Temporalizing Ontology-Based Data Access

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DRESDEN concept

DFG Deutsche Forschungsgemeinschaft

HAEC

Goal

Achieve higher-level Situation Awareness

Projection — Projecting how events may evolve over time, guess future behaviour

↑

Comprehension — Higher-level composite view of situation, at semantic level of human comprehension

forrest

↑

Perception — Sensors, Radar, Pictures, Videos, Eyewitness reports by humans

lots of trees

[Endsley; 1995]

Levels of Situation Awareness

Projection — danger of myocardial infarction

↑

Comprehension — medical ontology, patient record; hypertension, history of hypertension

↑

Perception — systolic pressure is high, red face

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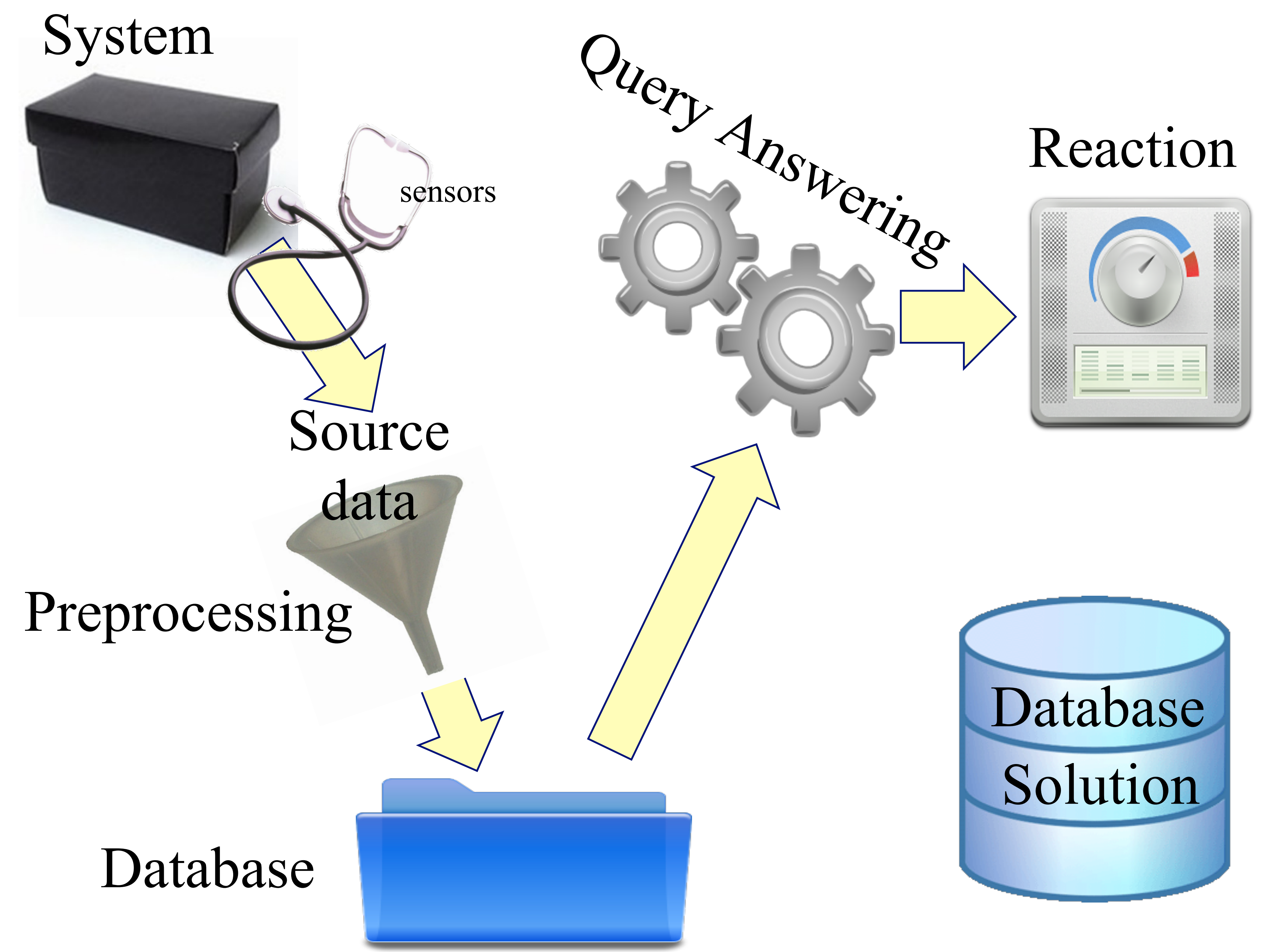

