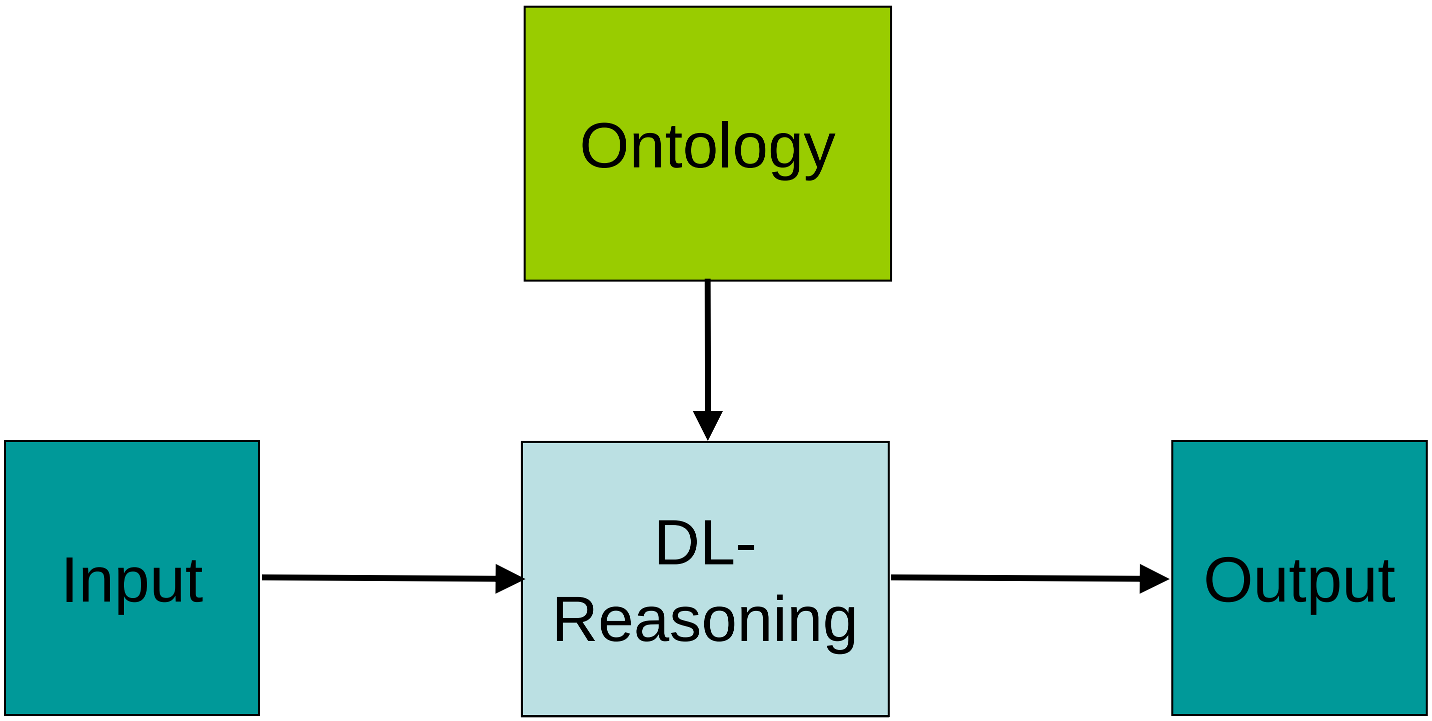
Approximation for the Semantic Web

The KnowledgeWeb point of view

Holger Wache
Vrije Universiteit Amsterdam

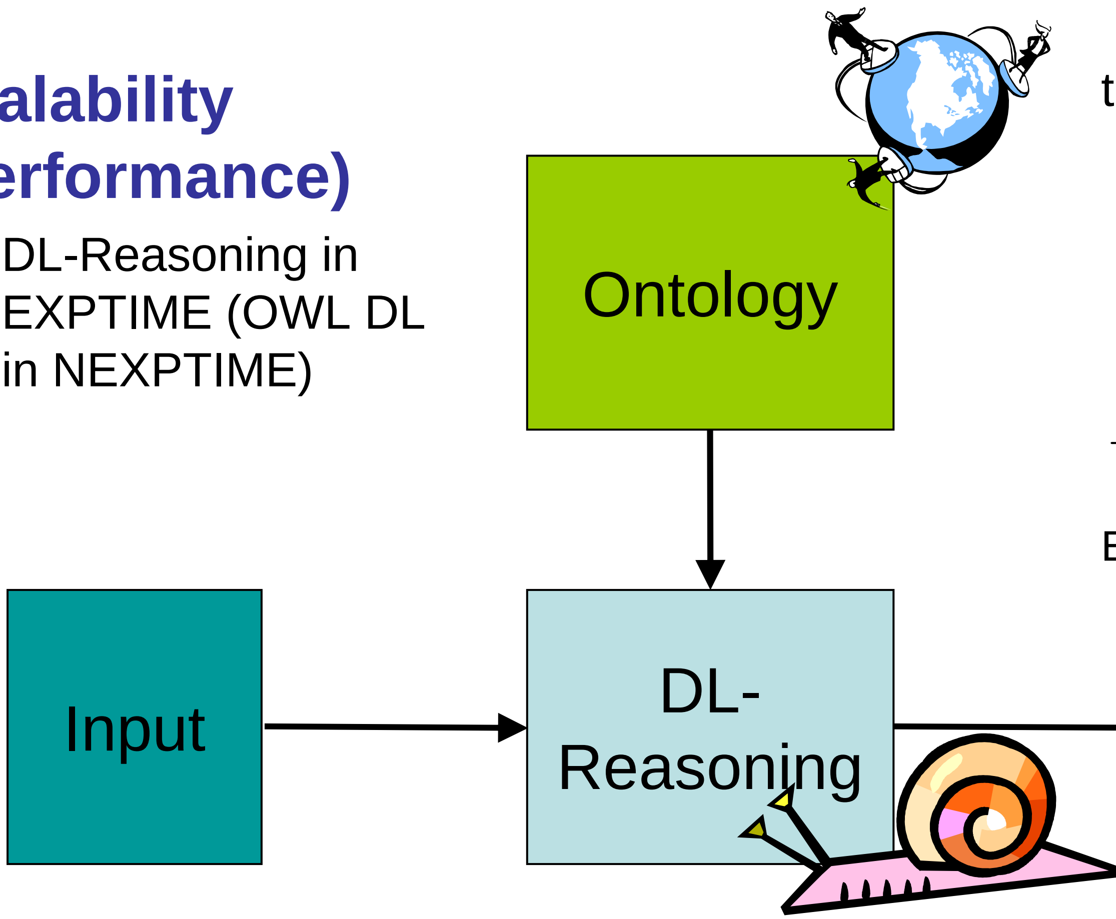
KMI Podium,
Milton Keynes, May 5th 2006

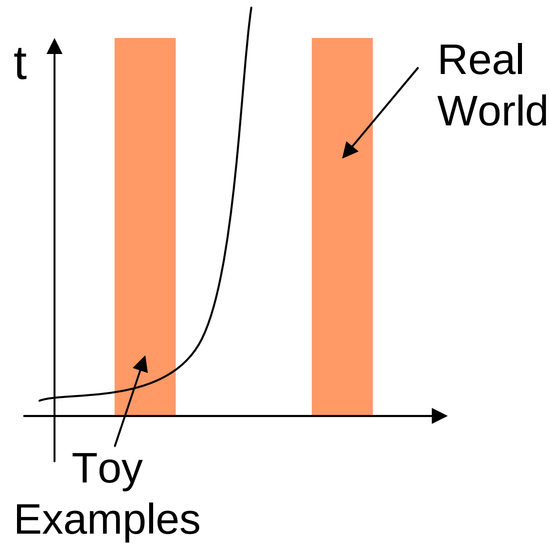
Semantic Web Systems in General



Problems tackled in KWEB

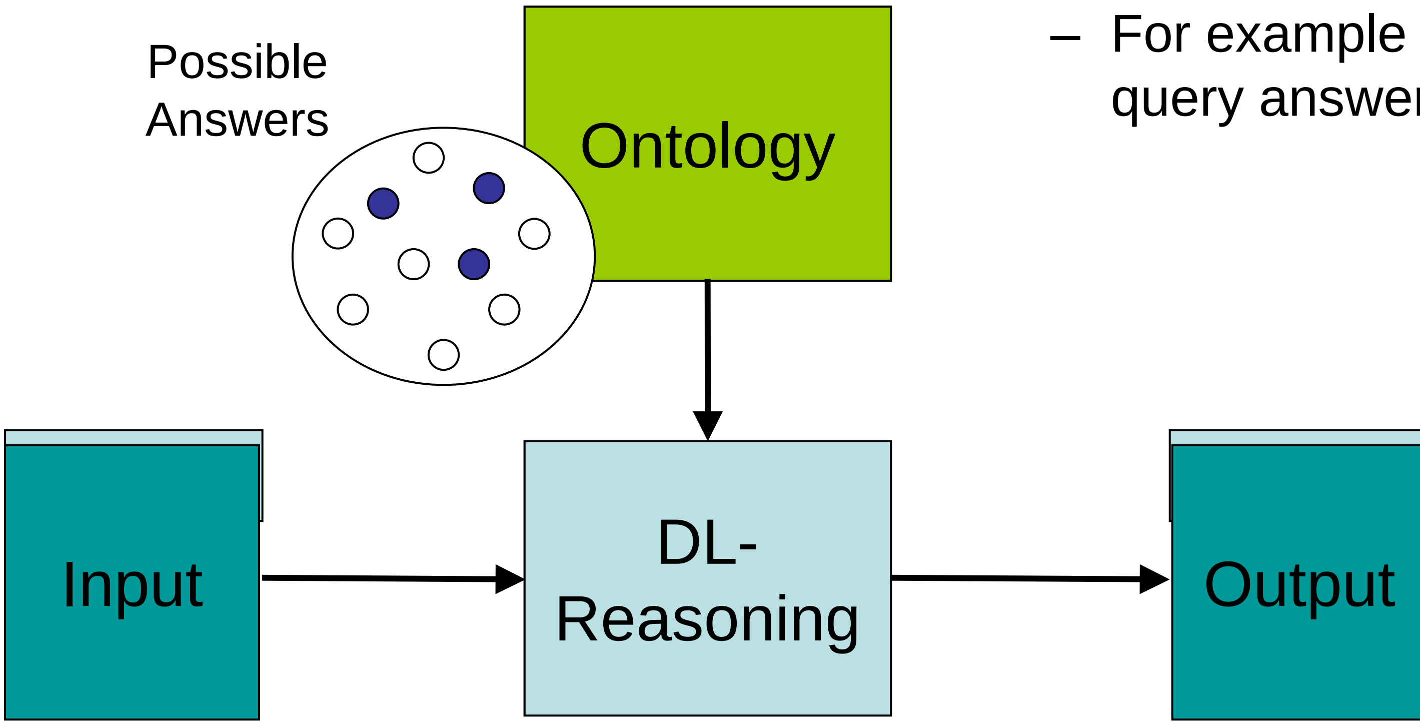
- **Scalability (Performance)**
  - DL-Reasoning in EXPTIME (OWL DL in NEXPTIME)



