Deduction Based Question Answering and its Application

LogAnswer Embedding AD in QAS

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Deutsche Forschungsgemeinschaft
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Loganswer

AR Aspects

(Application)

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LogAnswer - a Question-Answering System

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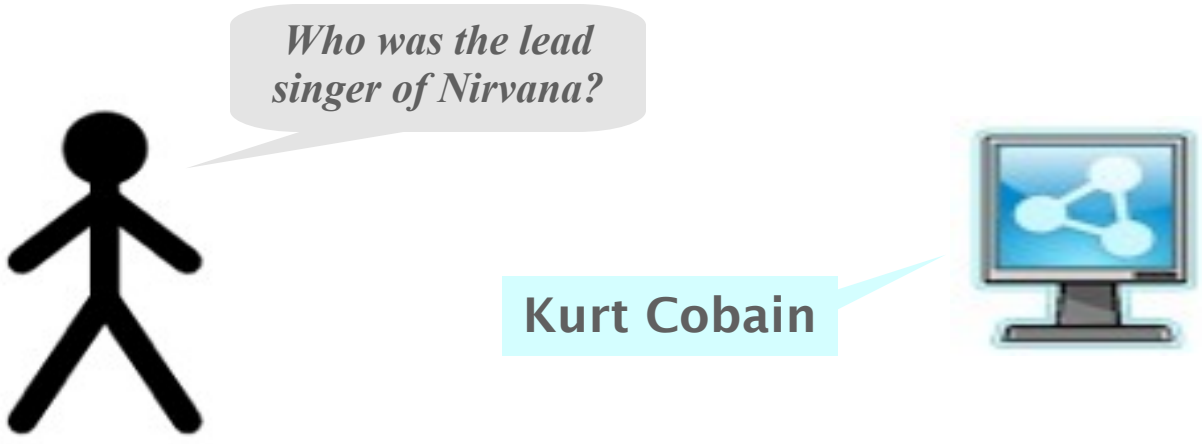
Who was the lead singer of Nirvana?

Kurt Cobain

LogAnswer - a Question-Answering System

An ***open domain question-answering system***

- receives a natural-language question regarding any topic, and
- returns a natural-language answer found in a knowledge-base.



Why use Logic in QA?

Shallow NLP fails when:

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Shallow NLP fails when:

- words in the knowledge sources do not match exactly:

When did Hannibal cross the Alps?

The Carthaginian general led his army over the Alps in 218 BC.

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Shallow NLP fails when:

- words in the knowledge sources do not match exactly:

When did Hannibal cross the Alps?

The Carthaginian general led his army over the Alps in 218 BC.

- words match, but they are too far apart:

What is the population of Mongolia?

Mongolia is very sparsely populated for its size. The landlocked country between China and Russia has a population of 2.9 million people.

The LogAnswer project combines

FernUniversität in Hagen **NLP**	UNIVERSITÄT KOBLENZ · LANDAU **Deduction**
• NLP-components • MultiNet knowledge base, based on snapshot of German Wikipedia	• theorem prover E-KRHyper

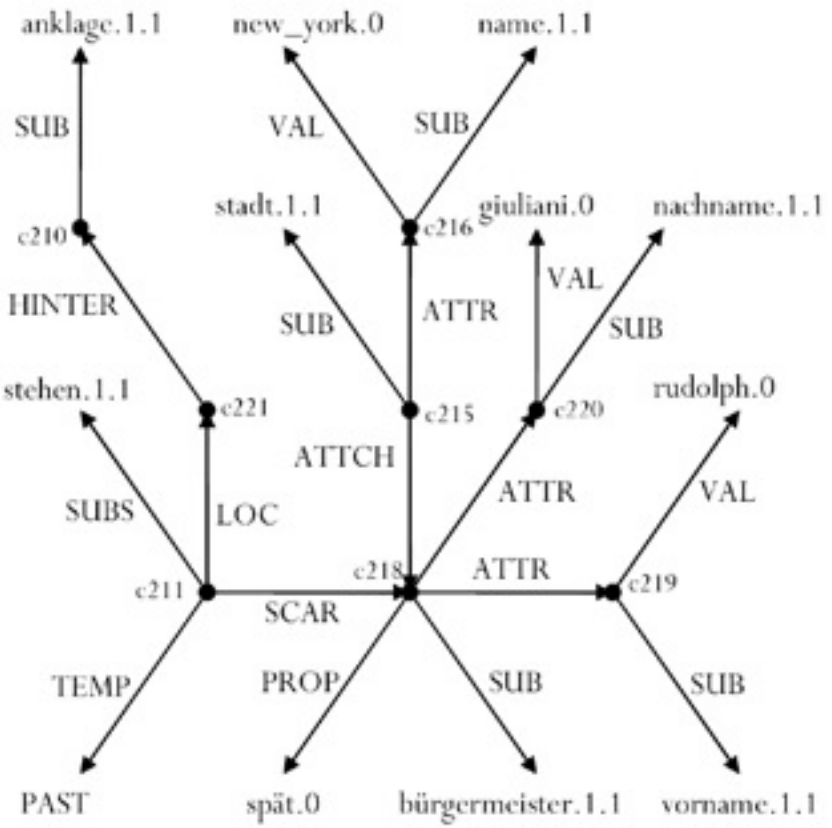
MultiNet Knowledge Base

MultiNet:

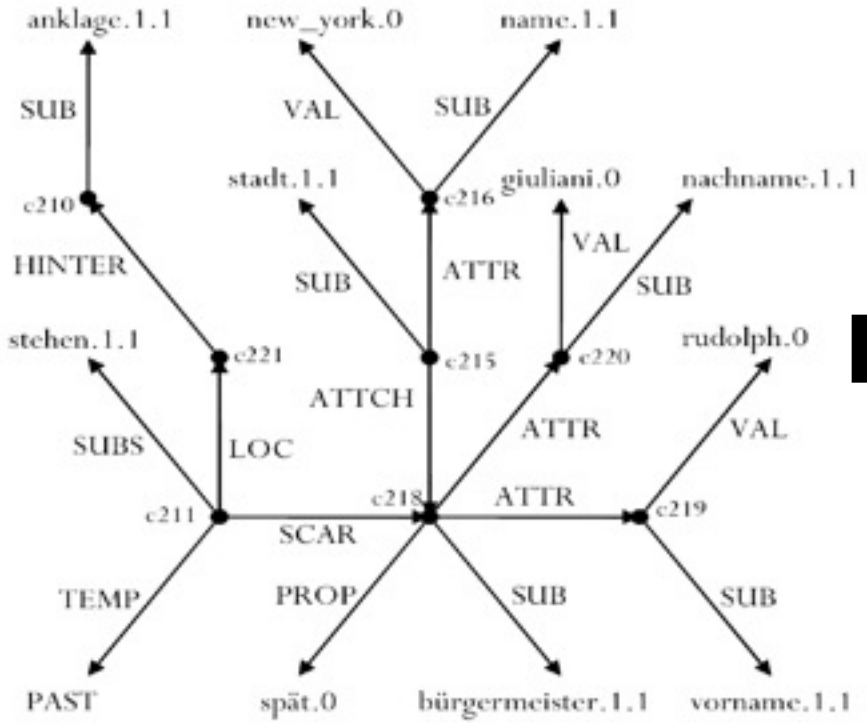
- **Multi**layered Extended Semantic **Net**works
- language independent, but tools mostly German

MultiNet Knowledge Base

"Hinter der Anklage stand der spätere Bürgermeister von New York, Rudolph Giuliani."



MultiNet to First-Order Logic



MultiNet

$$
\begin{aligned}
&\text{hinter}(c221,\ c210)\\
&\wedge\ \text{sub}(c220,\ nachname.1.1)\\
&\wedge\ \text{val}(c220,\ giuliani.0)\\
&\wedge\ \text{sub}(c219,\ vorname.1.1)\\
&\wedge\ \text{val}(c219,\ rudolph.0)\\
&\wedge\ \text{prop}(c218,\ spät.1.1)\\
&\wedge\ \text{attr}(c218,\ c220)\\
&\wedge\ \text{attr}(c218,\ c219)\\
&\wedge\ \text{sub}(c218,\ bürgermeister.1.1)\\
&\wedge\ \text{val}(c216,\ new\_york.0)\\
&\wedge\ \text{sub}(c216,\ name.1.1)\\
&\wedge\ \text{sub}(c215,\ stadt.1.1)\\
&\wedge\ \text{attch}(c215,\ c218)\\
&\wedge\ \text{attr}(c215,\ c216)\\
&\wedge\ \text{subs}(c211,\ stehen.1.1)\\
&\wedge\ \text{loc}(c211,\ c221)\\
&\wedge\ \text{scar}(c211,\ c218)\\
&\wedge\ \text{temp}(c211,\ past)\\
&\wedge\ \text{sub}(c210,\ anklage.1.1)
\end{aligned}
$$

First-Order Logic

MultiNet Knowledge Base

- snapshot of German Wikipedia
- formal representations of ~12 million sentences, generated semi-automatically
- plus ~12,000 background knowledge axioms, manually adapted from MultiNet inference rules and from WordNet

Hypertableau

- splitting with purification solves the problem of variables shared between tableau branches:
- only one branch needs to be worked on at any time — Jelia 96
- emphasis on unit operations
- proof confluent

E-hyper tableau calculus:

- clause tree instead of literal tree — Cade 07
- four extension rules instead of one
- adds term ordering (reduction ordering)
- adds redundancy handling

The LogAnswer question answering system:

"Who was Ian Fleming?"

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"Who was Ian Fleming?"

parse & transform

word info + FOL query

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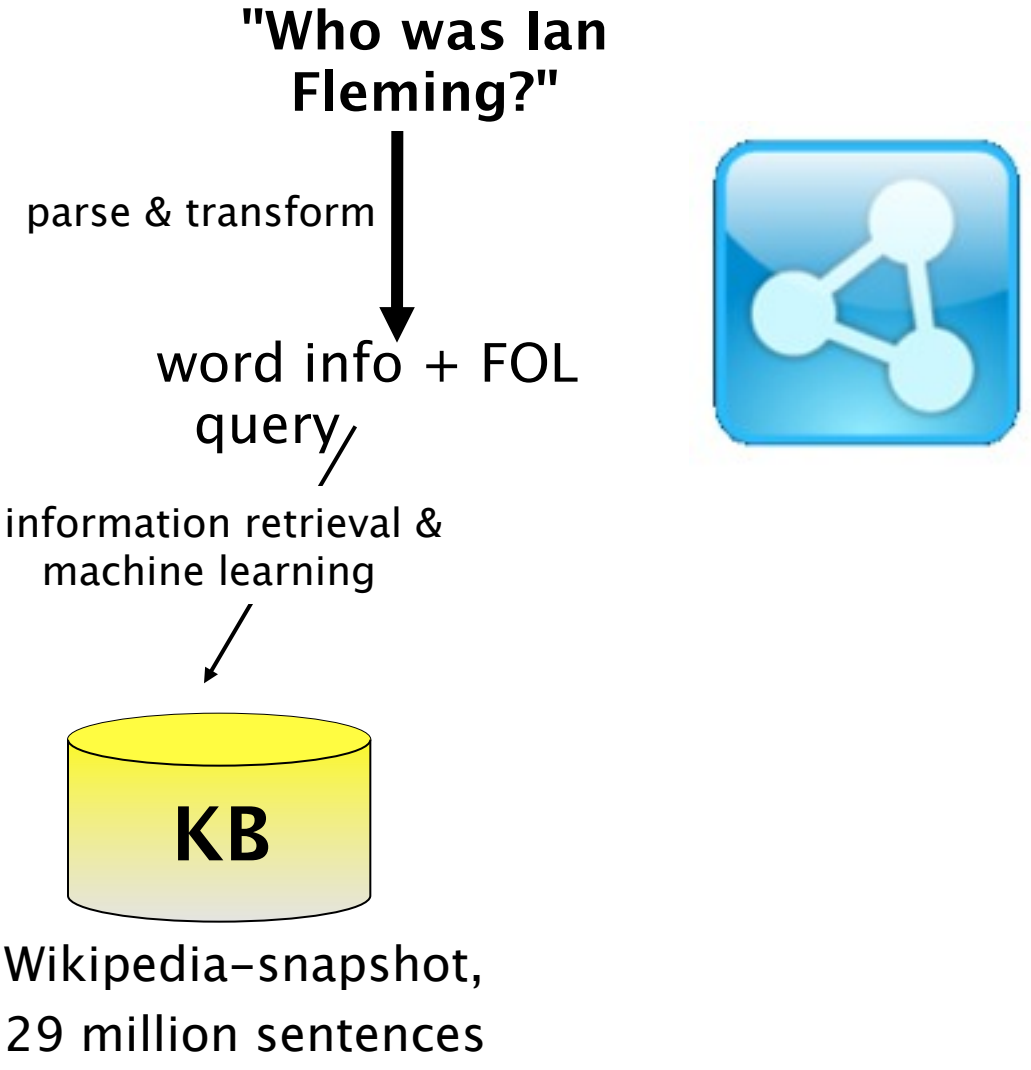