System
sensors
Query Answering
Reaction
Source data
Preprocessing
Database
Database Solution

Conjunctive queries

important subclass of SQL queries:
select-project-join queries

A conjunctive query (CQ)

is an existentially quantified conjunction of atoms:

$$\exists y.\mathit{Male}(x) \land \mathit{history}(x,y) \land \mathit{Hypertension}(y)$$

Complexity of CQs:
deciding whether there is an answer tuple is

- NP-complete w.r.t. combined complexity.
- In AC^0 w.r.t. data complexity.

complexity measured w.r.t. size of data and query

complexity measured w.r.t. size of data only

$$\mathrm{AC}^0 \subset \mathrm{LogSpace} \subseteq \mathrm{P}$$

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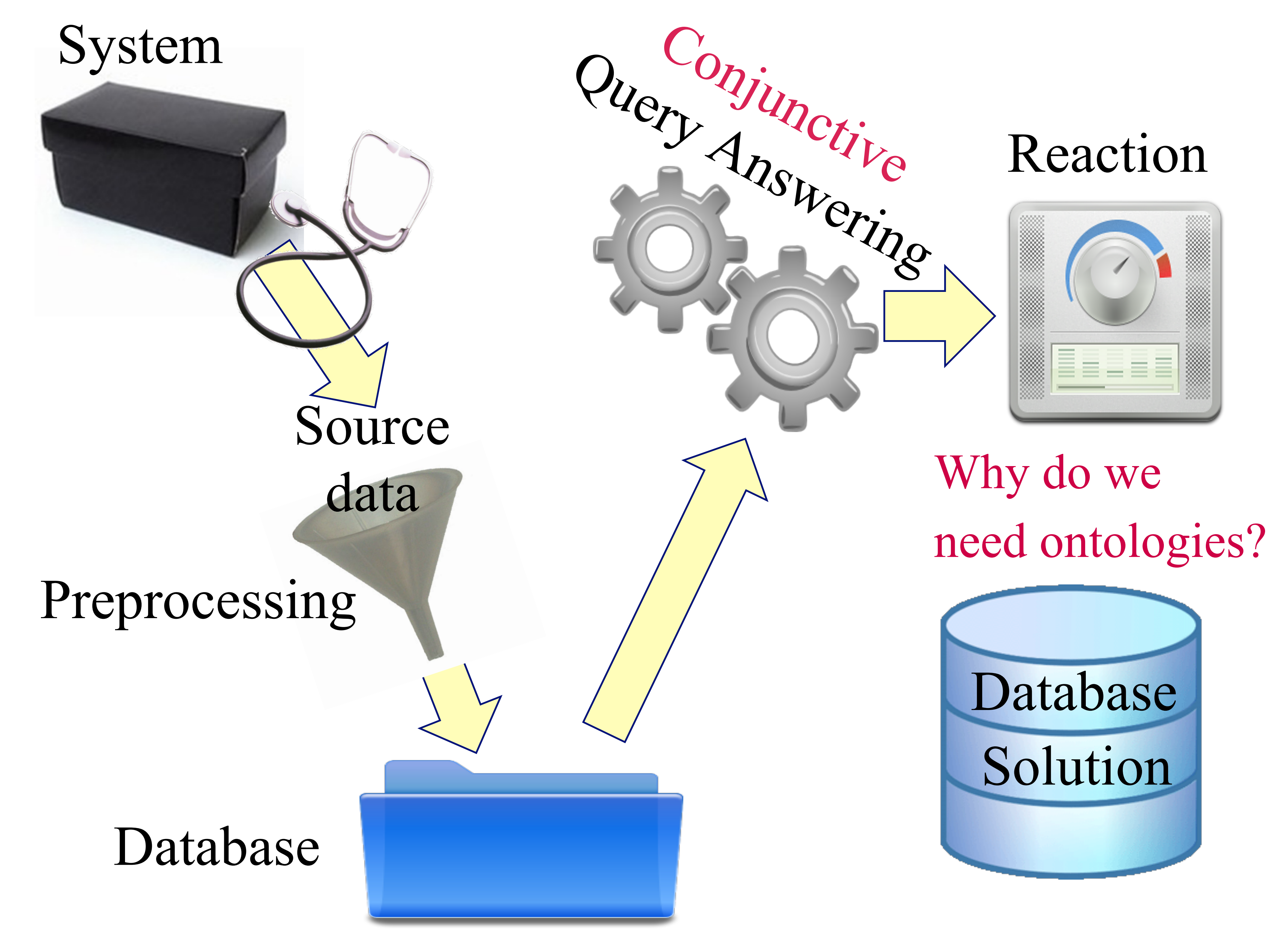
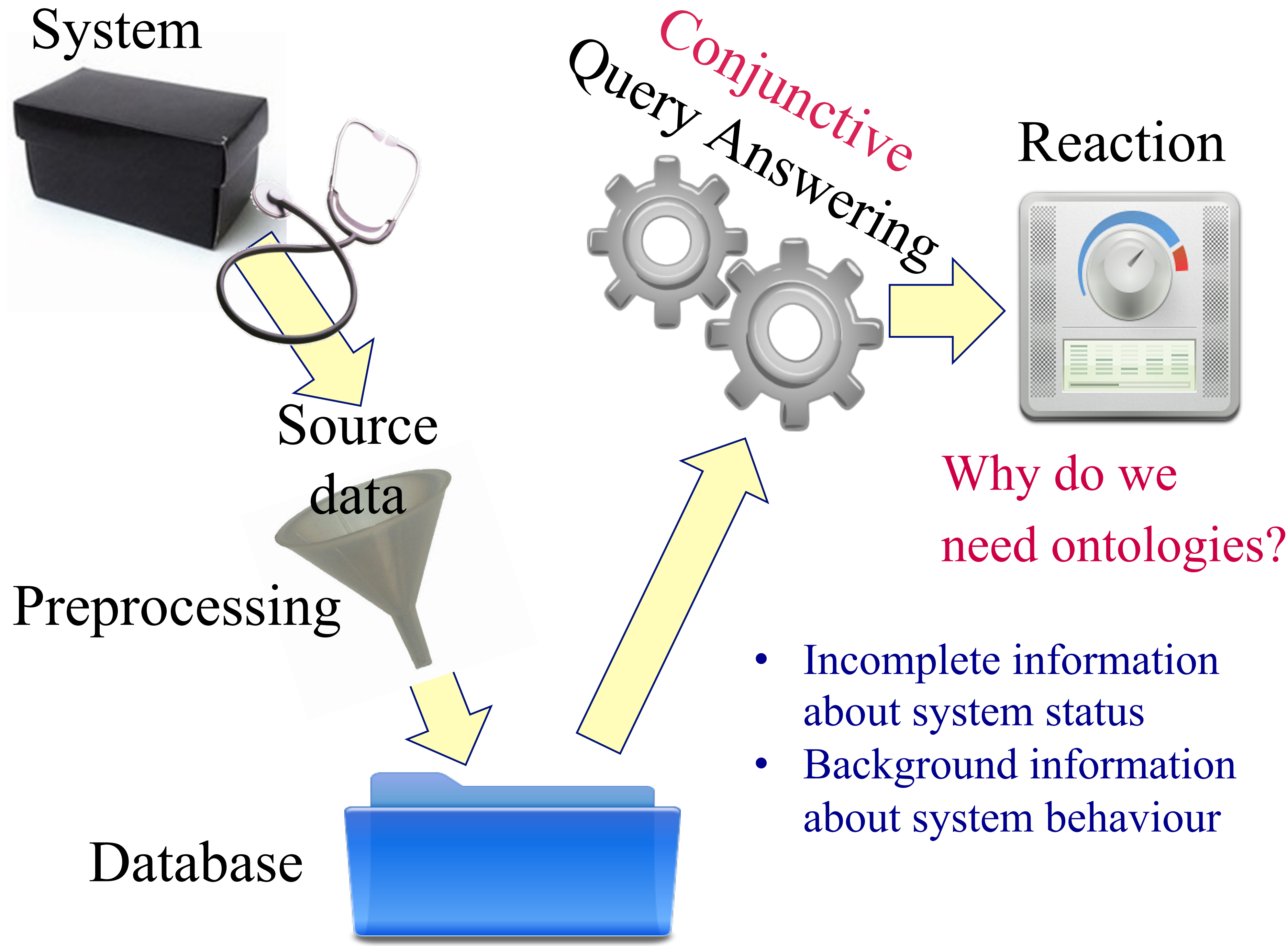
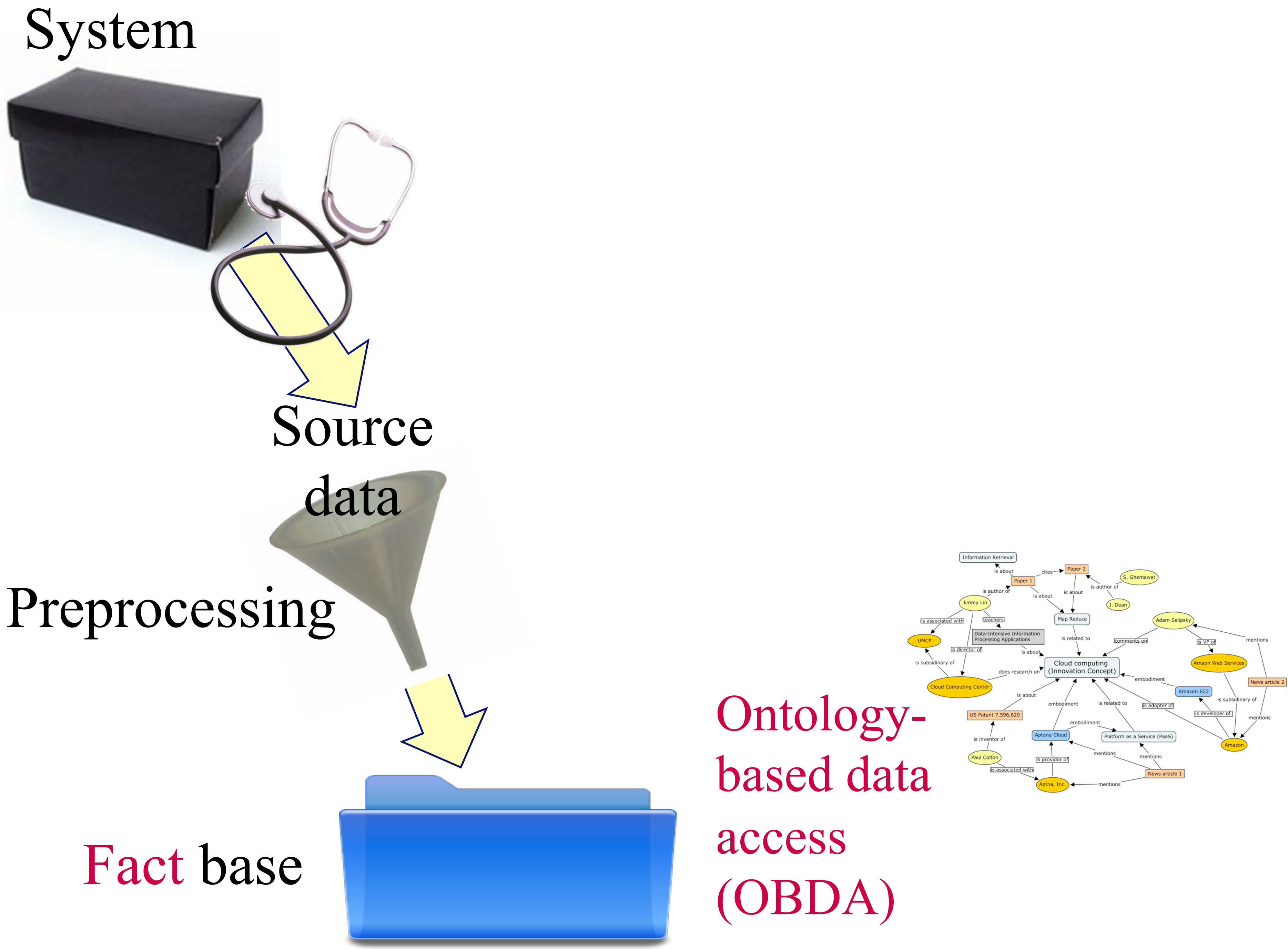
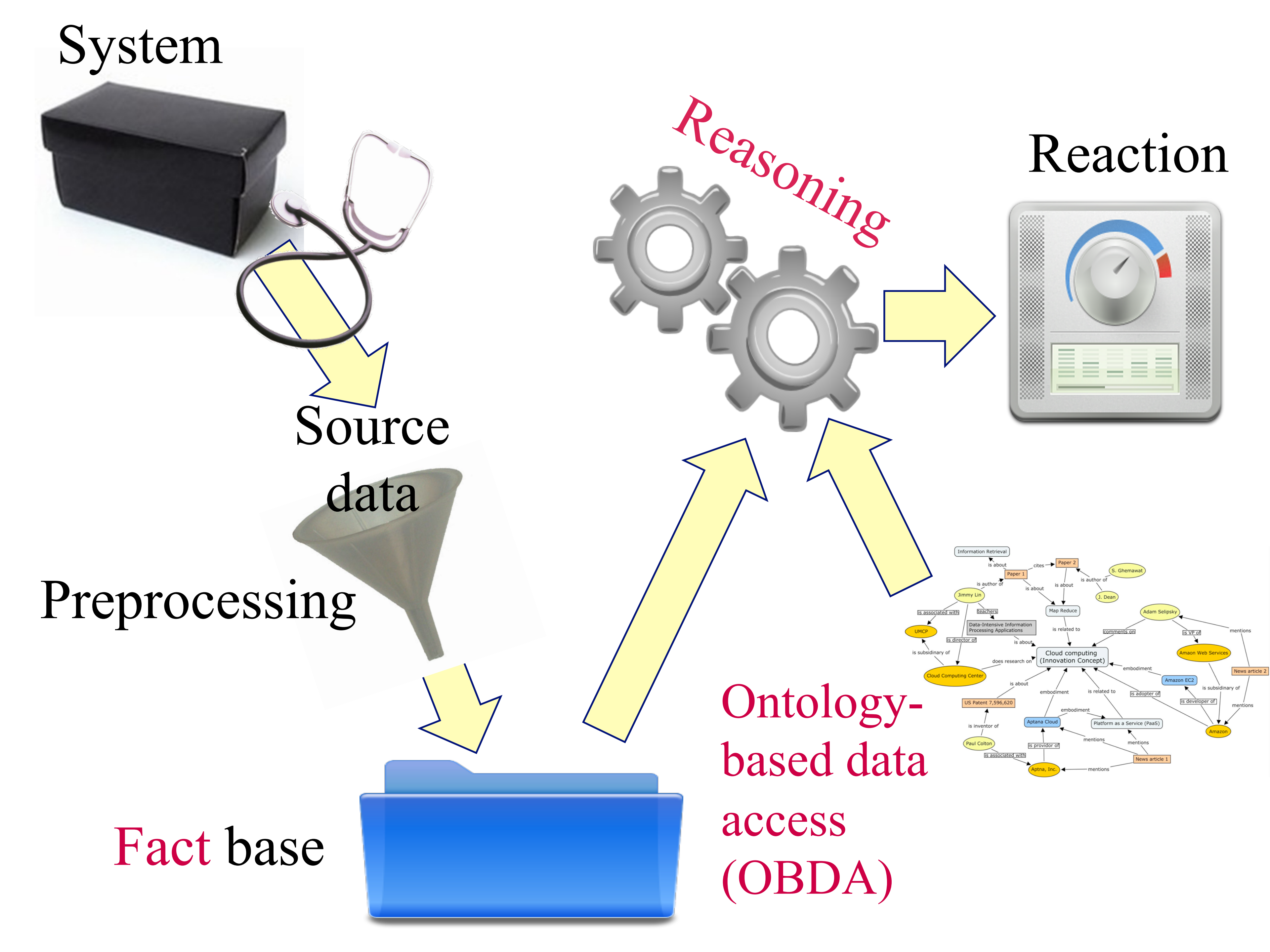