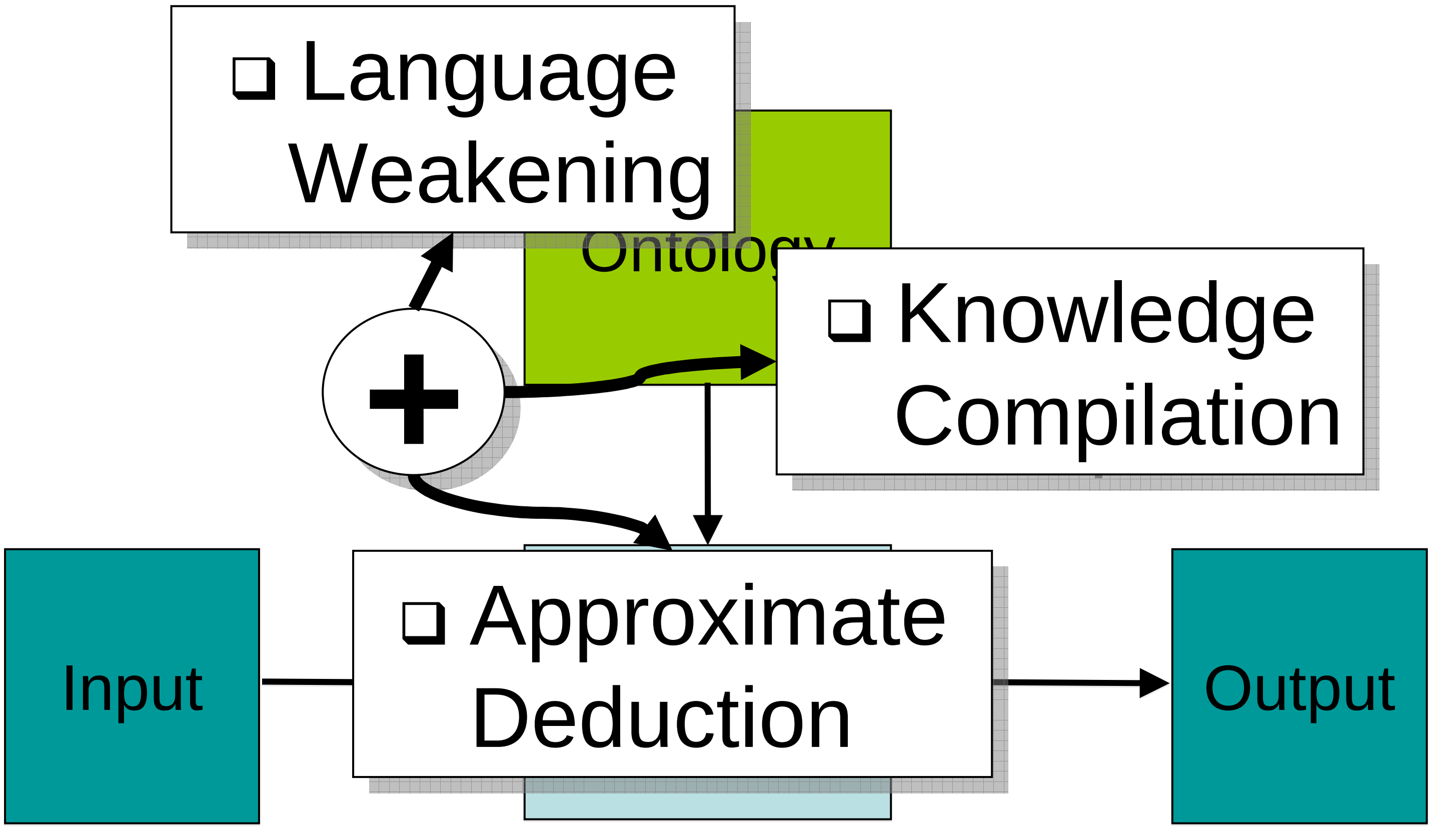


Problems tackled in KWEB

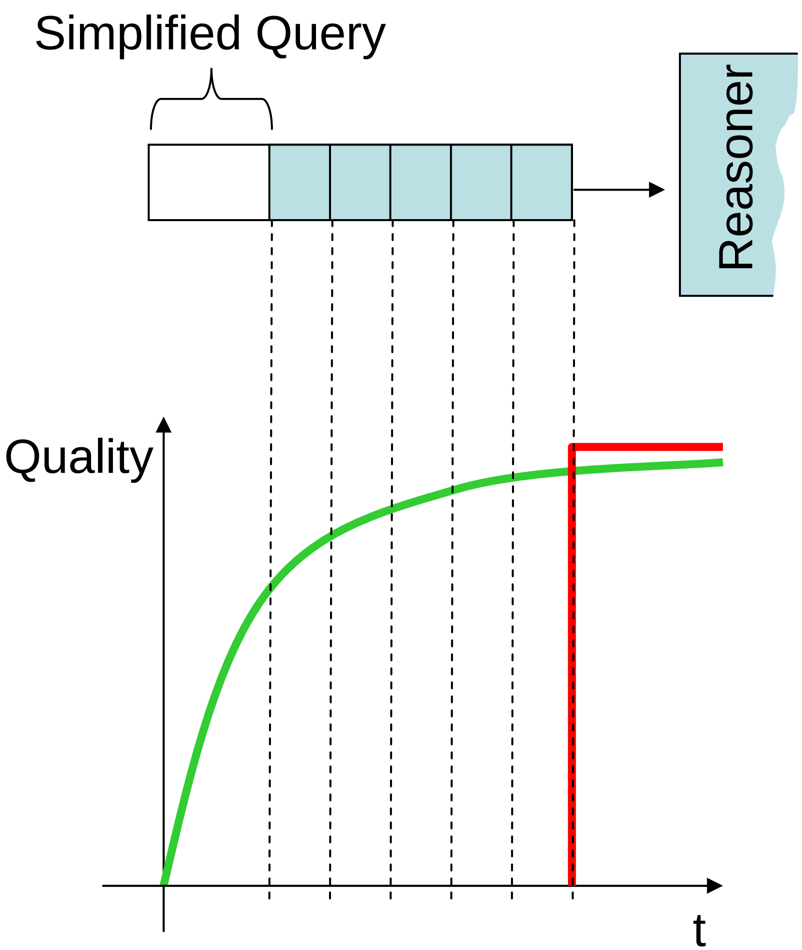
- Robustness
  - For example during query answering



Approximation Approaches



Approximate Deduction through Simplification



- Simplify query
- Simple query ⇒ fast query answering
- Simple query ⇒ approximated answers
- Continuously complete query

- Anytime behavior

How to simplify?

First Idea:
Omit some parts (e.g. Φ, Ψ)

$Q^I \overset{?}{\longleftrightarrow} Q^I$

$Q^I \subseteq Q^I$

$\text{Query} = \ldots \sqcap \Phi \sqcap \ldots \sqcap (\ldots \sqcup \Psi \sqcup \ldots)$

$Q^I \subseteq Q^I$

How to simplify? (II)

Second Idea:
Rewrite some parts (e.g. Φ, Ψ)

$Q^I \subseteq Q^I$

$Q^I \subseteq Q^I$ $Q^I \subseteq Q^I$

$$\text{Query} = \ldots \sqcap \top \sqcap \ldots \sqcap (\ldots \sqcup \top \sqcup \ldots)$$

$$\phi \mapsto \psi$$

Cadoli-Schaerf-Approximation for DLs

$$C_i^{\top} : \exists R.C \mapsto \top$$
$$C_i^{\bot} : \exists R.C \mapsto \bot$$

- Replacing some sub terms in concept expressions
- Well-founded theory with (theoretically) nice results

Cadoli-Schaerf-Approximation: Example

Depth of subconcept *D*:
number of universal quantifiers that have *D* in its scope.

$$(\exists \text{friend.tall}) \sqcap \forall \text{friend.}((\forall \text{friend.doctor}) \sqcap \exists \text{friend.}\neg\text{doctor})$$

Depth: 0 — $\exists$friend.tall