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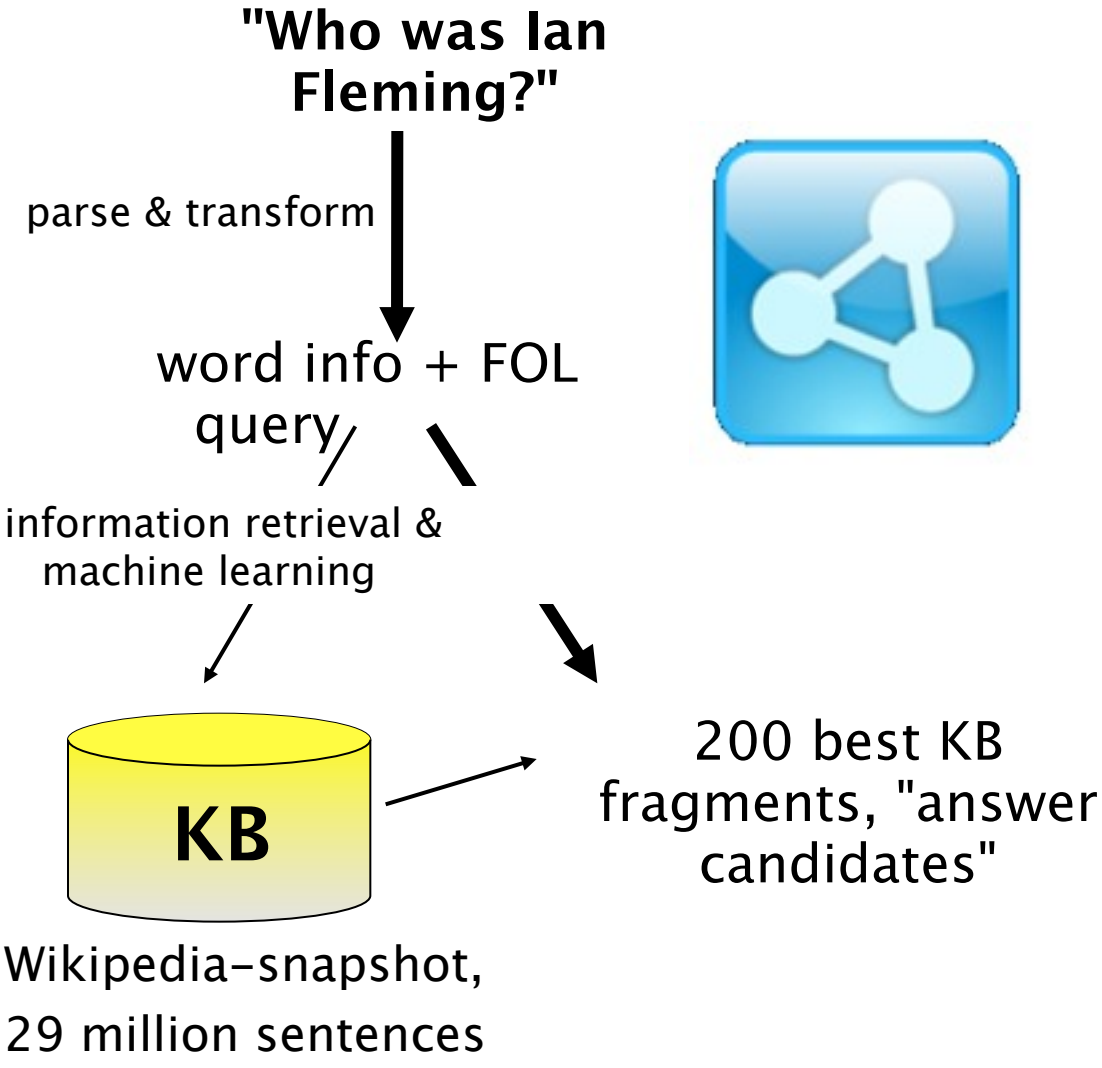

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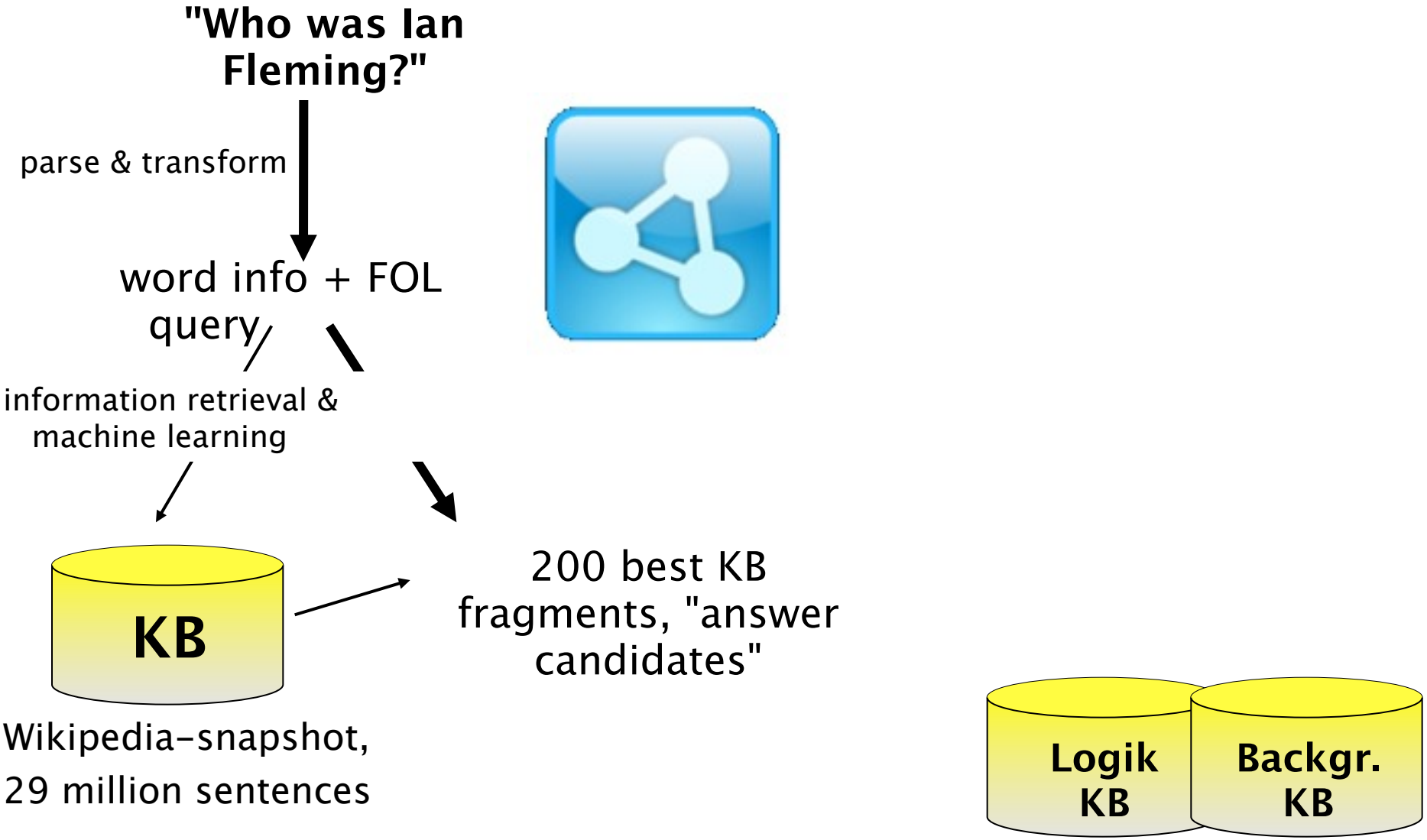

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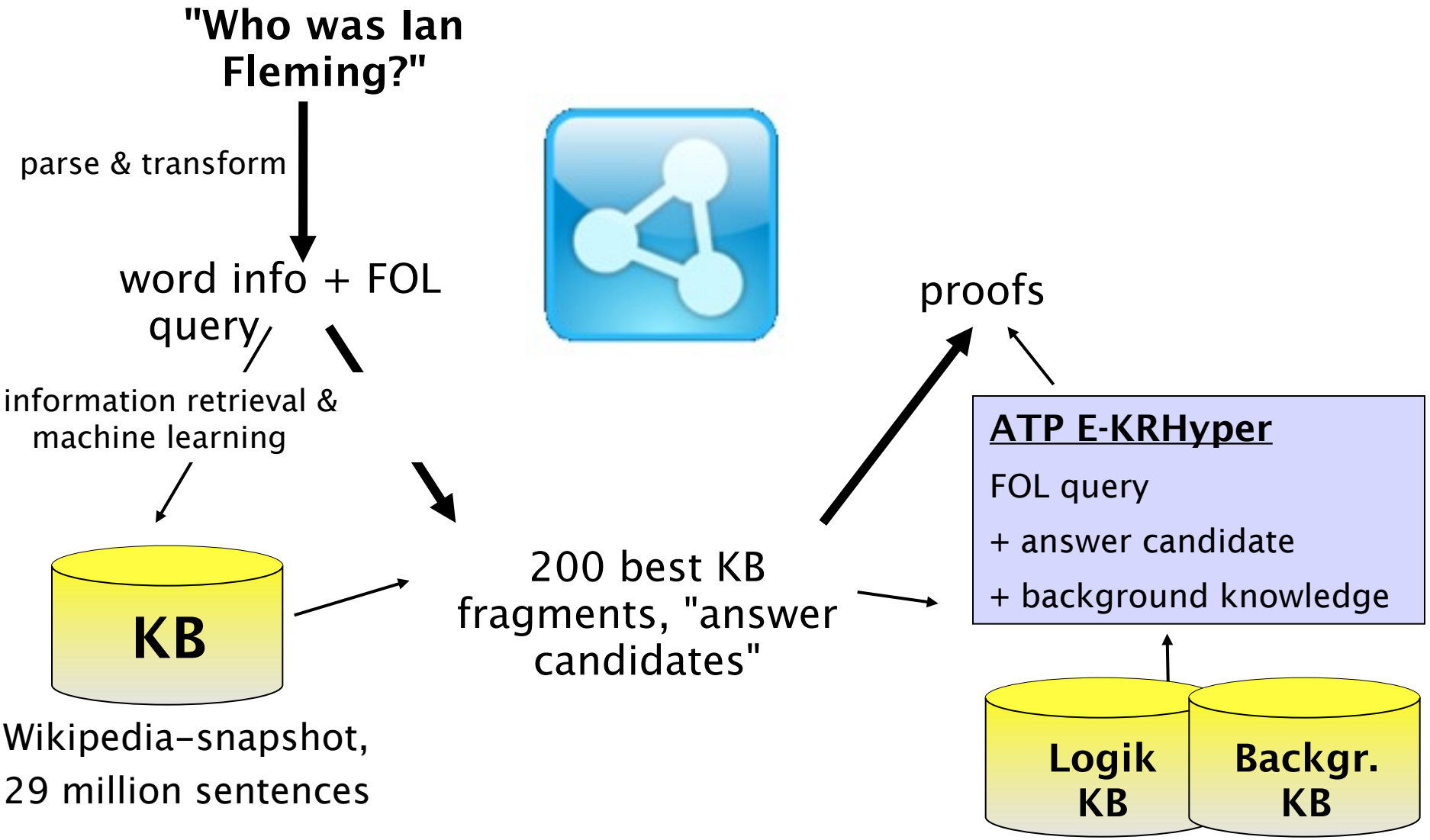

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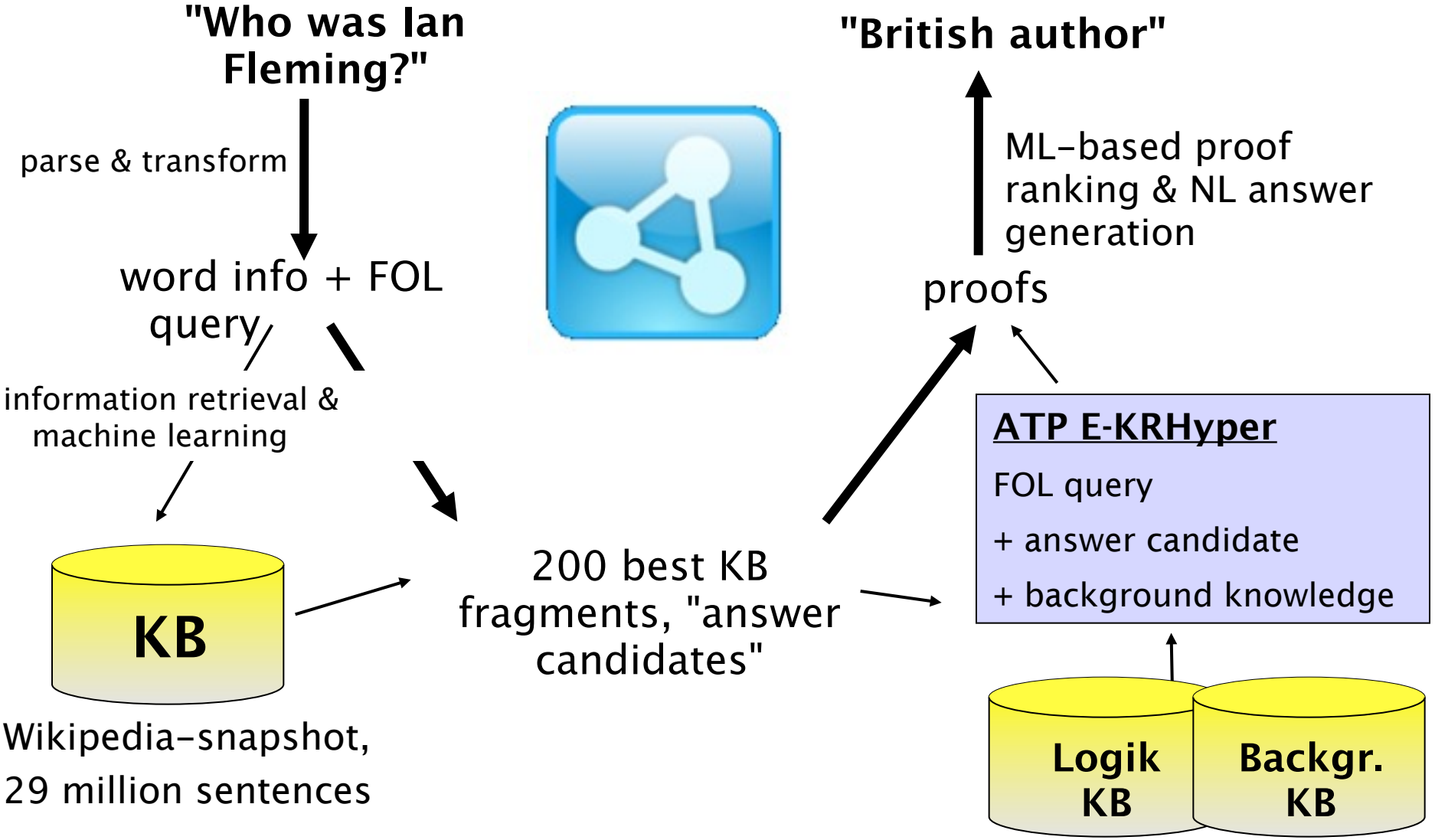

