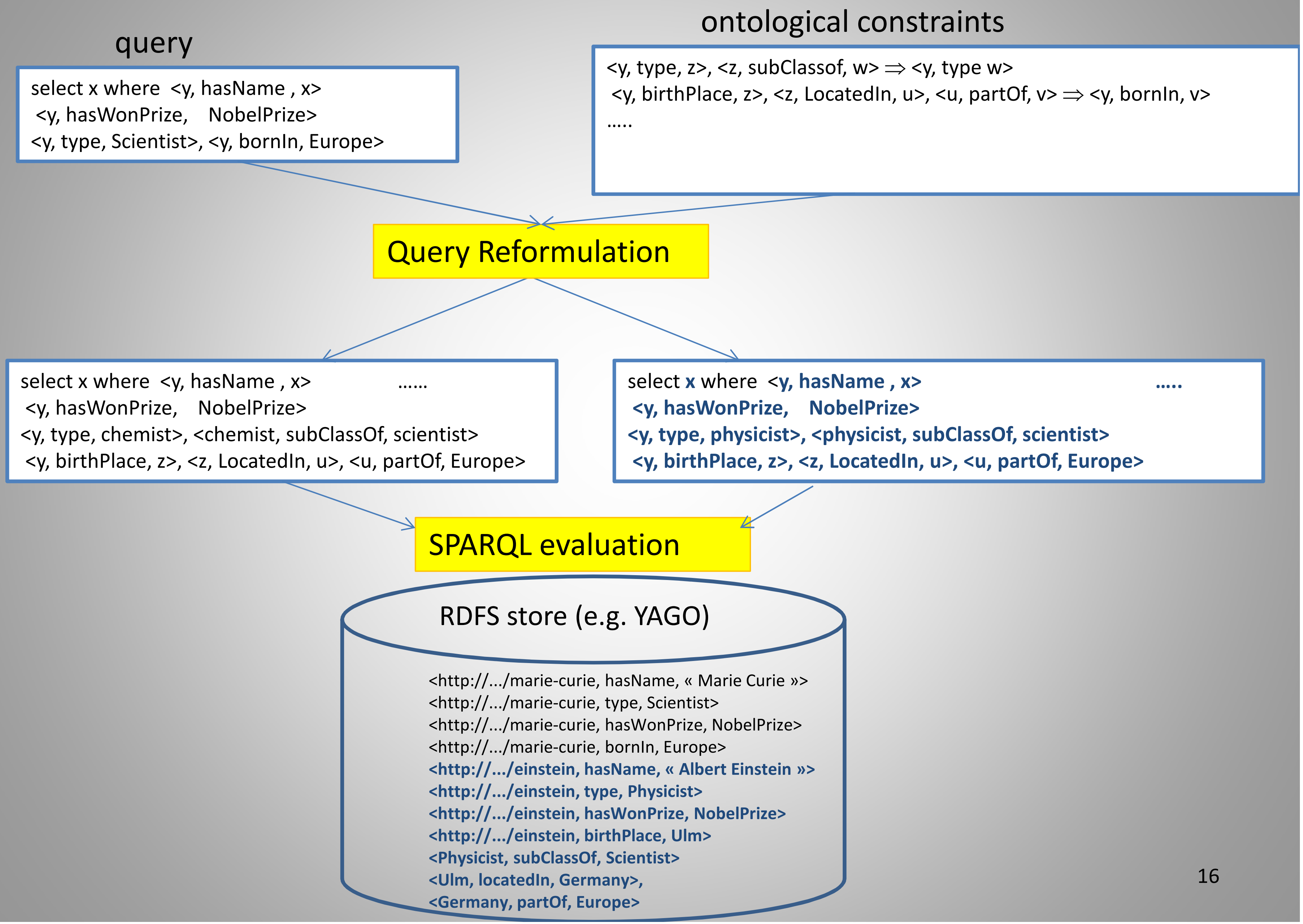
$\Rightarrow$ a set a queries: the reformulations of the input query

- an **evaluation step**
  - of the (SPARQL) query reformulations on the (RDF) data
  - independent of the ontology

$\Rightarrow$ Main advantage

- makes possible to use an SQL or SPARQL engine
- thus taking advantage of well-established query optimization strategies supported by standard relational DBMS

Illustration



DL-Lite by example

Professor $\sqsubseteq \exists$ Teaches

$\forall x\ (\text{Professor}(x) \Rightarrow \exists y\ \text{Teaches}(x,y))$

$\exists$ Teaches^{-} $\sqsubseteq$ Course

$\forall x \forall y\ (\ \text{Teaches}(x,y) \Rightarrow \text{Course}(y))$

ResponsibleFor $\sqsubseteq$ Teaches

$\forall x \forall y\ (\ \text{ResponsibleFor}(x,y) \Rightarrow \text{Teaches}(x,y))$

(funct ResponsableFor^{-})

$\forall x \forall y \forall z (\text{ResponsibleFor}(y,x) \wedge \text{ResponsibleFor}(z,x) \Rightarrow y=z)$