Depth: 2 — friend.doctor

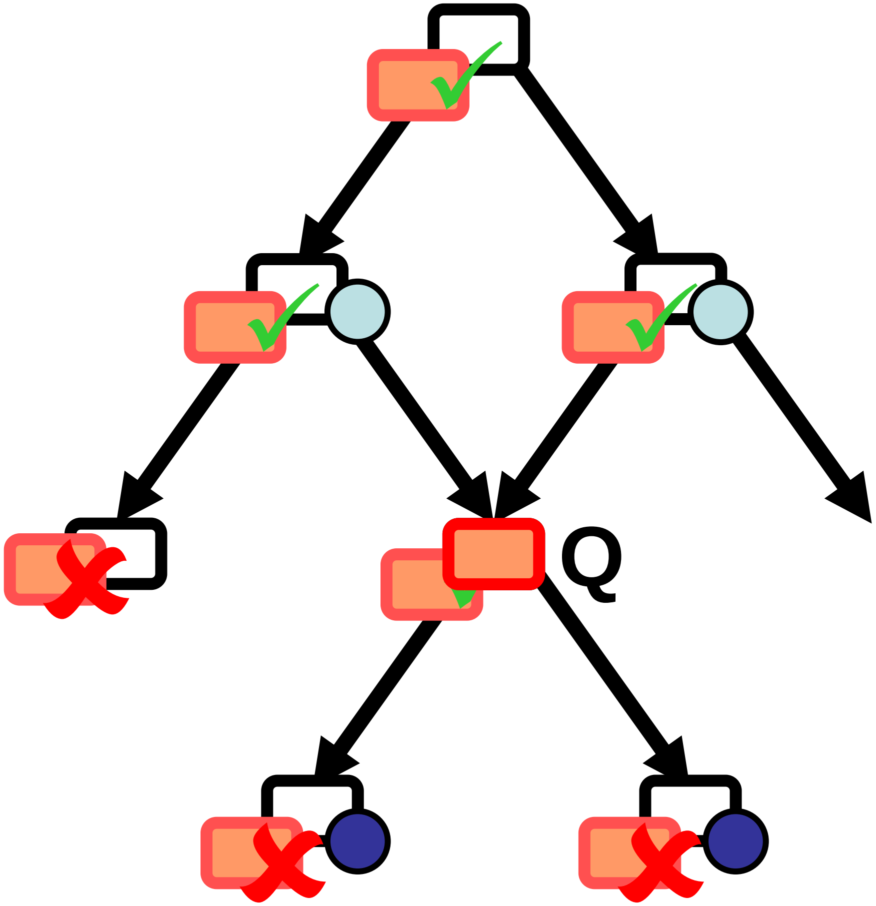
Depth: 1 — $\exists$friend.$\neg$doctor

$S_0^\top$ $\quad \top \sqcap \forall \text{friend.}((\forall \text{friend.doctor}) \sqcap \top)$

$S_1^\top$ $\quad (\exists \text{friend.tall}) \sqcap \forall \text{friend.}((\forall \text{friend.doctor}) \sqcap \top)$

$S_2^\top$ $\quad (\exists \text{friend.tall}) \sqcap \forall \text{friend.}((\forall \text{friend.doctor}) \sqcap \exists \text{friend.}\neg\text{doctor}).$

Application: Classification



- Central process
  Classify Term Q
- Contained in
  - Generating the subsumption hierarchy
  - Instance Retrieval

Mixed Results: Classifying in TAMBIS

- Application: Classification of Concepts
  $\Rightarrow$ sequence of subsumption test: $C \sqsubseteq D$

≈0 ≈24 ≈279 ≈0

	normal			$C_i^\perp$			$C_i^\top$			$C_i^\perp \& C_i^\top$		
		true	false		true	false		true	false		true	false
Tambis (16)				$C_0^\perp$	157	32	$C_0^\top$	8	181	$C_0^\perp$	157	32
				$C_1^\perp$			$C_1^\top$			$C_0^\top$	8	149
	N	24	279	N			N			N		

$(C \not\sqsubseteq D)_i^\perp \Rightarrow C \not\sqsubseteq D$ $\qquad$ $(C \sqsubseteq D)_i^\top \Rightarrow C \sqsubseteq D$

$(C \sqcap \neg D)_i^\perp$ is satisfiable $\qquad$ $(C \sqcap \neg D)_i^\top$ is unsatisfiable

$\Rightarrow (C \sqcap \neg D)$ is satisfiable $\qquad$ $\Rightarrow (C \sqcap \neg D)$ is unsatisfiable