System
Conjunctive
Query Answering
Reaction
Source
data
Preprocessing
Why do we
need ontologies?
Database
Solution
Database


System
Conjunctive
Query Answering
Reaction
Source
data
Preprocessing
Database
Why do we
need ontologies?
• Incomplete information about system status
• Background information about system behaviour


System
Source data
Preprocessing
Fact base
Ontology-based data access (OBDA)



System
Reasoning
Reaction
Source data
Preprocessing
Fact base
Ontology-based data access (OBDA)
Information Retrieval
Paper 1
Paper 2
S. Ghemawat
J. Dean
Jimmy Lin
Map Reduce
UMCP
Data-Intensive Information Processing Applications
Adam Selipsky
Cloud computing (Innovation Concept)
Amaon Web Services
Cloud Computing Center
Amazon EC2
News article 2
US Patent 7,596,620
Aptana Cloud
Platform as a Service (PaaS)
Amazon
Paul Colton
News article 1
Aptna, Inc.

Ontology-based data access

Generalizes answering queries over databases in two directions:

- Presence of an ontology $\mathcal{O}$:
  predicates used in the queries are constrained by ontology axioms

- Incompleteness:
  Queries evaluated over a fact base $\mathcal{A}$ rather than a database
  (no closed-word assumption)

We want to compute certain answers of $\phi(x_1, \ldots, x_n)$ over $\mathcal{A}$ w.r.t. $\mathcal{O}$:

- a tuple $(a_1, \ldots, a_n)$ of individuals occurring in $\mathcal{A}$ such that
- $(a_1, \ldots, a_n)$ is an answer tuple of $\phi(x_1, \ldots, x_n)$ w.r.t. $\mathcal{D}$
- for all databases $\mathcal{D}$ that satisfy the axioms in $\mathcal{O}$ and the facts in $\mathcal{A}$.