Retrieval of Answer Candidates

Pre-analysed and indexed text passages allow quick computation of syntactic filtering criteria:

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- *matchRatio*: relative proportion of lexical concepts and numerals in the question which find a match in the text passage,
- *failedMatch*: number of lexical concepts and numerals in the question which find no match in the text passage,
- *failedNames*: proper names which find no match in the text passage,
- *containsBrackets*: indicates whether passage contains parentheses. *"...Sydney (Australia) ..."*

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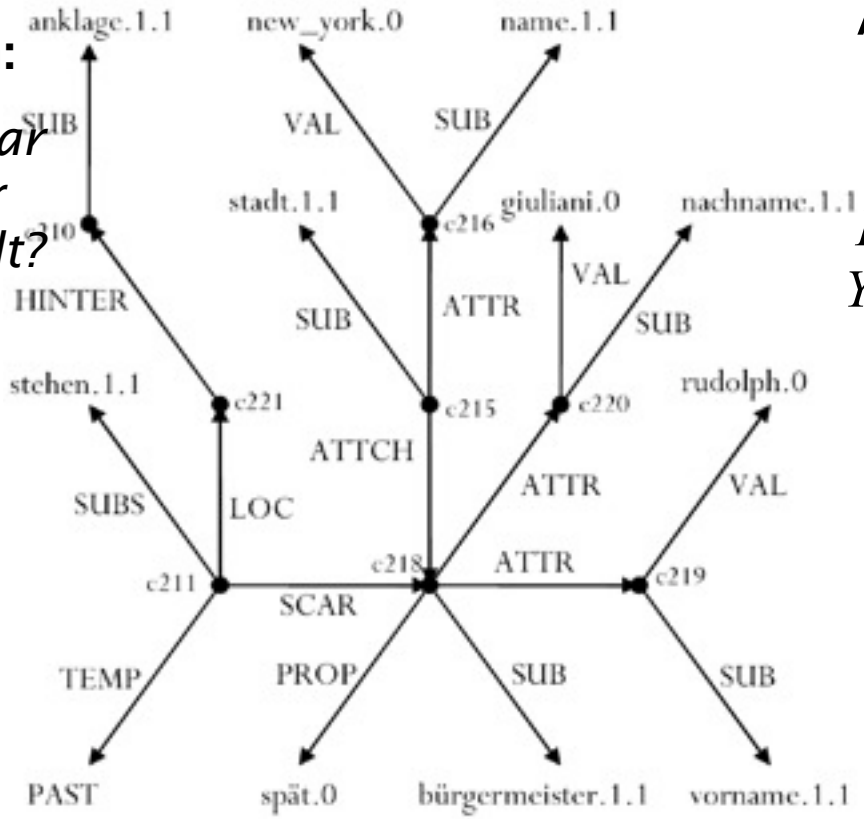
Scores are aggregated into a quality estimate using decision trees. The 'best' 200 logical text passage representations are answer candidates and will be evaluated deductively.

User question:

Rudy Giuliani war Bürgermeister welcher US-Stadt?



Answer candidate:

"Hinter der Anklage stand der spätere Bürgermeister von New York, Rudolph Giuliani."

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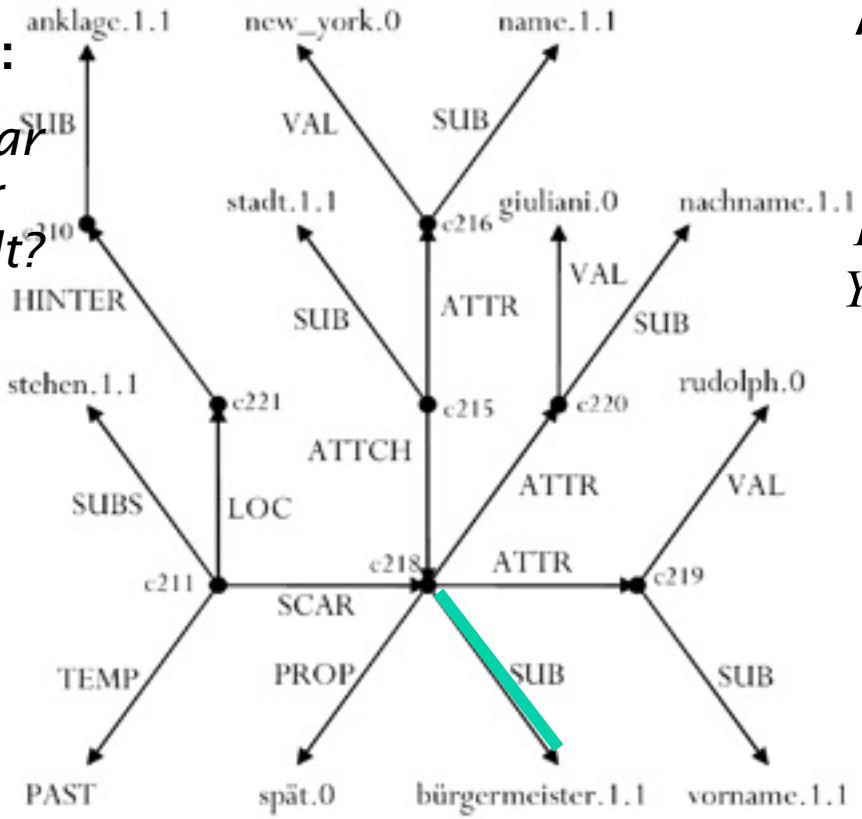

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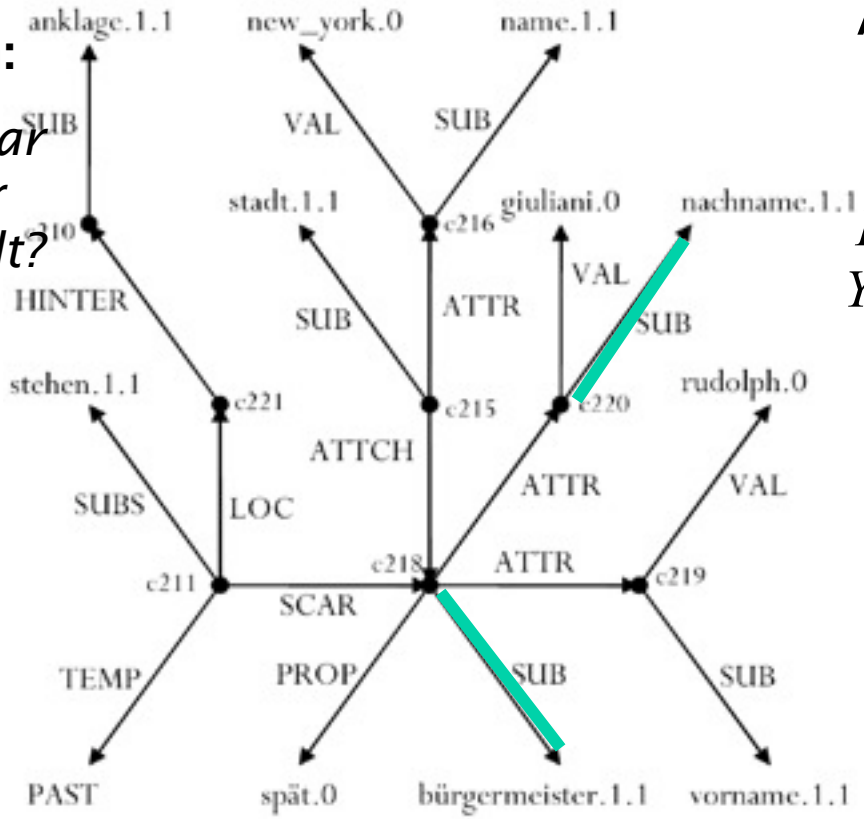

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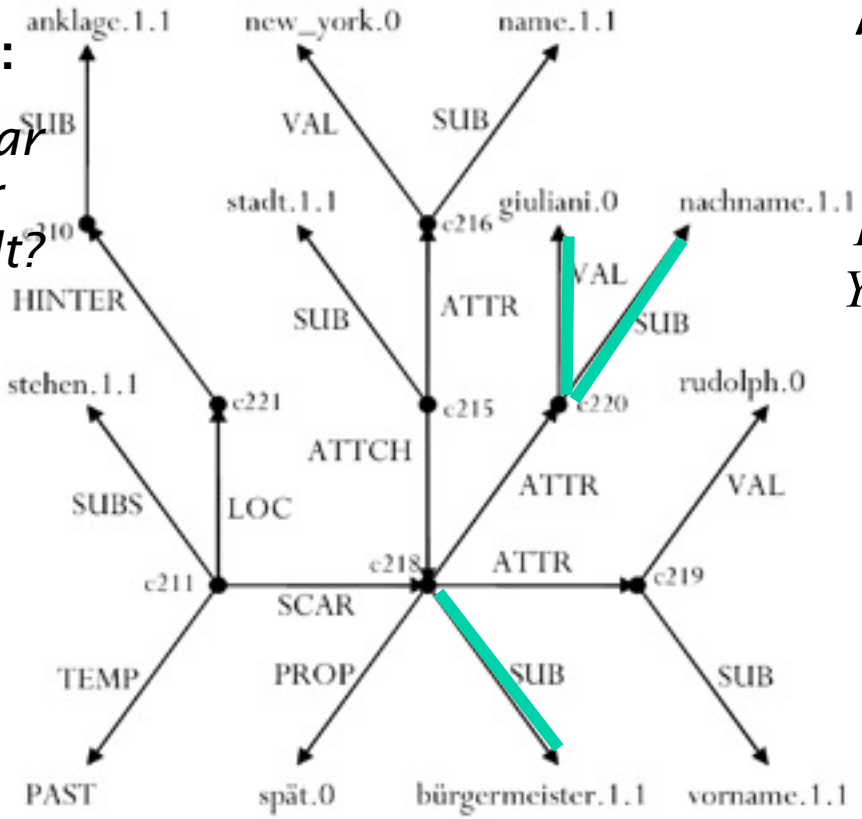

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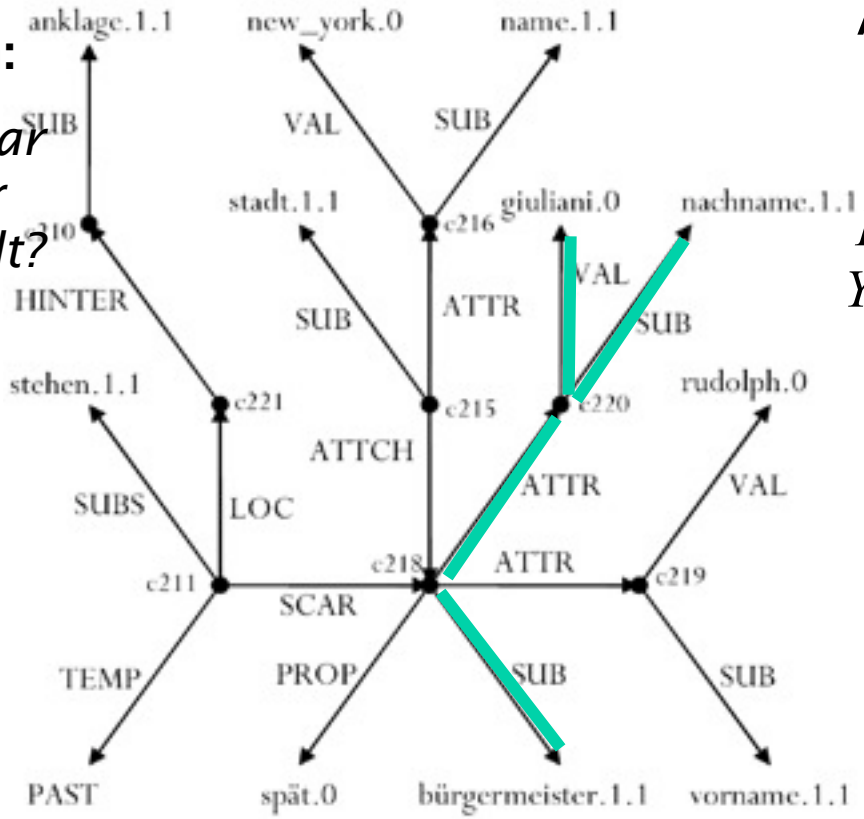

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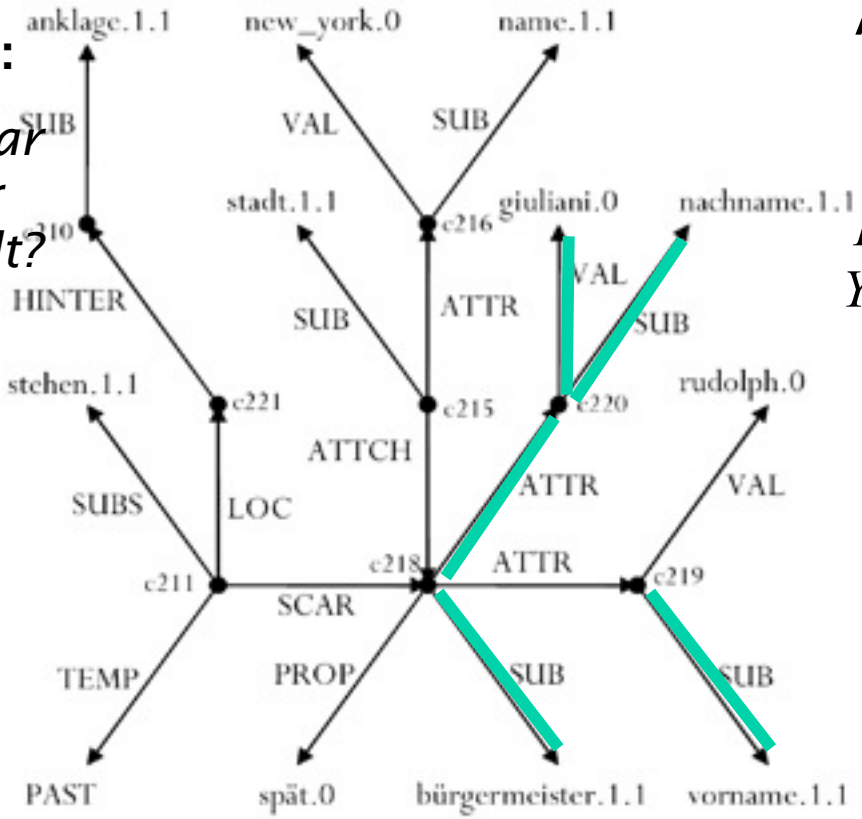