Further Results

		normal		$C_i^\perp$		$C_i^\top$		$C_i^\perp \& C_i^\top$	
		true	false	true	false	true	false	true	false
Dolce (10)	$C_0^\perp$	-	-	0	0	-	-	0	0
	$C_0^\top$	-	-	-	-	0	0	0	0
	normal	10	113	10	113	10	113	10	113
Galen (10)	$C_0^\perp$	-	-	0	0	-	-	0	0
	$C_0^\top$	-	-	-	-	0	0	0	0
	normal	10	12190	10	12190	10	12190	10	12190
Monet (10)	$C_0^\perp$	-	-	0	0	-	-	0	0
	$C_0^\top$	-	-	-	-	0	0	0	0
	normal	20	656	20	656	20	656	20	656
MadCow (10)	$C_0^\perp$	-	-	145	0	-	-	145	0
	$C_0^\top$	-	-	-	-	5	140	5	140
	normal	66	152	66	152	61	152	61	152
Wine (10)	$C_0^\perp$	-	-	228	1	-	-	228	1
	$C_0^\top$	-	-	-	-	6	223	6	222
	normal	33	252	33	251	27	252	27	251

Problem: Term Collapsing

Subsumption Queries have this structure very often

Query =  $\bot$

- Term C
  - very often conjunction of subterms
  - e.g. conjunctive queries
- Term D
  - Very often also conjunction of subterms

Classifying in TAMBIS (IV)

	normal			$C_i^{\bot}$			$C_i^{\top}$			$C_i^{\bot}\&C_i^{\top}$		
		true	false		true	false		true	false		true	false
Tambis (16)				$C_0^{\bot}$	157	32	$C_0^{\top}$	8	181	$C_0^{\bot}$	157	32
				$C_1^{\bot}$	0	0	$C_1^{\top}$	0	0	$C_0^{\top}$	8	149
	N	24	279	N	24	247	N	16	279	N	16	247

Term Collapsing: 157 = 100% 65 = 35,9% 190 = 62,1%

Lessons learned

$$\phi \mapsto \psi$$

- Avoid Term Collapsing
  - Replace ψ with something else than $\top$ or $\bot$
- Find better places to rewrite
  - Ontology-adapted ϕ?

Focused Case: Instance Retrieval

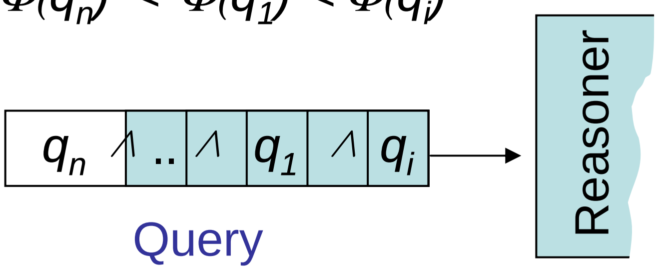
- Find all instances *a* which belongs to a query *Q*: *a:Q*
- Tool *InstanceStore:*
  - Try to replace DL reasoning as much as possible with (scalable) DB retrieval
  - Only applyable to role-free A-Boxes
    $a{:}Q \leftrightarrow I_a \sqsubseteq Q$; I_a concept description of instance a
- Boolean Conjunctive Queries
  - $q_1 \wedge \cdots \wedge q_n$, where $q_1, \cdots, q_n$ are of the form $x{:}C$ or $\langle x,y \rangle{:}R$
  - Restrict to those which can be converted to a concept expression *C*

New Approximation Method: Heuristic Ordering of Conjuncts

$q_1 \wedge .. \wedge q_i \wedge .. \wedge q_n$

$\Phi(q_1) \quad \Phi(q_i) \quad \Phi(q_n)$

$\Phi(q_n) < \Phi(q_1) < \Phi(q_i)$



- Compute a ranking value for each conjunct

$$\Phi(q_i) : C \mapsto I\!R$$

- Order the conjuncts $q_1, \cdots, q_n$ according to their value
- Complete approximated query with more and more expensive conjuncts

How to order conjuncts?

- According to the needed computation time for each conjunction
  - Estimate the computation time a priori
- According to the possible search space reduction
  - Prefer conjuncts which eliminate a lot of instances

How to estimate the computation costs?

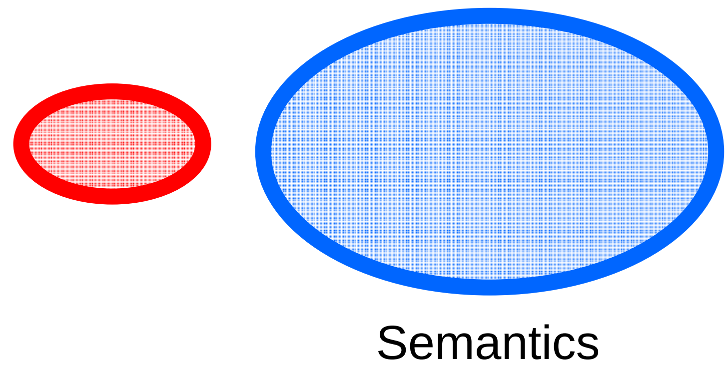
$$\Phi(A) = 1$$
$$\Phi(\neg A) = 0$$
$$\Phi(C \sqcap D) = 2 + \Phi(C) + \Phi(D)$$
$$\Phi(C \sqcup D) = \phi + 2 + \Phi(C) + \Phi(D)$$
$$\Phi(\exists\ R.C) = 2 + \Phi(C)$$
$$\Phi(\forall\ R.C) = n + n \cdot \Phi(C)$$

where ϕ is the current value of $\Phi(E)$

where n is the number of existential quantifiers in E

Effects of Cadoli-Schaerf for Subsumption

$C \sqsubseteq D$

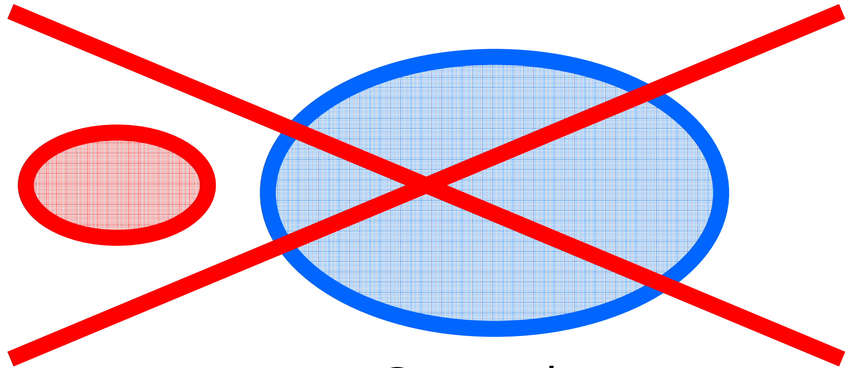


$(C \sqsubseteq D)^{\perp}$ “$\mapsto\perp$“

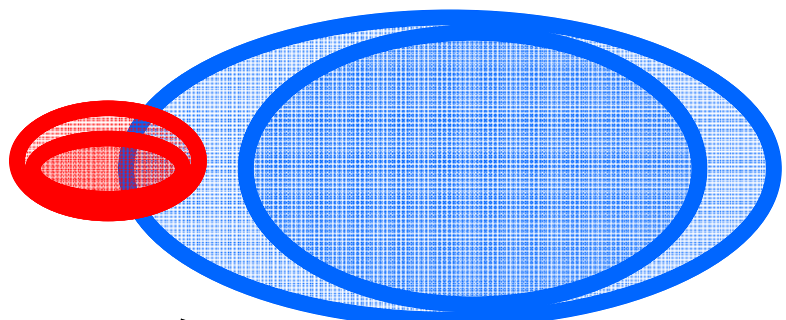
$$C \sqsubseteq D \;\leftrightarrow\; \not\models C \sqcap \neg D$$

Effects of Cadoli-Schaerf for Subsumption

$C \not\sqsubseteq D$



$(C \not\sqsubseteq D)^\perp$ "$\mapsto\perp$"