Ontology-based data access

$\mathcal{O}$

$$\exists \textit{systolic\_pressure}.\textit{High\_pressure} \sqsubseteq \exists \textit{finding}.\textit{Hypertension}$$

$$\exists \textit{finding}.\textit{Hypertension} \sqcap \exists \textit{history}.\textit{Hypertension} \sqsubseteq \exists \textit{risk}.\textit{Myocardial\_infarction}$$

$\mathcal{A}$

$$\textit{systolic\_pressure}(\textit{BOB}, \textit{P1})$$
$$\textit{High\_pressure}(\textit{P1})$$
$$\textit{history}(\textit{BOB}, \textit{H1})$$
$$\textit{Hypertension}(\textit{H1})$$
$$\textit{Male}(\textit{BOB})$$

$$\exists y.\textit{Male}(x) \wedge \textit{risk}(x, y) \wedge \textit{Myocardial\_infarction}(y)$$

BOB is a certain answer of this query over $\mathcal{A}$ w.r.t. $\mathcal{O}$.

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Ontology-based data access

Investigated in detail for the case where:

- the ontology is expressed using an appropriate description logic,
- the query is a conjunctive query.

For the expressive DL $\mathcal{ALC}$, deciding whether there is a certain answer is

- ExpTime-complete w.r.t. combined complexity.
- coNP-complete w.r.t. data complexity.

For the inexpressive DLs of the DL-Lite family, deciding whether there is a certain answer is

- NP-complete w.r.t. combined complexity.
- in AC^0 w.r.t. data complexity.

Ontology-based data access

Why temporalize OBDA?

To recognize certain situations, we need to consider the system status at different points in time.

> Example: recognize "history of hypertension" instead of assuming that it is directly stated in the patient record.

Set-up considered in this talk:

- instead of a single fact base consider a finite sequence of fact bases
- background knowledge is encoded in a global $\mathcal{ALC}$- or DL-Lite-ontology
- temporalized conjunctive queries obtained from propositional linear temporal logic (LTL) by replacing propositional variables by conjunctive queries

Ontology-based data access

temporalized OBDA

To recognize certain situations, we need to consider the system status at different points in time.

Example: recognize "history of hypertension" instead of assuming that it is directly stated in the patient record.

$$\underbrace{\mathit{Male}(x)}_{p} \wedge \bigcirc^{-}\Diamond^{-} \underbrace{(\exists y.\mathit{finding}(x,y) \wedge \mathit{Hypertension}(y))}_{q}$$

TCQ

$$p \wedge \bigcirc^{-}\Diamond^{-} q$$

- temporalized conjunctive queries obtained from propositional linear temporal logic (LTL) by replacing propositional variables by conjunctive queries

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Ontology-based data access

temporalized OBDA

To recognize certain situations, we need to consider the system status at different points in time.

> Example: recognize "history of hypertension" instead of assuming that it is directly stated in the patient record.

$$\underbrace{\mathit{Male}(x)}_{p} \wedge \bigcirc^{-}\Diamond^{-} \underbrace{(\exists y.\mathit{finding}(x,y) \wedge \mathit{Hypertension}(y))}_{q} \qquad \text{TCQ}$$

$$p \wedge \bigcirc^{-}\Diamond^{-} q$$

Rigid versus flexible concepts and roles:

- flexible symbols can change their interpretations over time,
- whereas rigid ones cannot.

Temporalized OBDA

our results for $\mathcal{ALC}$

Complexity of TCQ entailment: is a given tuple a certain answer for a given TCQ w.r.t. a sequence of fact bases and a global $\mathcal{ALC}$-ontology?

Combined complexity of TCQ entailment w.r.t. $\mathcal{ALC}$-ontology

- ExpTime-complete without rigid symbols
- co-NExpTime-complete w.r.t. rigid concepts
- 2-ExpTime-complete w.r.t. rigid concepts and roles

same as without temporal operators

Data complexity of TCQ entailment w.r.t. $\mathcal{ALC}$-ontology

- coNP-complete without rigid symbols
- coNP-complete w.r.t. rigid concepts
- co-NP-hard / in EXPTIME w.r.t. rigid concepts and roles

same as without temporal operators

Temporalized OBDA

How to show the results?

Hardness results:

- Data complexity: reduction from the atemporal case
- Combined complexity: reduction from unsatisfiability in $\mathcal{ALC}$-LTL [B., Ghilardi, Lutz; 2008]

Upper bounds: adapt satisfiability algorithms for $\mathcal{ALC}$-LTL.
Split problem into

- satisfiability problem for propositional LTL,
- entailment problem for atemporal conjunctive queries w.r.t. $\mathcal{ALC}$-ontologies.