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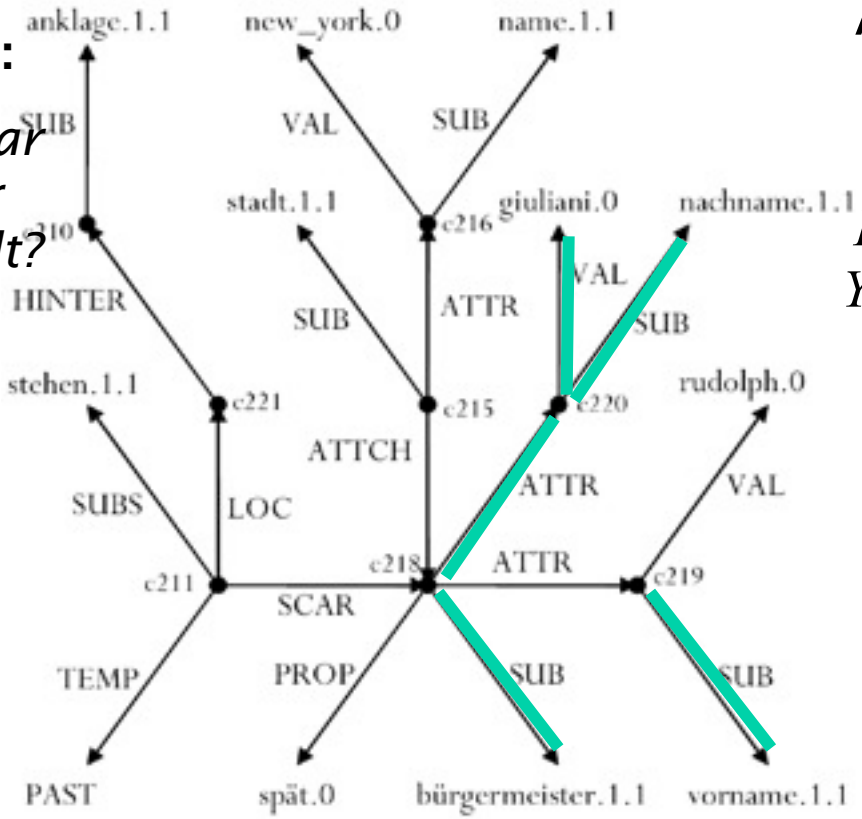

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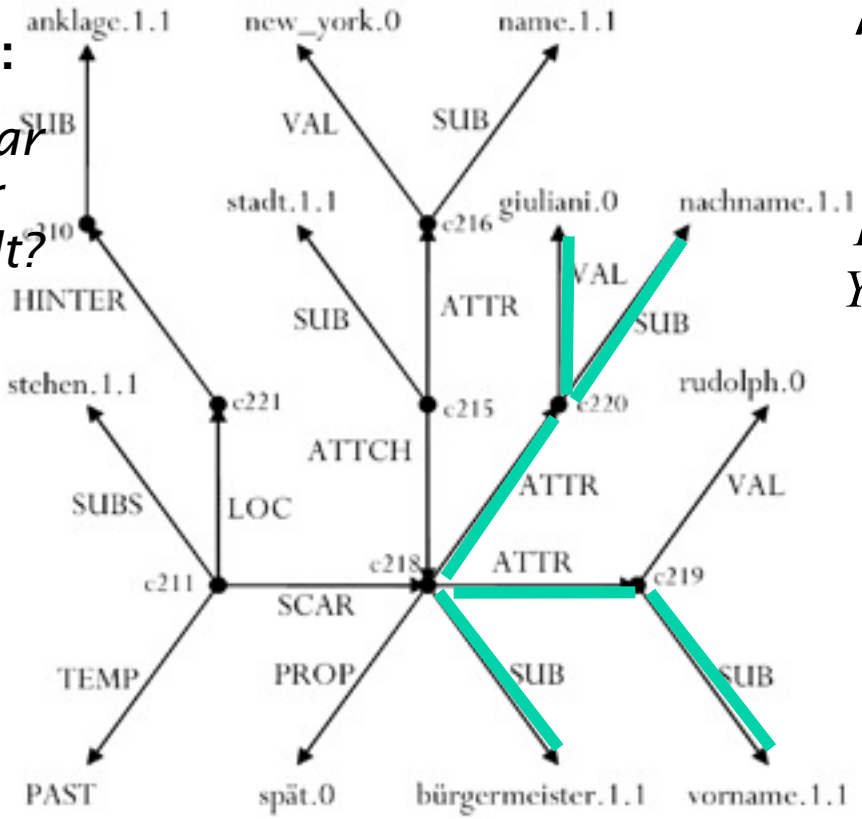

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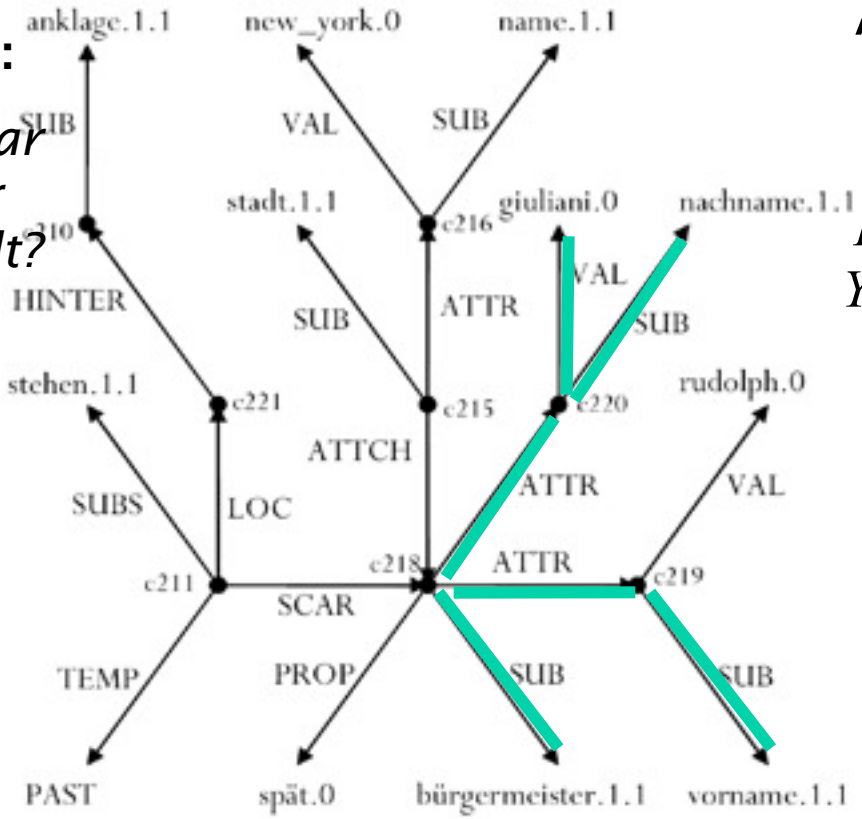

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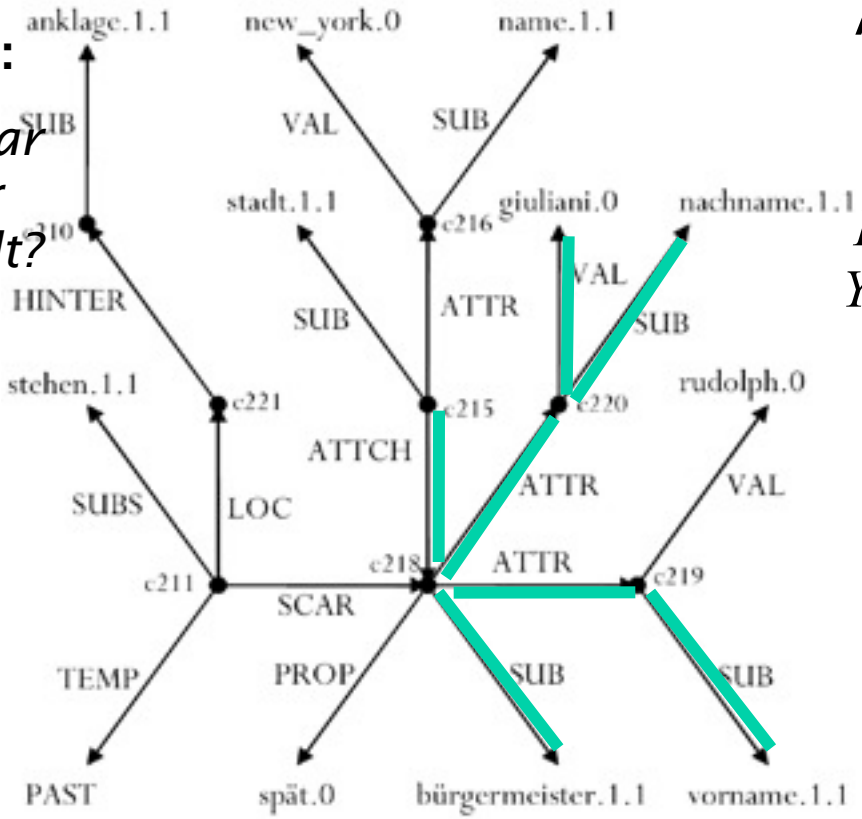

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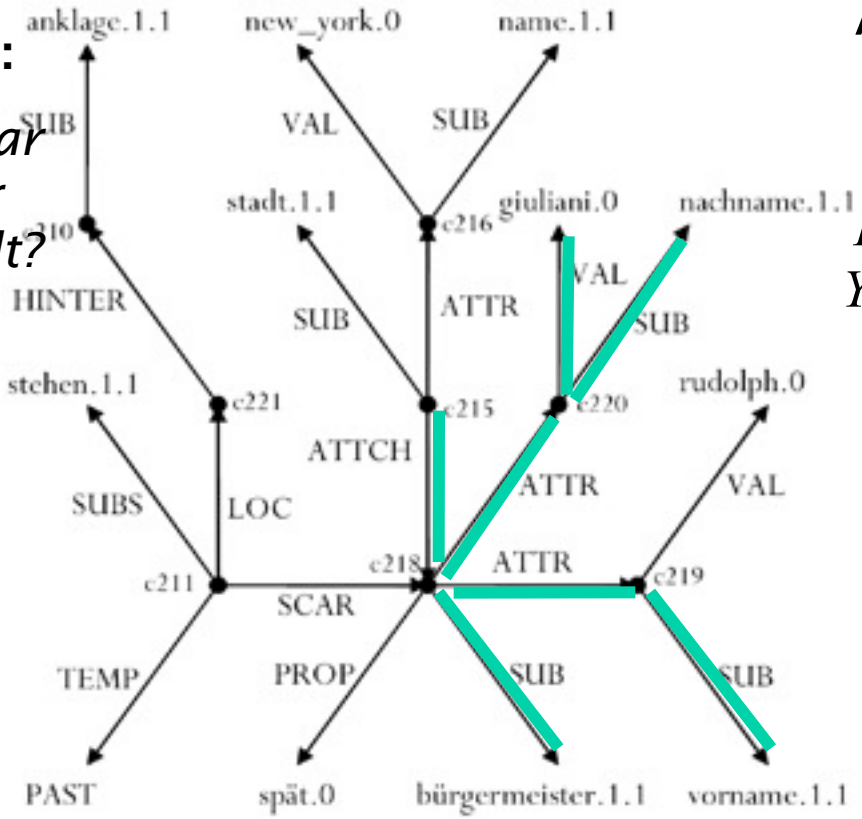