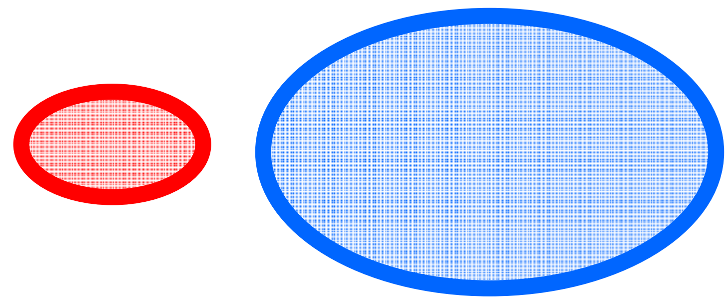


$(C \sqsubseteq D)^\perp \leftrightarrow \not\models (C \sqcap \neg D)^\perp$

$\downarrow C^\perp \quad \neg D^\perp \updownarrow$

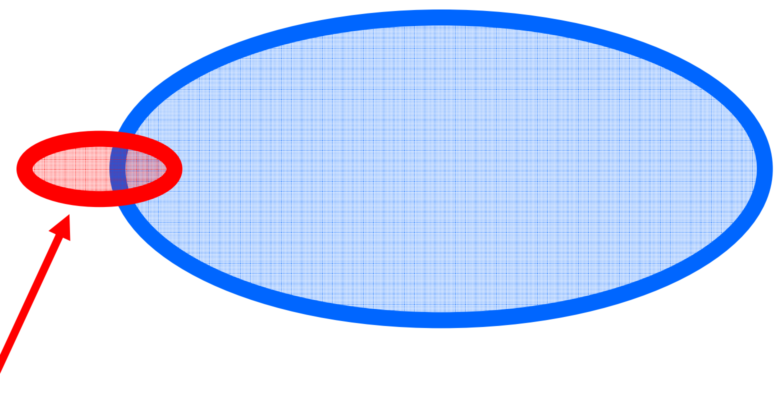
Effects of CS for Subsumption: Term Collapsing

$C \not\sqsubseteq D$



Semantics

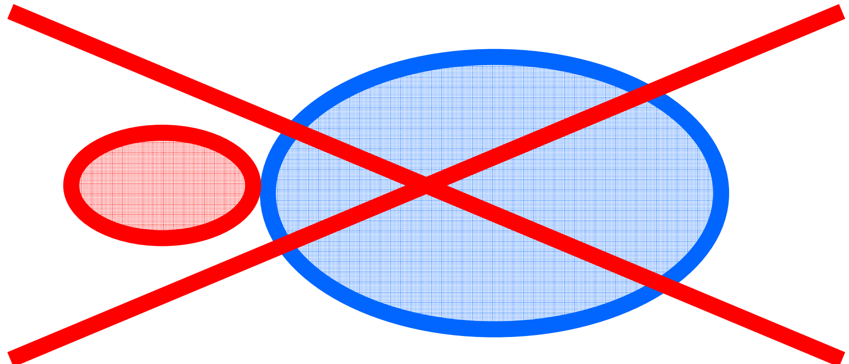
$(C \not\sqsubseteq D)^{\perp}$ “$\mapsto \perp$“



Term collapsing

Effects of new Approximation

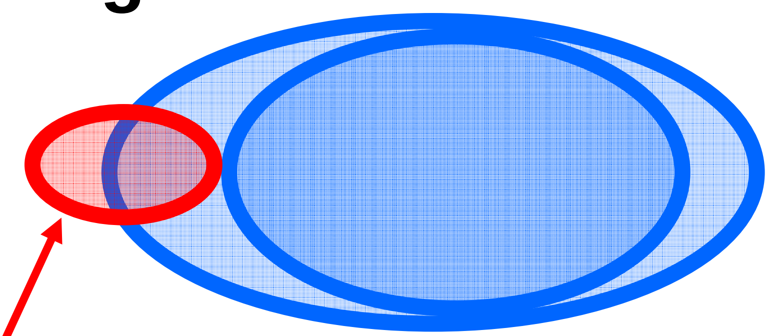
$(C_a \not\sqsubseteq Q)$



Semantics

only Q changed

$(C_a \not\sqsubseteq Q)^{\Delta}$



not changed;
Term collapsing avoided

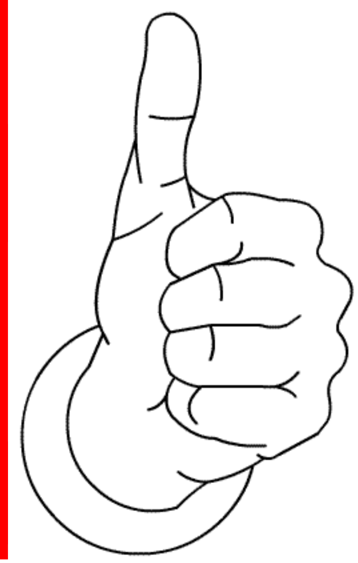
Results: Subsumption tests

More Levels

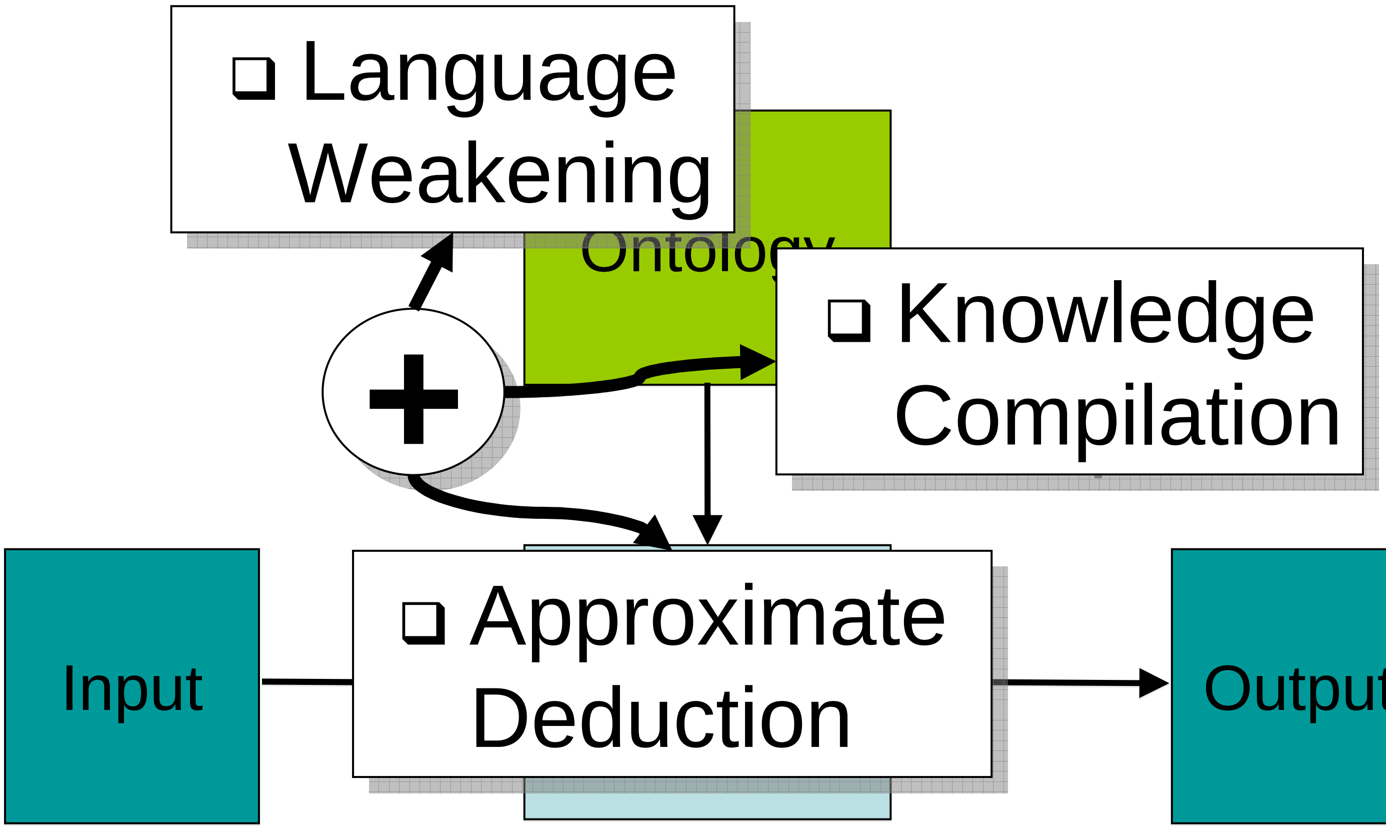
	normal			$c^{\top}$			[illegible]			c^{Δ}		
		true	false		true	false		true	false		true	false
Q2										$L0$	20	0
										$L1$	20	0
				$L0$	0	19	$L0$	19	0	$L2$	9	11
	normal	9	11	normal	9	11	normal	9	11	normal	9	0
Q8				$L0$	0	606	$L0$	606	0	$L0$	607	0
										$L1$	10	597
	normal	10	597	normal	10	597	normal	10	597	normal	10	0
Q12				$L0$	0	7871	$L0$	7871	0	$L0$	15	7856
	normal	15	7856	normal	15	7856	normal	15	7856	normal	15	0
Q14										$L0$	408	0
										$L1$	5	403
				$L0$	0	407	$L0$	407	0	$L2$	5	0
	normal	5	403	normal	5	403	normal	5	403	normal	5	0
Q15				$L0$	0	6693	$L0$	6693	0	$L0$	6693	0
	normal	46	6647	normal	46	6647	normal	46	6647	normal	46	6647
Q17				$L0$	0	7873	$L0$	7873	0	$L0$	1	7872
	normal	1	7872	normal	1	7872	normal	1	7872	normal	1	0