More effort needed to deal with CQs instead of $\mathcal{ALC}$-axioms in LTL formula and to get tight data complexity results.

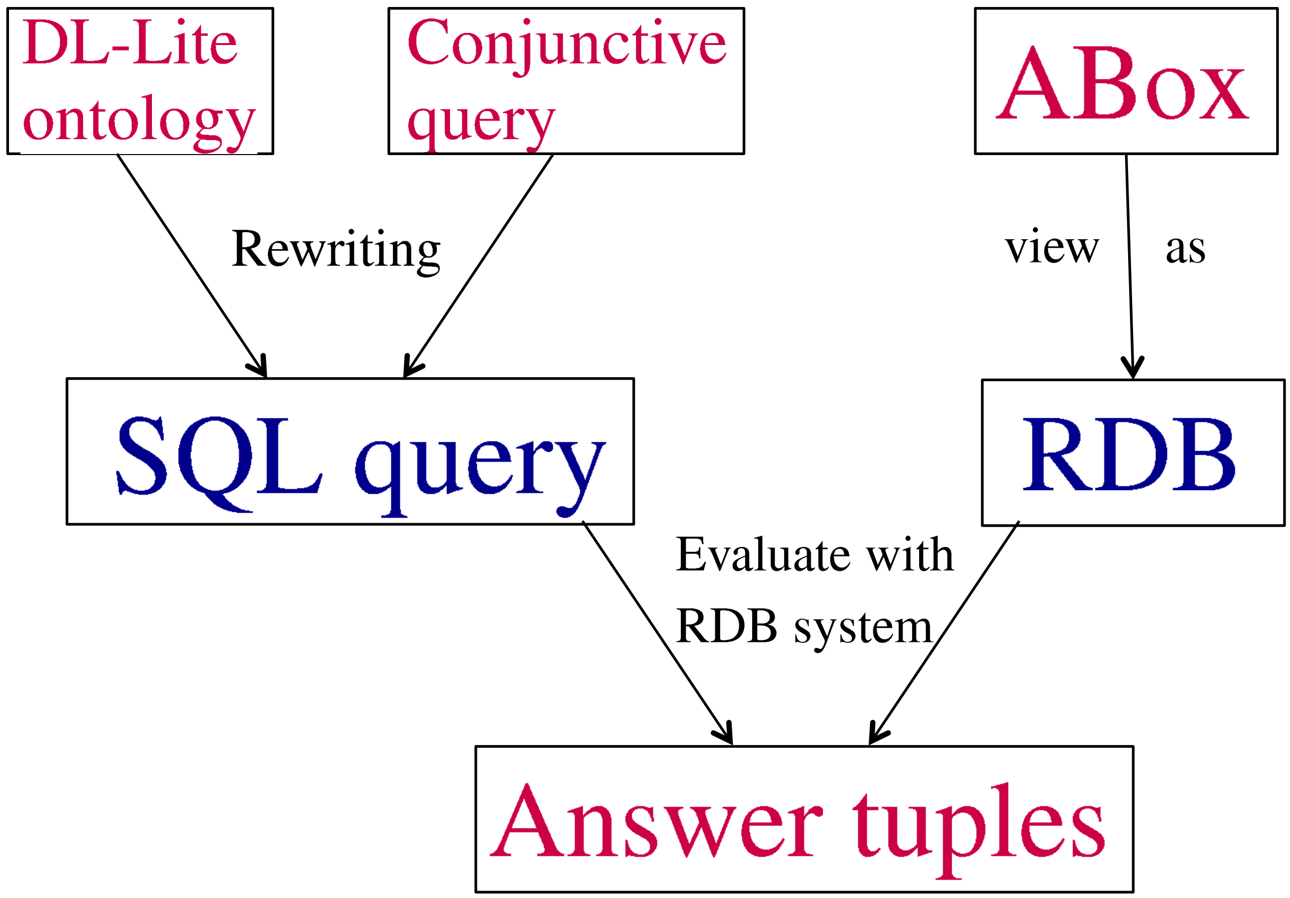
Temporalized OBDA

our results for DL-Lite

Show that the query rewriting approach for DL-Lite also works in the temporal case if the TCQs are negation free.