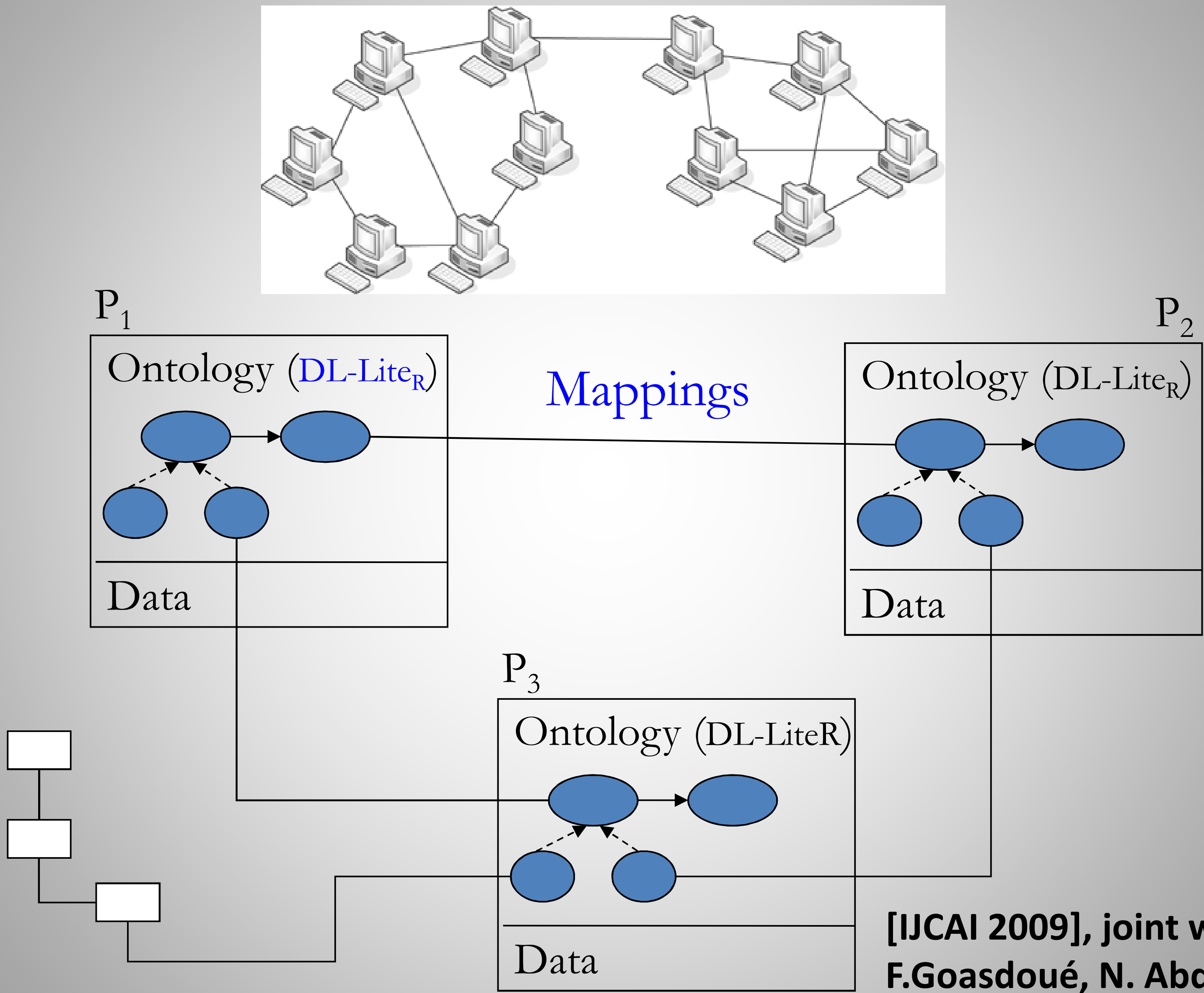
Lecturer $\sqsubseteq \neg$ ($\exists$ResponsibleFor)

$\forall x\ \forall y\ (\text{Lecturer}(x) \wedge \text{ResponsibleFor}(x,y) \Rightarrow \bot)$

DL-Lite: a frontier for FOL reducibility

- The reasoning step is polynomial in the size of the ontology
- The evaluation step has the same data complexity as standard evaluation of conjunctive queries over relational databases
  - in AC_0 (strictly contained in LogSpace and thus in P)
- The interaction between relation inclusion constraints and functionality constraints makes reasoning in DL-Lite P-complete in data complexity
  - **DL-Lite$_A$ is FOL-reducible**
  - **full DL-Lite is not FOL-reducible**
    - reformulating a query may require recursion (Datalog)

Decentralized ontology-based data access



[IJCAI 2009], joint work with F.Goasdoué, N. Abdallah

Conclusion

- The scalability of reasoning on Web data requires light-weight ontologies
- RDFS is not expressive enough to express useful constraints
- Forget about (most of fragments) of OWL

$\Rightarrow$extend RDFS with constraints expressible in a logic for which data management is FOL reducible

  - **DL-Lite$_A$** is an example of such a logic
  - (some fragments of) **Datalog^{+-}** too

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