Results: Time

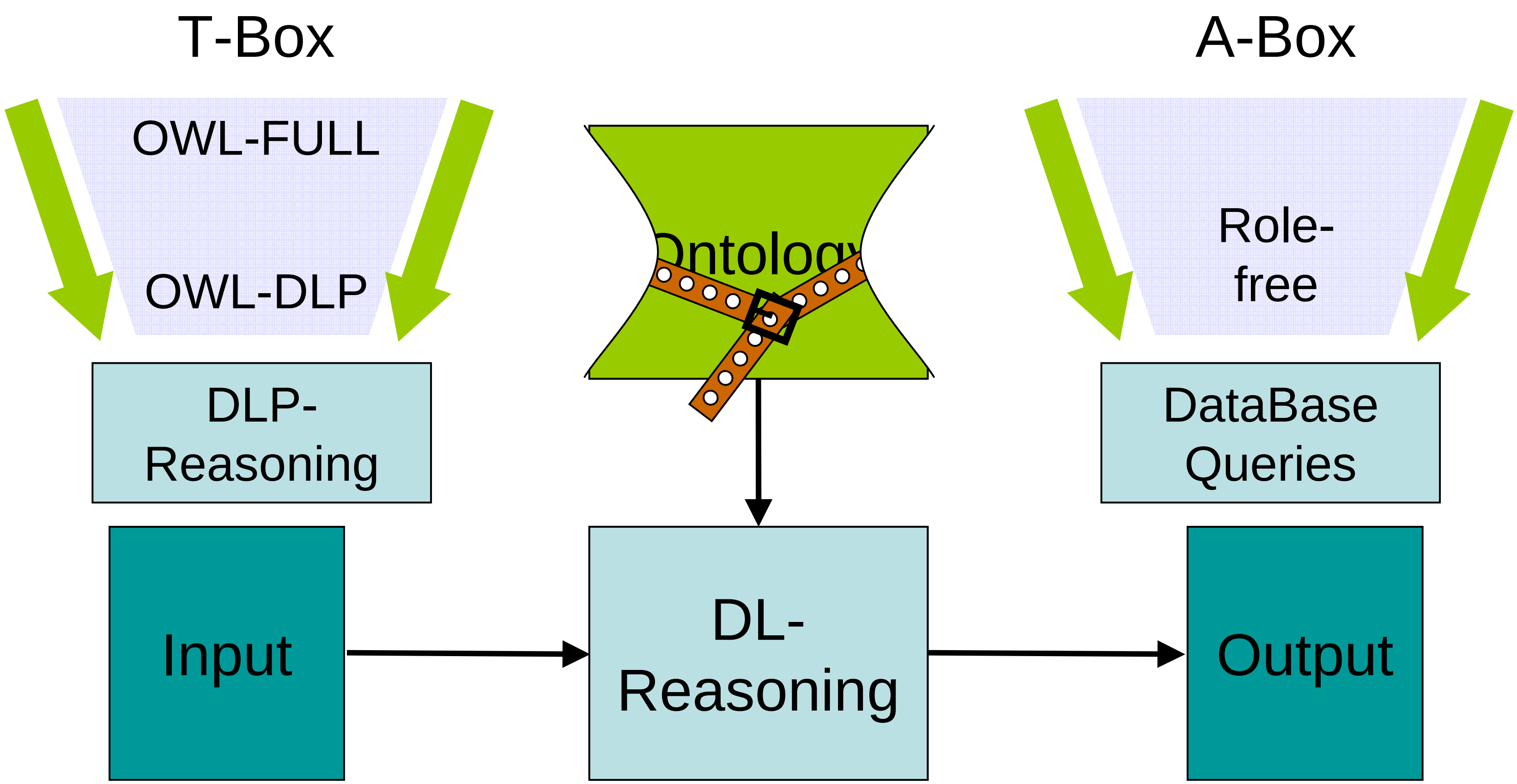
	normal	$C^{\top}$	$C^{\perp}$	C^{Δ}
Q2	175	348	299	547
Q8	5373	8383	7753	9912
Q12	[illegible]	[illegible]	[illegible]	56478
Q14	[illegible]	6837	[illegible]	7391
Q15	61560	90847	83714	114162
Q17	113289	[illegible]	[illegible]	93074