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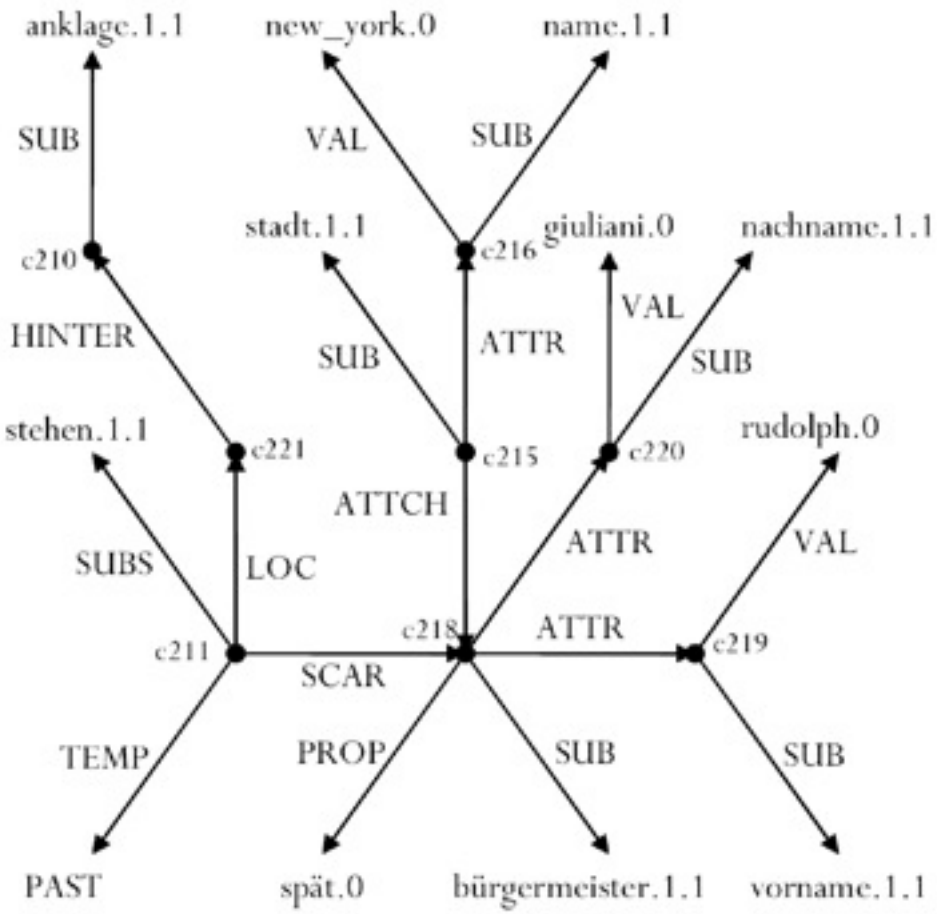
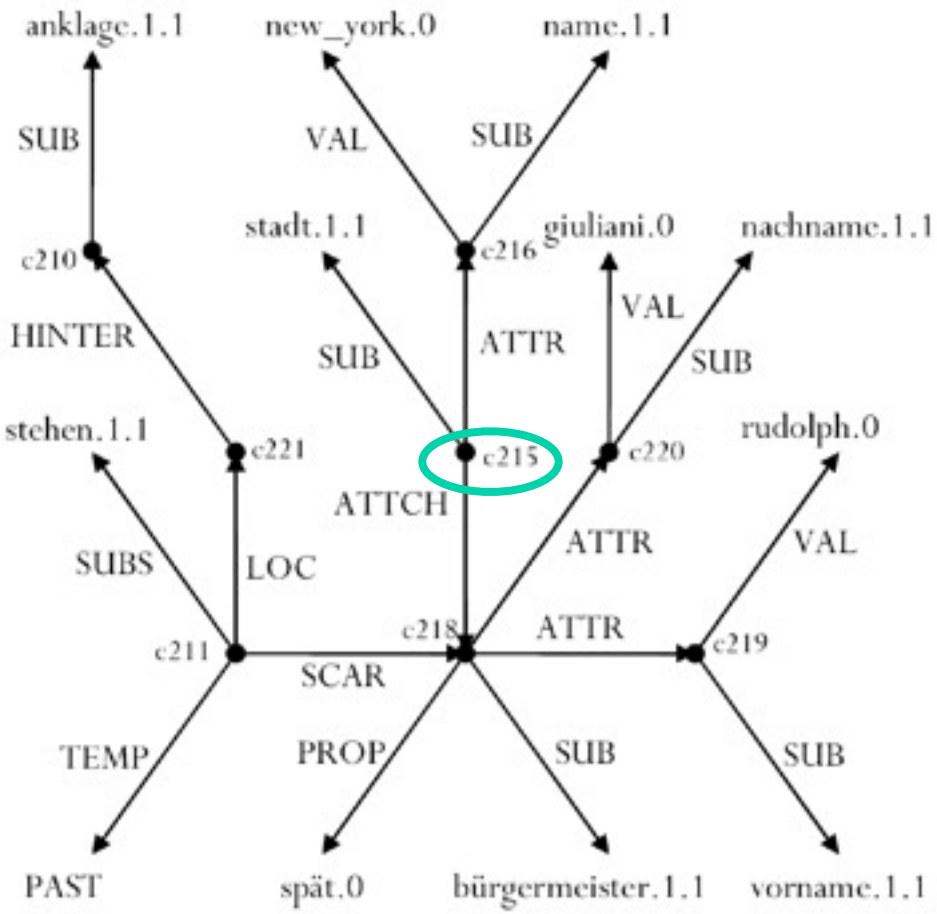
⇒ FOCUS = c215 (2 relaxations)

Answer Generation



The FOCUS-variable represents the core object of the question.

Answer Generation



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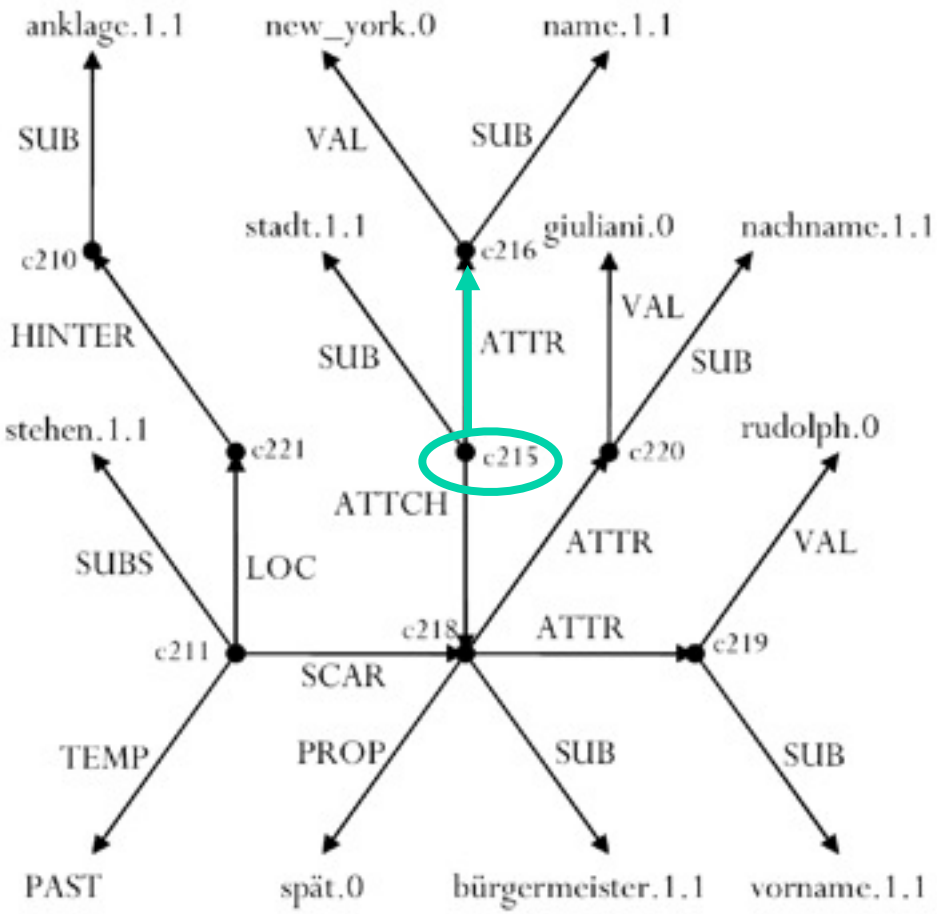

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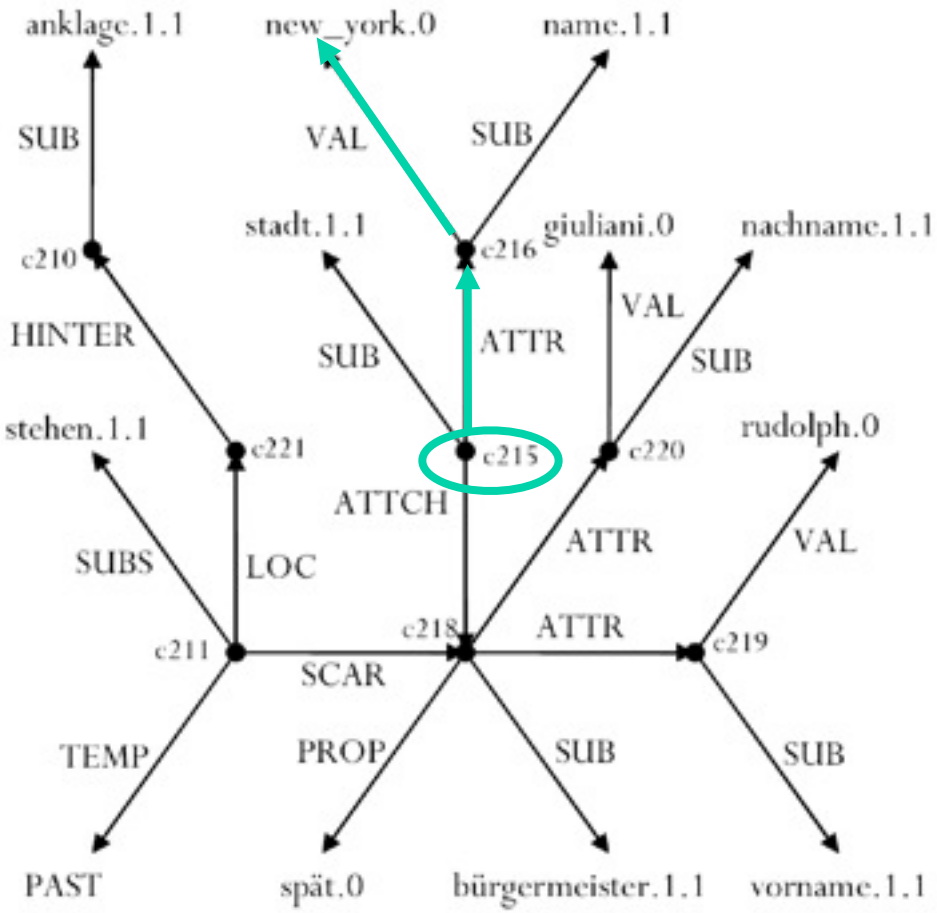

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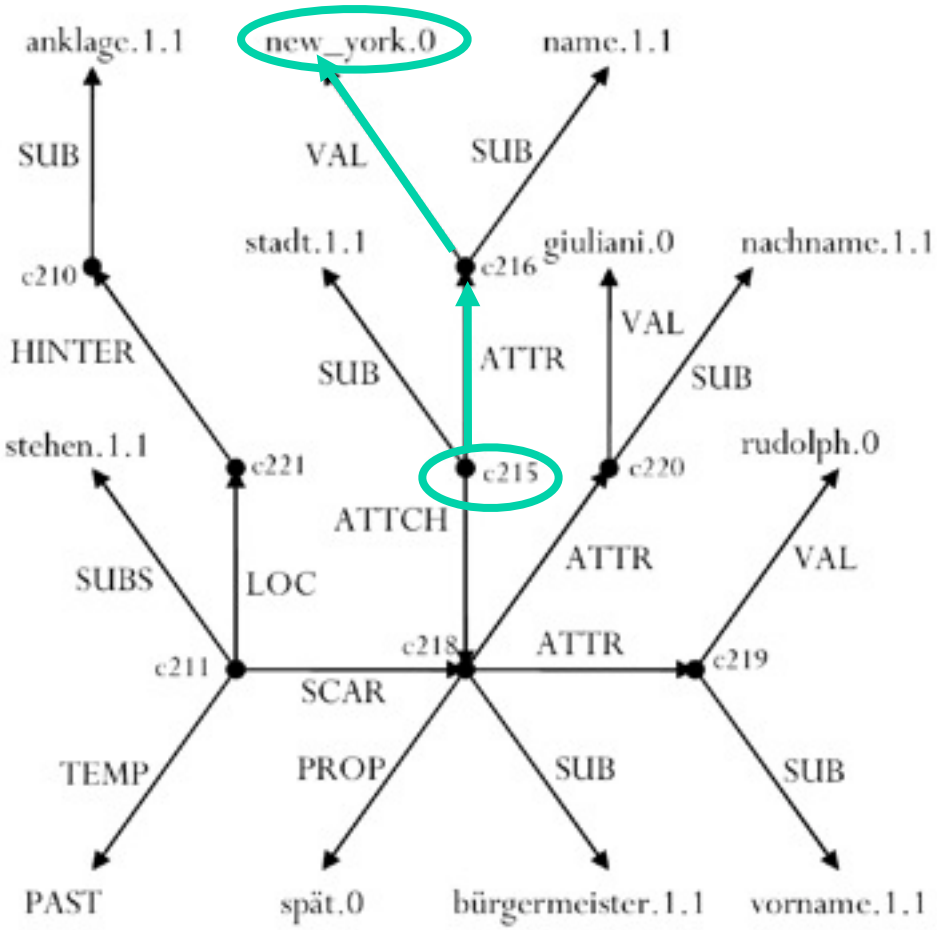

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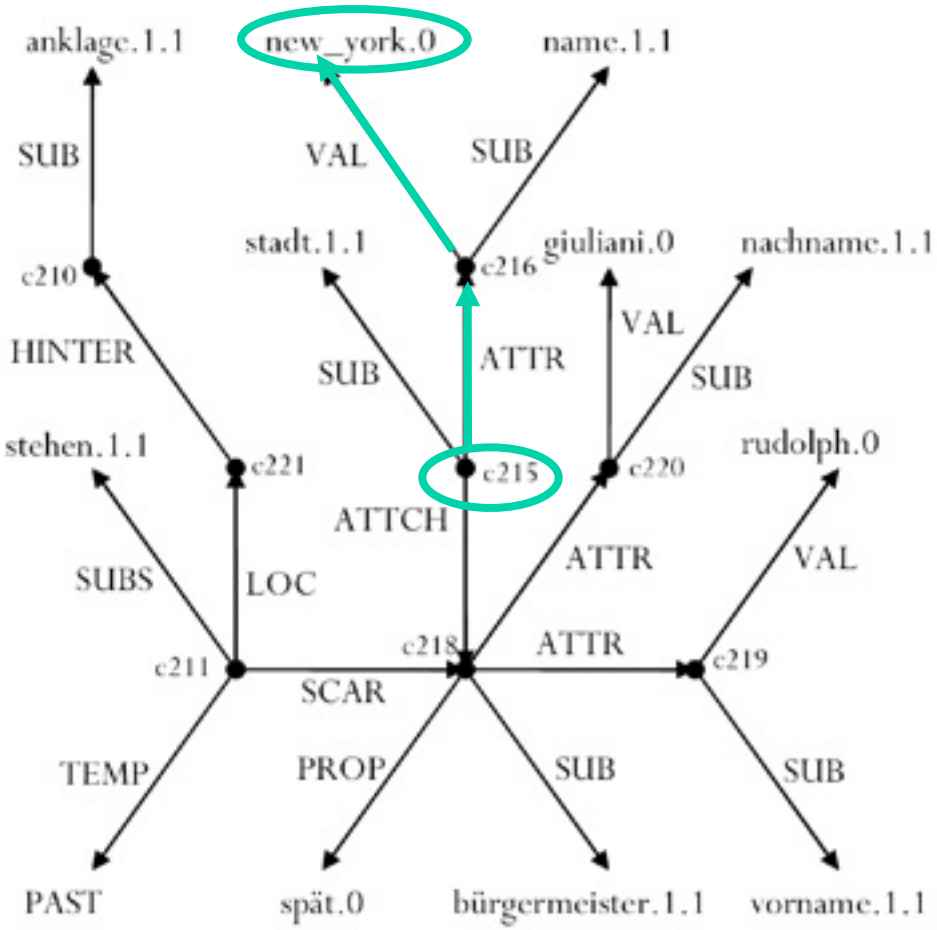


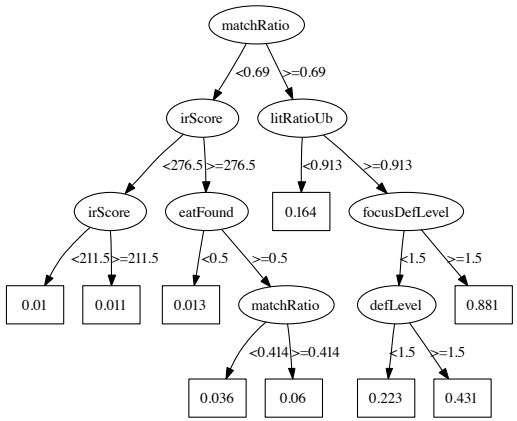
The FOCUS-variable represents the core object of the question.