Query rewriting

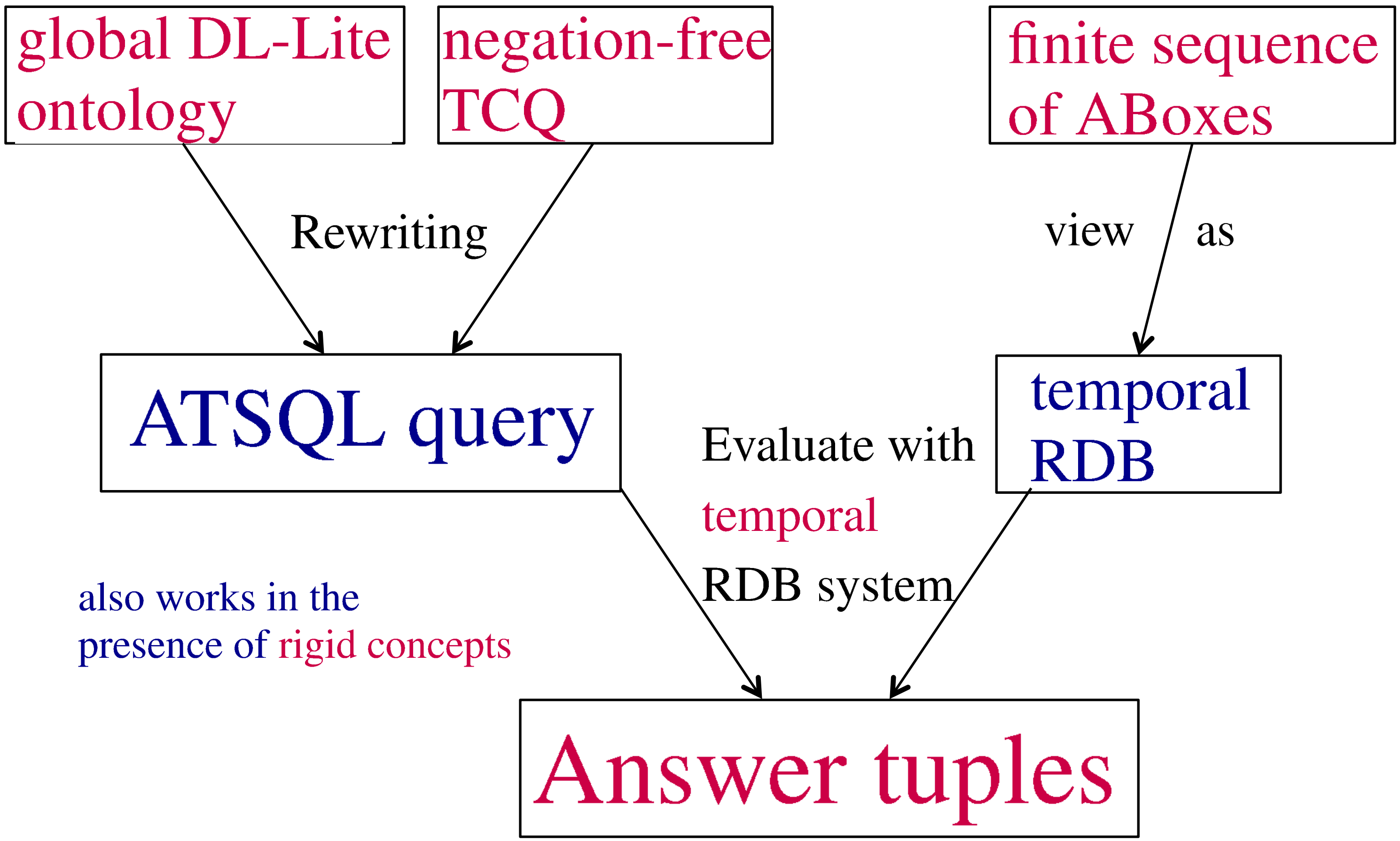
the atemporal case



Temporalized OBDA

our results for DL-Lite

Show that the query rewriting approach for DL-Lite also works in the temporal case if the TCQs are negation free.



also works in the presence of rigid concepts

Conclusion

Our results for $\mathcal{ALC}$ show:

- without rigid symbols, the complexity does not increase
- rigid symbols may increase the combined complexity, but enable a limited projection into the future

For DL-Lite, the rewriting approach works if

- TCQs do not contain negation
- only rigid concepts are allowed

Future work:

- for $\mathcal{ALC}$, close gap for data complexity for rigid concepts and roles
- for DL-Lite, investigate TCQs with negation and the case of rigid roles

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References

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Stefan Borgwardt, Marcel Lippmann, and Veronika Thost:

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In Proceedings of the 9th International Symposium on Frontiers of Combining Systems (FroCoS 2013), volume 8152 of Lecture Notes in Computer Science. Nancy, France, Springer-Verlag, 2013.