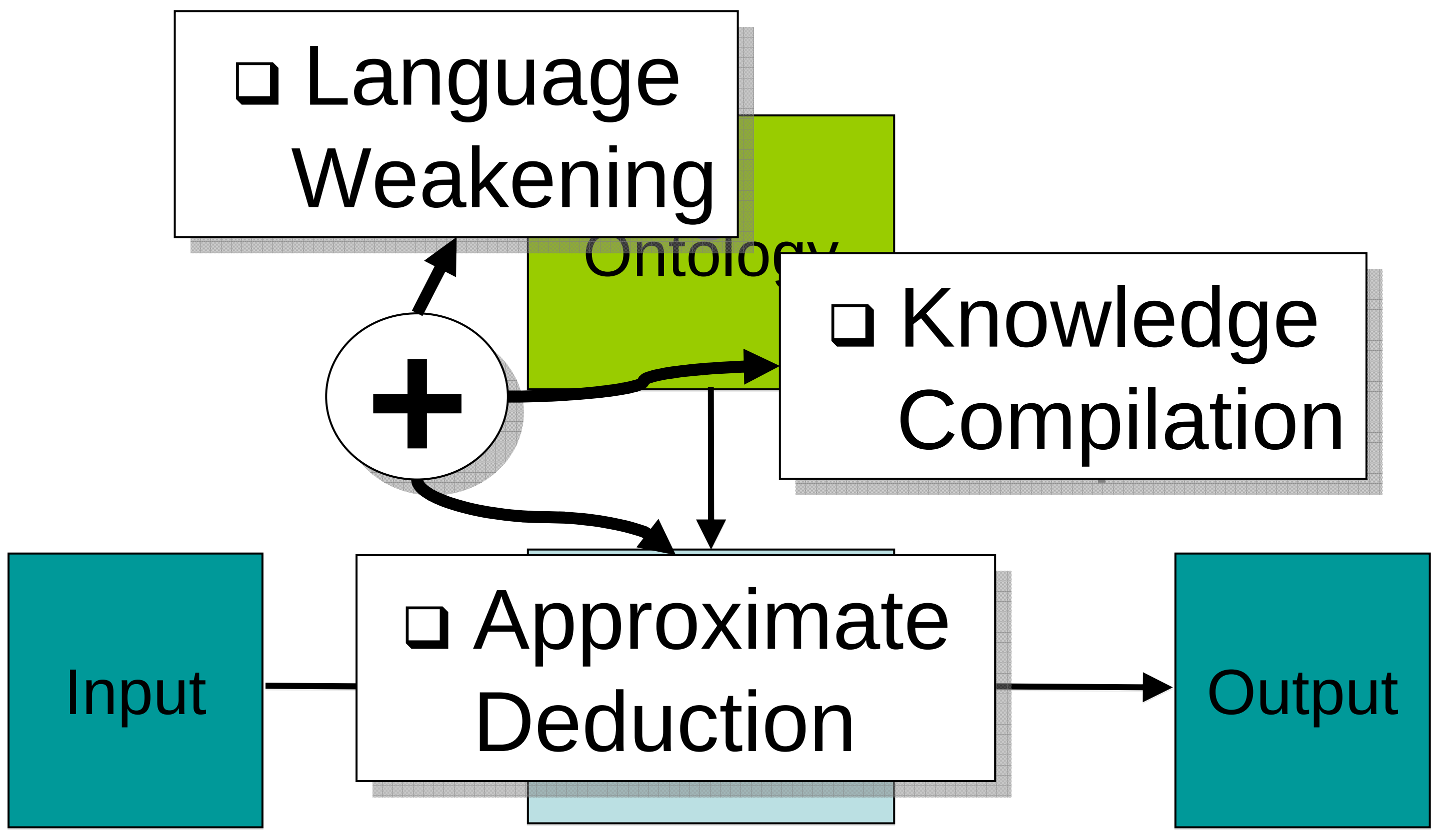
Approximation Approaches



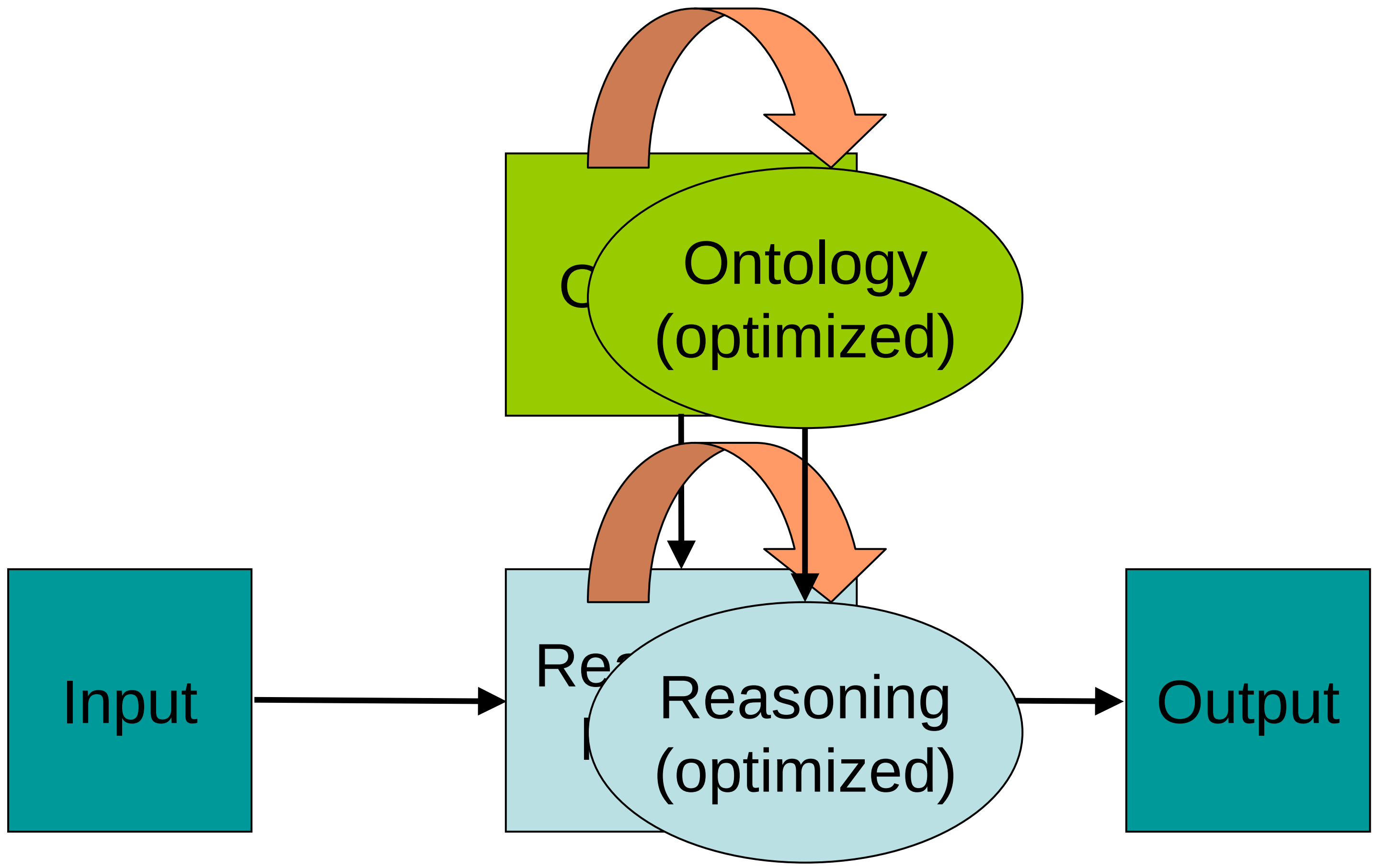
Approximation through Language Weakening