"New York"

Answer Presentation

Decision tree computes a quality score for each answer, using criteria like:

- *skippedLits*: number of query literals skipped by relaxation,
- *npFocus*: FOCUS-variable was bound to a nominal phrase constant,
- *focusEatMatch*: answer type matches expected answer type,
- *irScore*: the original quality estimate for the text passage



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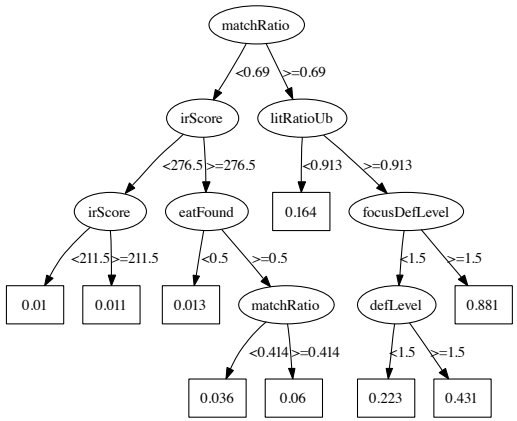
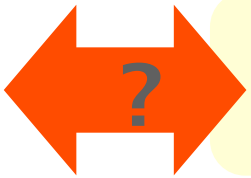


The top 5 answers are presented to the user, together with the text passages to provide context and links to the documents.

Performance Issues

Many prover runs for a single question:

- 200 candidates with up to 5 relaxations each
- >12,000 clauses input for each run



short response time (~5 sec)

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- 2(
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creating index structures for input can exceed time slot

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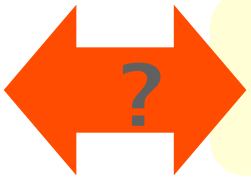


short response time (~5 sec)

Plenty of overlap between prover runs:

- all runs use the same background knowledge base (~97% of the clauses in a run)
- all relaxation runs for a candidate use the same candidate

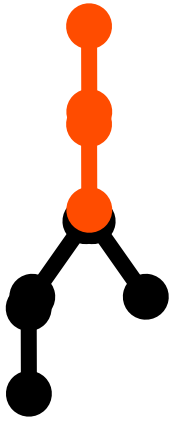
Performance Issues - Incremental Reasoning

Use overlap between relaxation runs for one candidate:

- input sets for runs differ only in one (dropped) query literal
- relaxed query clause subsumes the previous query clause

$$\neg Q_1 \vee \neg Q_2 \vee \neg Q_4 \vee \neg Q_5 \quad \subseteq \neg Q_1 \vee \neg Q_2 \vee \neg Q_3 \vee \neg Q_4 \vee$$

- all clauses derived before first derivation *Split* can be reused in next run



Performance Issues - Incremental Reasoning

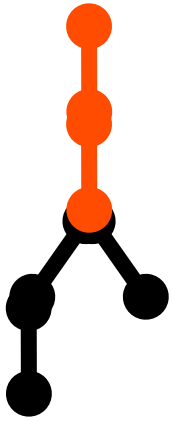
Use overlap between relaxation runs for one candidate:

- input sets for runs differ only in one (dropped) query literal
- relaxed query clause subsumes the previous query clause

$$\neg Q_1 \vee \neg Q_2 \vee \neg Q_4 \vee \neg Q_5 \quad \subseteq \neg Q_1 \vee \neg Q_2 \vee \neg Q_3 \vee \neg Q_4 \vee$$

- all clauses derived before first derivation *Split* can be reused in next run

no rigid variables !



Extensions of Reasoning

- Webservices
- Background knowledge
- Partitioning and Heuristics

Webservices in E-KRHyper

Webservices in E-KRHyper

- **webservice query/answer pair: *kb(q, a)***

  where *q* and *a* may be arbitrarily complex terms

  kb(conv(eur, usd, 299.95), 392.87)

  kb(q, a) is true iff *a* is a webservice-reply to *q*.

- **webservices representation: KB^{ext} of ground unit clauses *kb(q, a)***

- use non-ground kb-literals in clauses to access webservices:

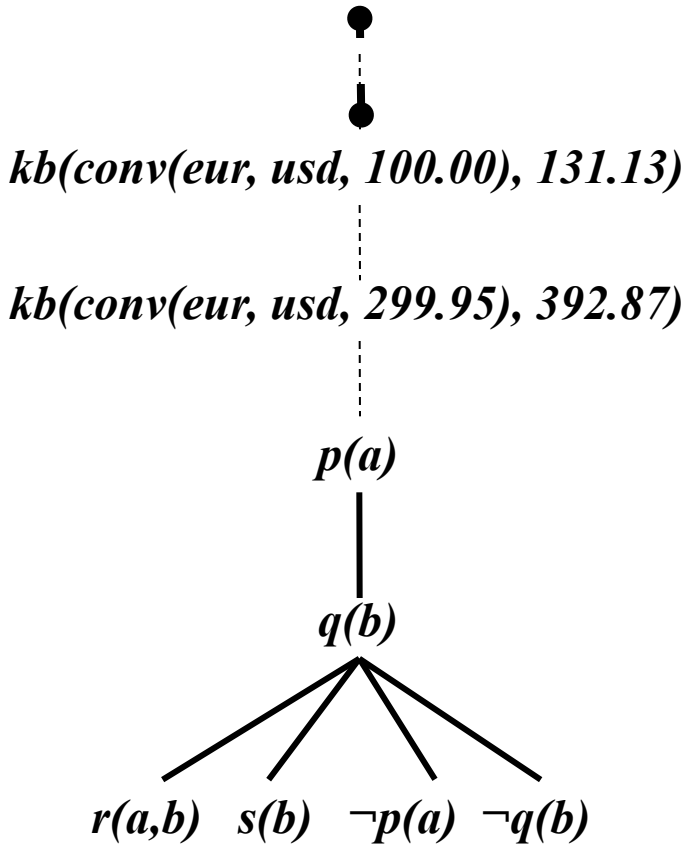
  $dollarprice(x,z) \leftarrow europrice(x,y) \wedge kb(conv(eur, usd, y), z).$

Webservices in E-KRHyper

In theory:

Webservices in E-KRHyper

In theory:



Webservices in E-KRHyper

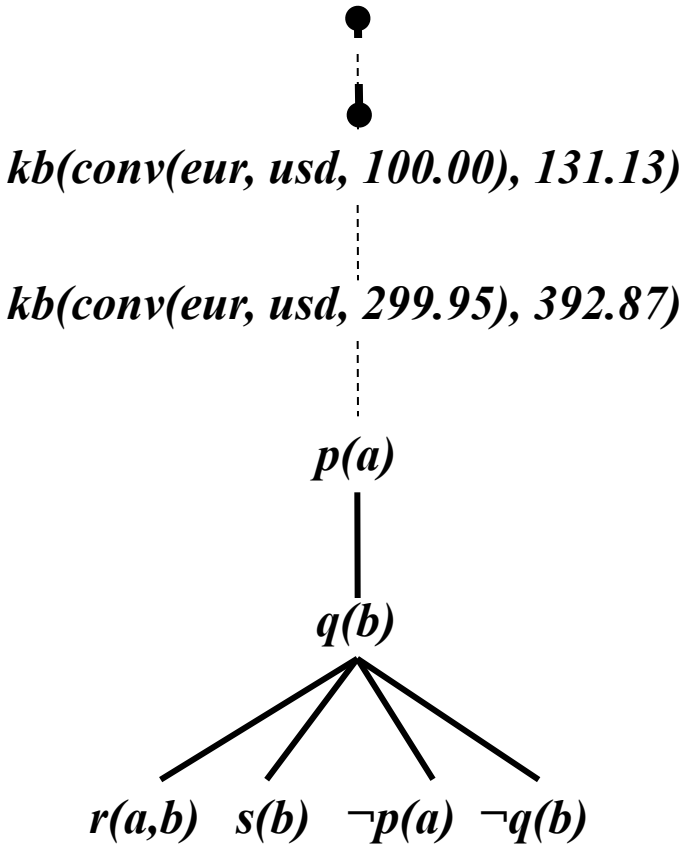
In theory:

Infeasible in practice:

KB^{ext} may be infinite,

retrieving a *kb(q,a)* takes time.

⇒ minimize accesses to KB^{ext}.



Example:

...

dollarprice(x,z) ← europrice(x,y) ∧ kb(conv(eur, usd, y), z).

europrice(coke, 1.20)

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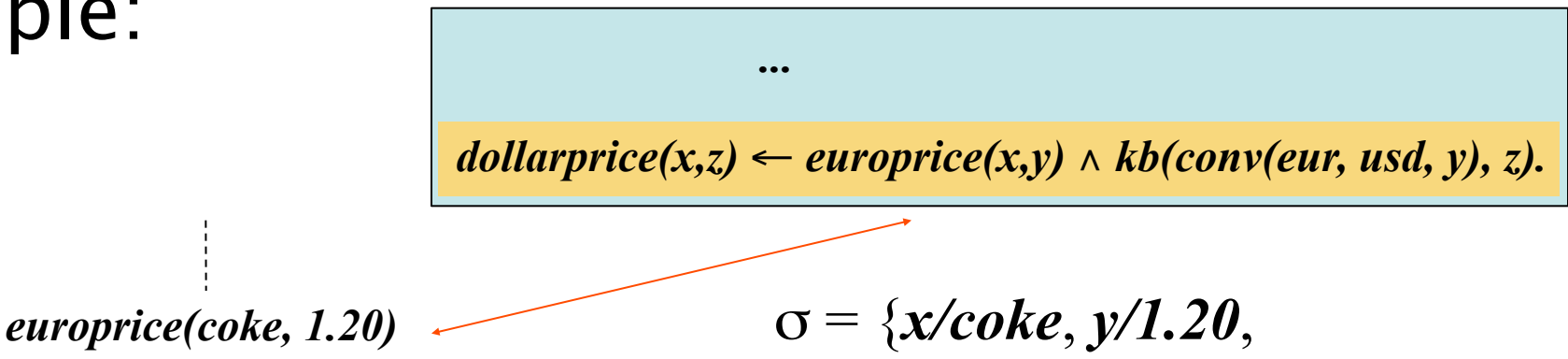
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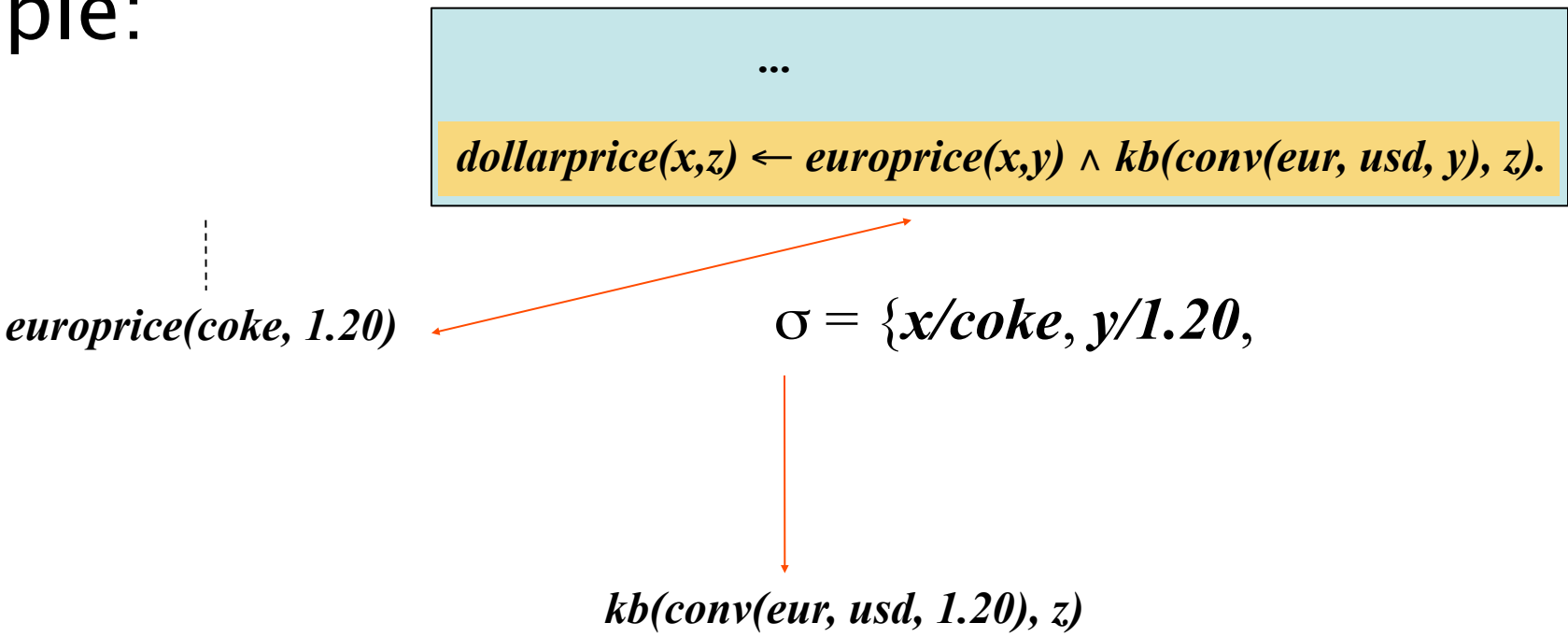
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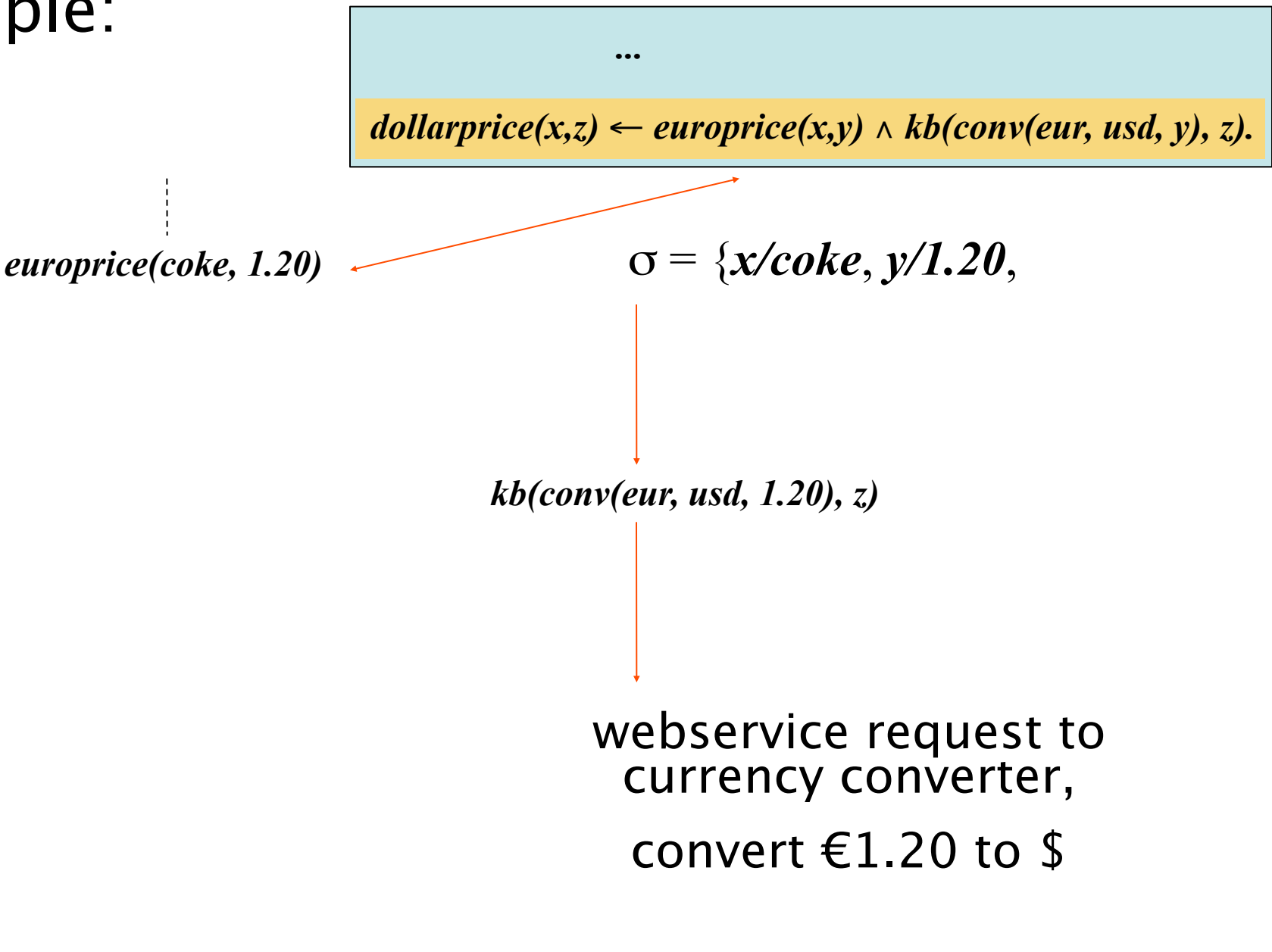
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webservice request to currency converter,
convert €1.20 to $