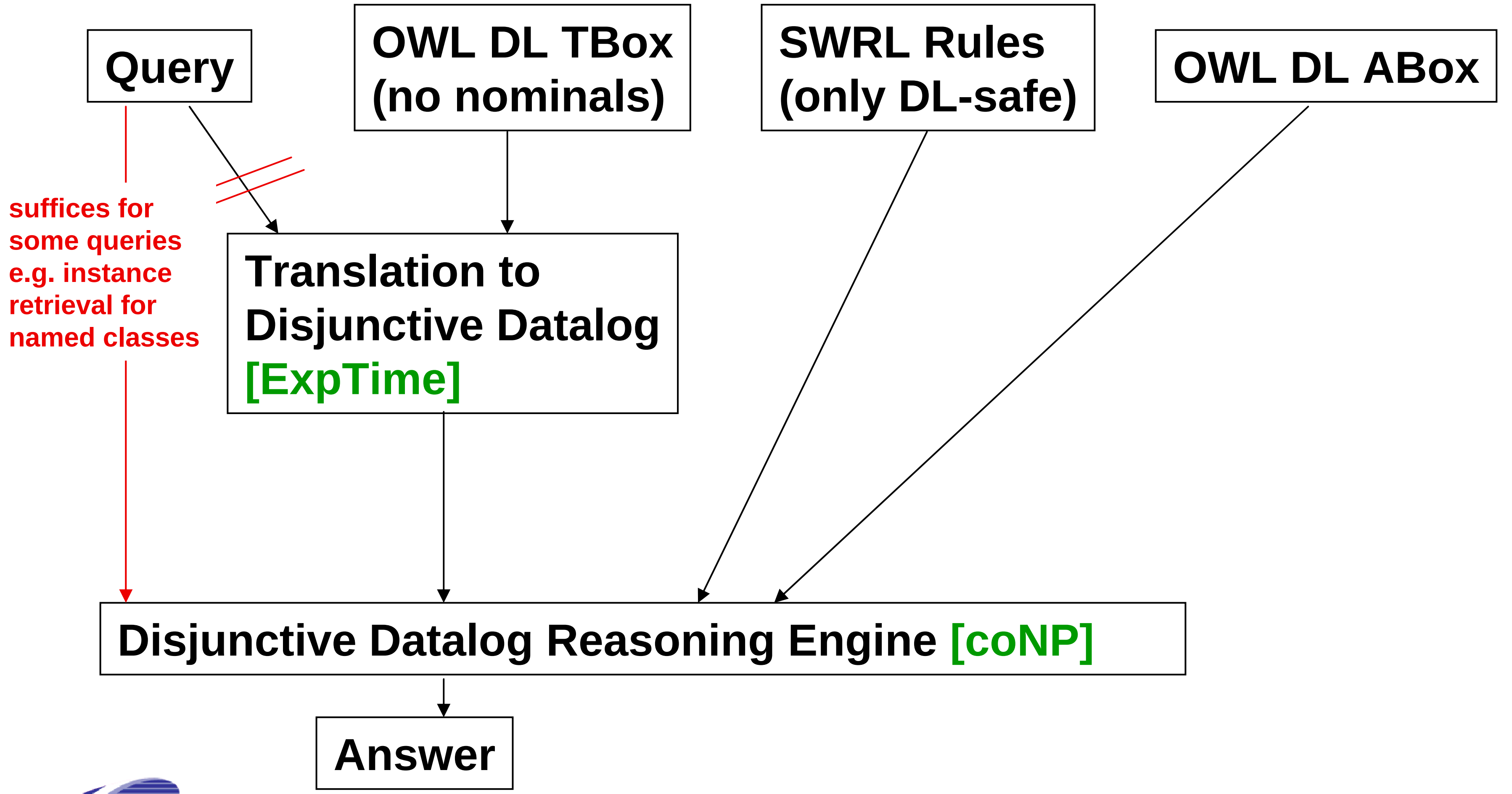
Approximation Approaches



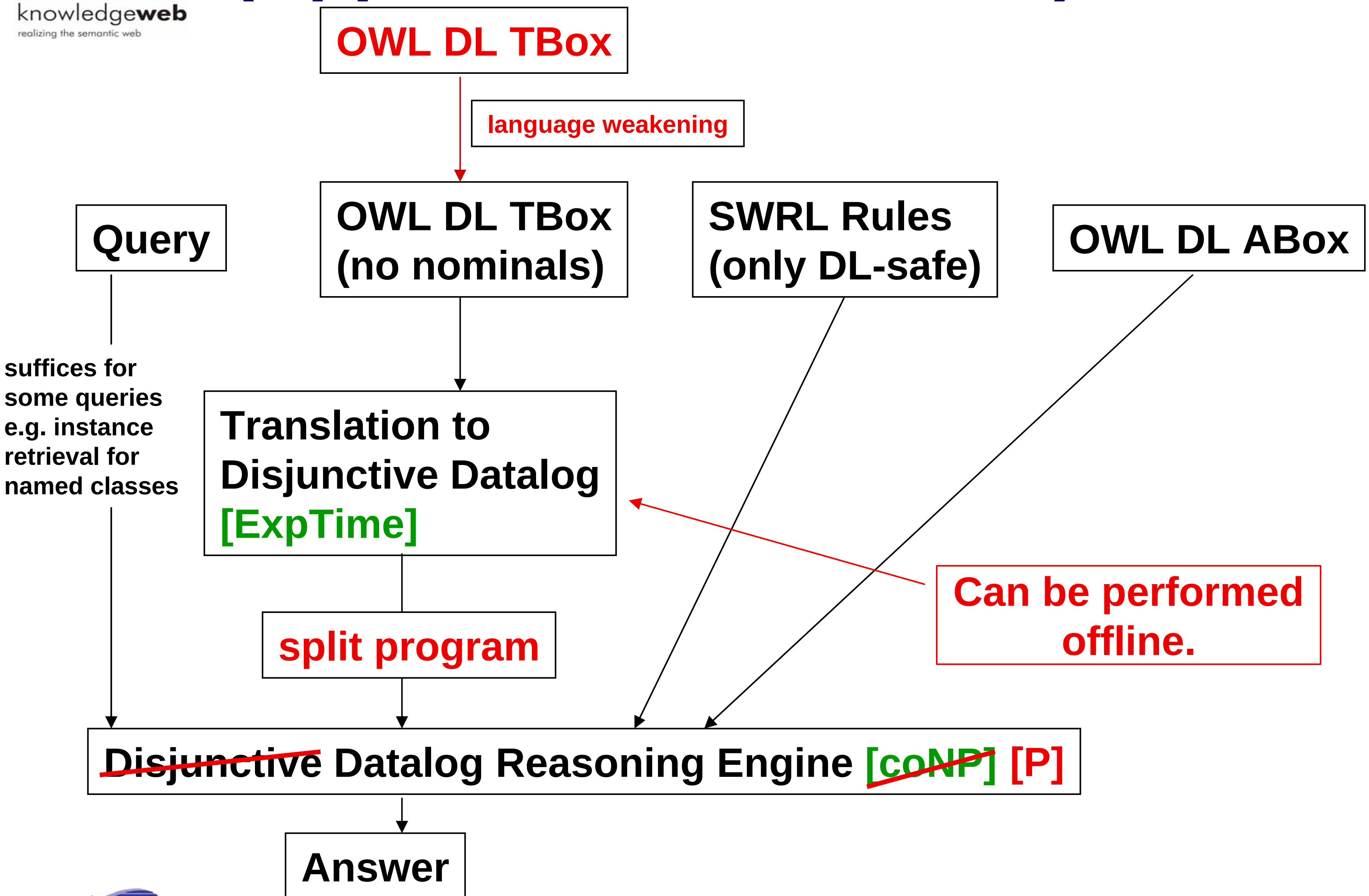
Approximation through Knowledge Compilation



Standard: KAON2



(Approximated: KAON2) = Screech



Screech simple example

serbian $\sqcup$ croatian $\sqsubseteq$ european
eucitizen $\sqsubseteq$ european
german $\sqcup$ french $\sqcup$ beneluxian $\sqsubseteq$ eucitizen
beneluxian $\equiv$ luxembourgian $\sqcup$ dutch $\sqcup$ belgian

serbian(ljiljana).	serbian(nenad).	german(pascal).
french(julien).	croatian(boris).	german(markus).
german(stephan).	croatian(denny).	indian(sudhir).
belgian(saartje).	german(rudi).	german(york).

Screech simple example

beneluxian $\equiv$ luxembourgian $\sqcup$ dutch $\sqcup$ belgian

KAON2 translates into the following four clauses:

~~luxembourgian(x) $\vee$ dutch(x) $\vee$ belgian(x) $\leftarrow$ beneluxian(x)~~

beneluxian(x) $\leftarrow$ luxemburgian(x)

beneluxian(x) $\leftarrow$ dutch(x)

beneluxian(x) $\leftarrow$ belgian(x)

Screech split first clause:

luxembourgian(x) $\leftarrow$ beneluxian(x)

dutch(x) $\leftarrow$ beneluxian(x)

belgian(x) $\leftarrow$ beneluxian(x)

$\vdash$ **luxembourgian(saartje)**

$\vdash$ **dutch(saartje)**

$\vdash$ **belgian(saartje)**

Screech reasoning

- data complexity is **P**

- complete
- but unsound

- inference can be described in terms of standard notions from *non-monotonic reasoning*

Screech Performance (not optimized yet)

- Galen ontology
  - 673 axioms, 175 classes
  - randomly populated with 500 individuals

- After KAON2: 267 disjunctions in 133 rules eliminated

- Complete run:
  - queried for the extensions of all 175 Galen classes
  - resulting in 5809 classifications (Screech)
    - 5353 (i.e. **92.2%**) **correct**
  - For 138 out of 175 classes: computed extension correct
  - Average **time saved: 39.0%**

Summary

- Approximation approaches start to improve performance
  - Cadoli-Schaerf Approximation seems to not to work in practical settings
  - Heuristic approximation but performance improvements (only) in restricted cases?!
  - Screech 40% speed-up with only 8% wrong answers but only in one use-case
- Open questions:
  - Try to understand (theoretically) why they work
  - Benchmarking (more use-cases)
  - What about Robustness?

Thank you for your attention!