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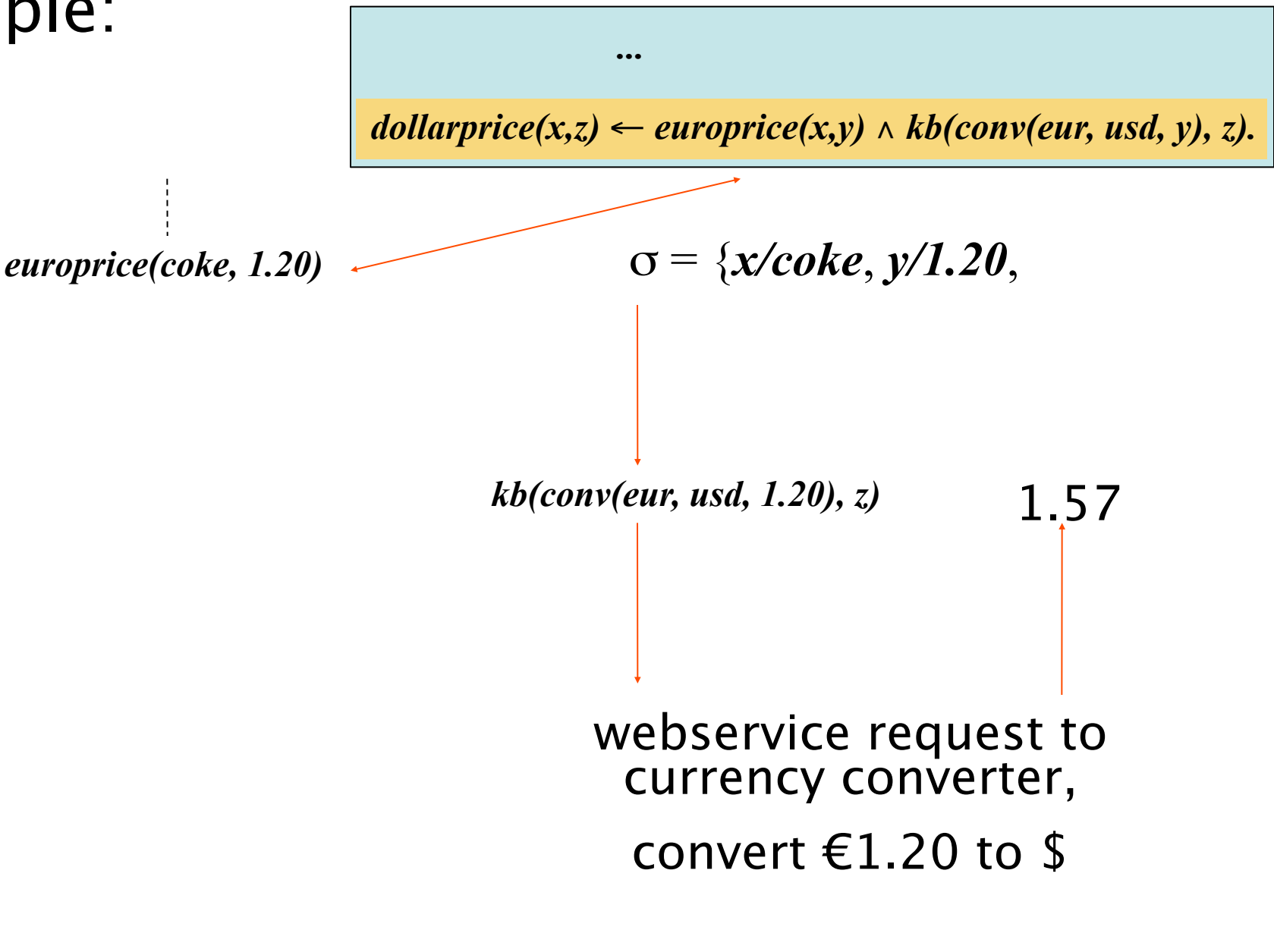
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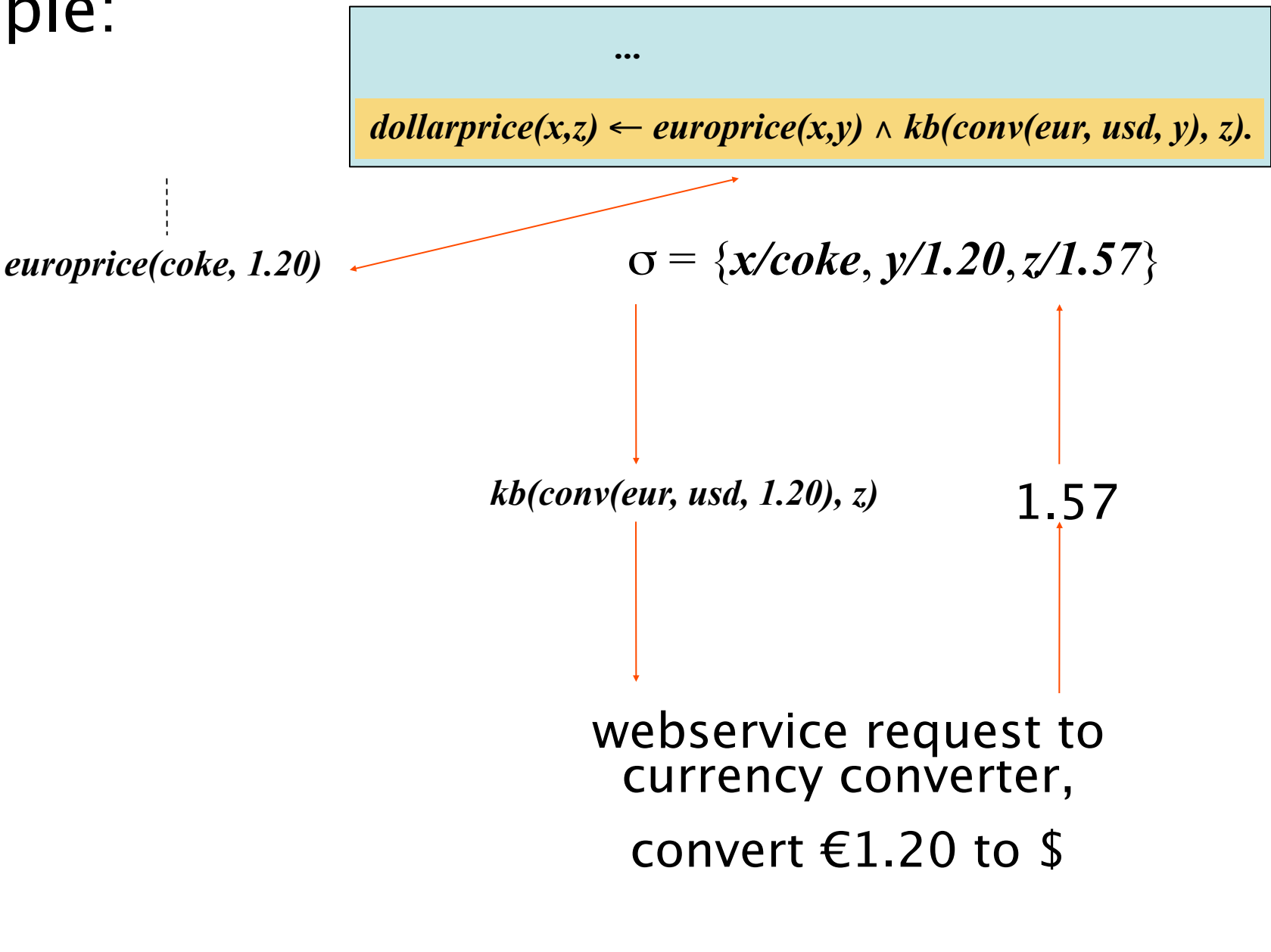
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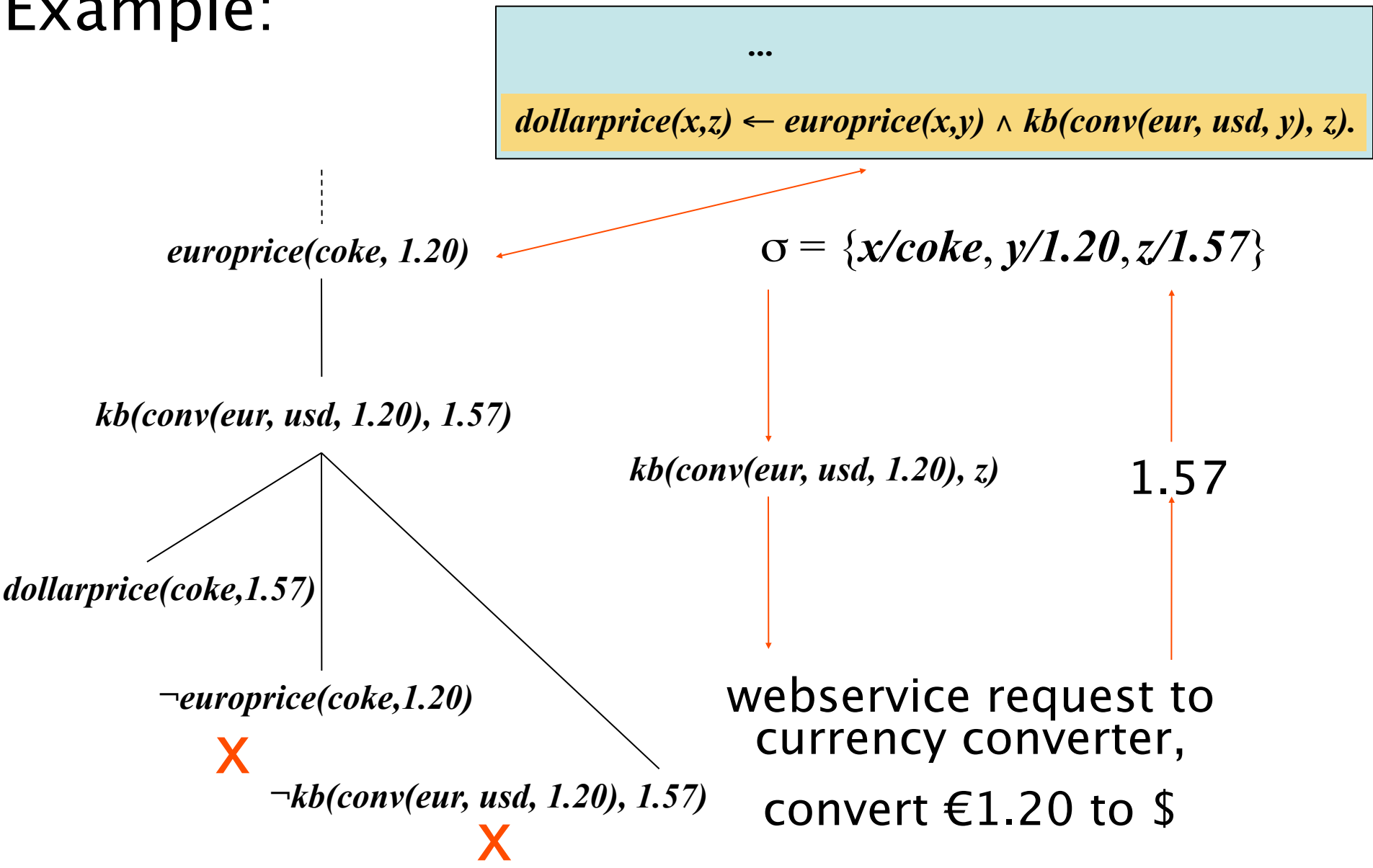
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1.57
dollarprice(coke,1.57)
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X
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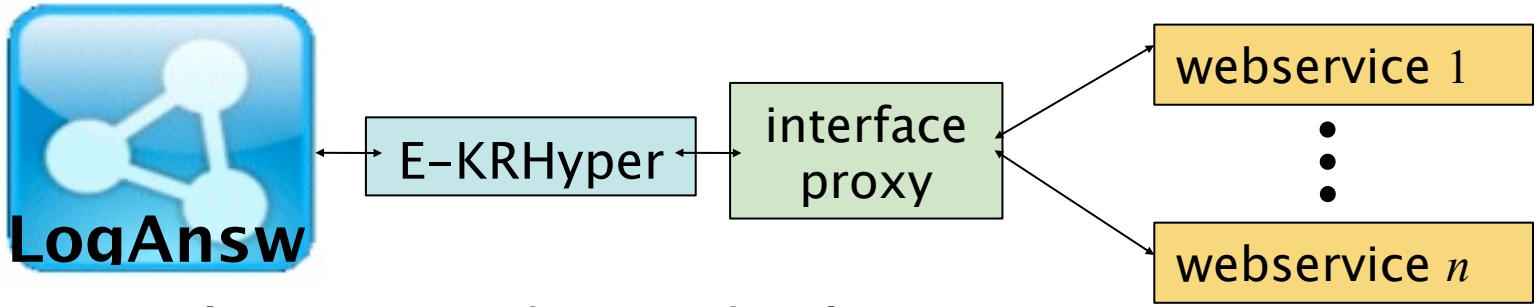
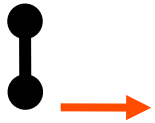
Webservice via proxy

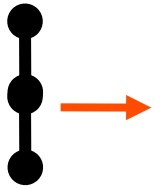


proxy always responds immediately:

- "wait" - proxy asks webservice; prover does other inferences and will ask again later
- <result> - webservice has been asked and result is in proxy cache
- "no result" - webservice has been asked but cannot provide a useful result



ws-query 1: "wait" Continue in current branch with other inferences.



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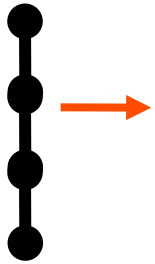

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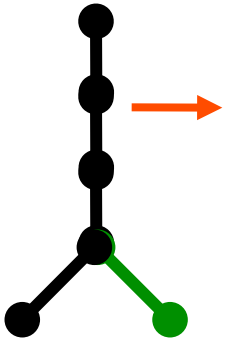

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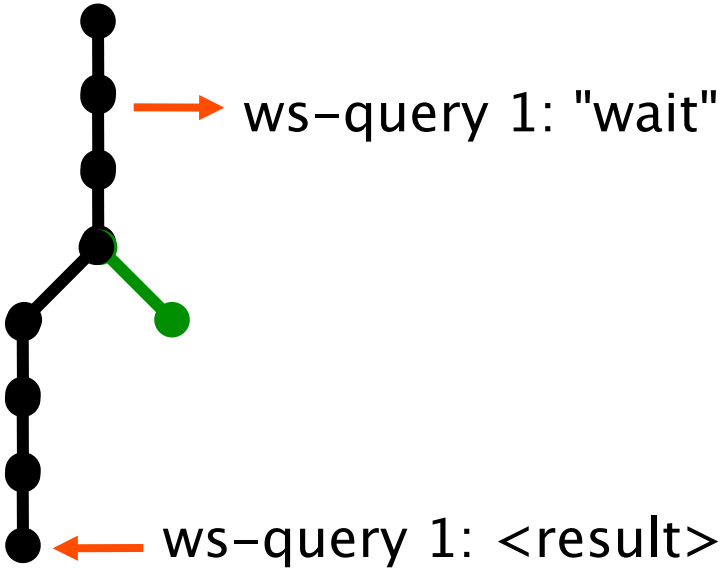
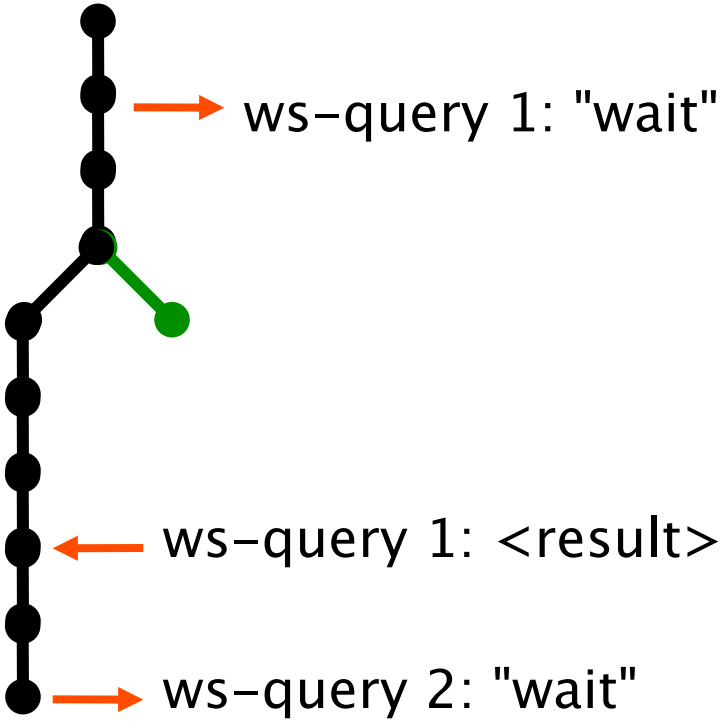

ws-query 1: "wait"
Continue in current branch with other inferences.
ws-query 1: <result>



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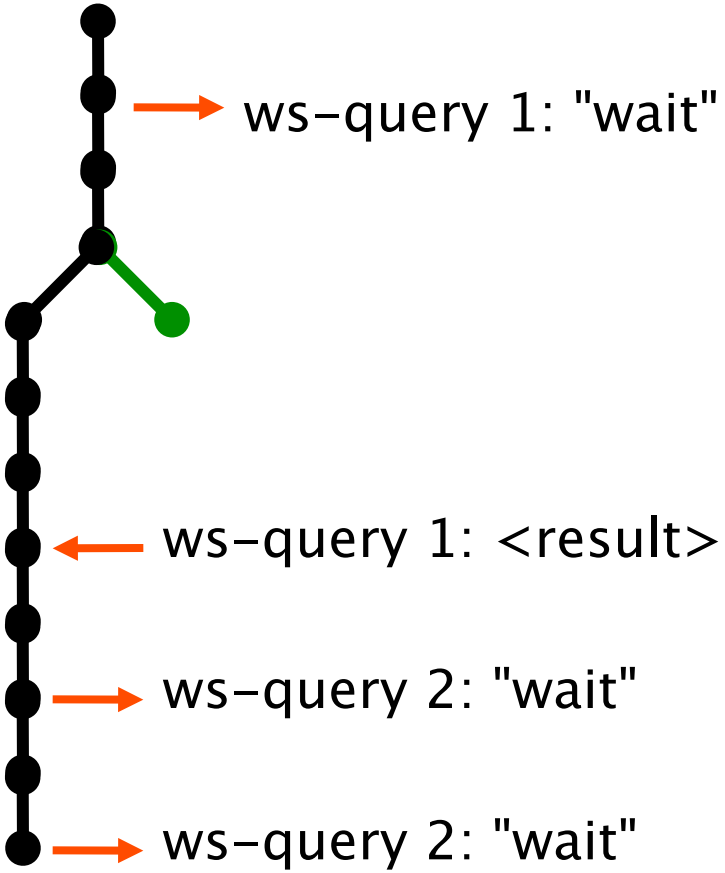

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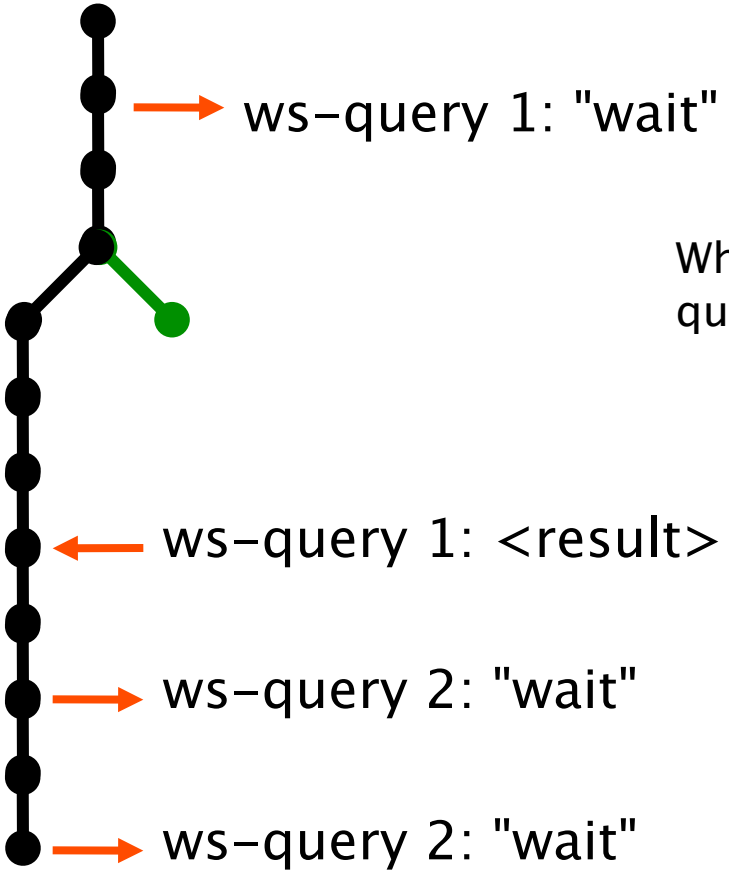
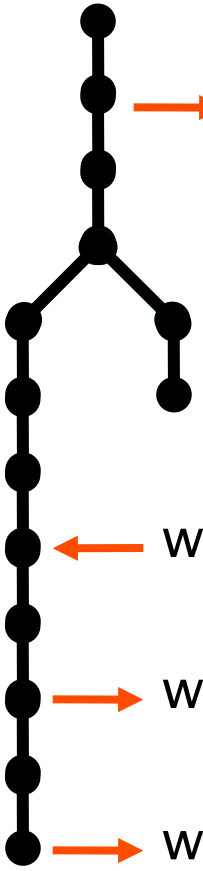


Continue in current branch with other inferences.

When the current branch is exhausted and a query is still waiting, postpone the branch.

postponed



ws-query 1: "wait"

Continue in current branch with other inferences.

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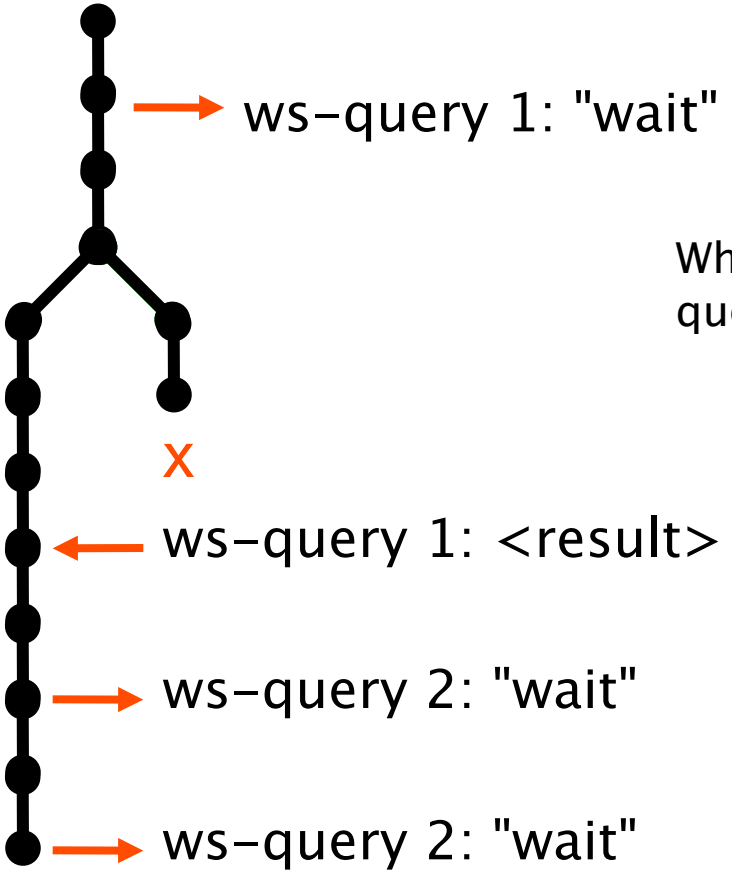
ws-query 1: <result>

ws-query 2: "wait"

ws-query 2: "wait"

postponed



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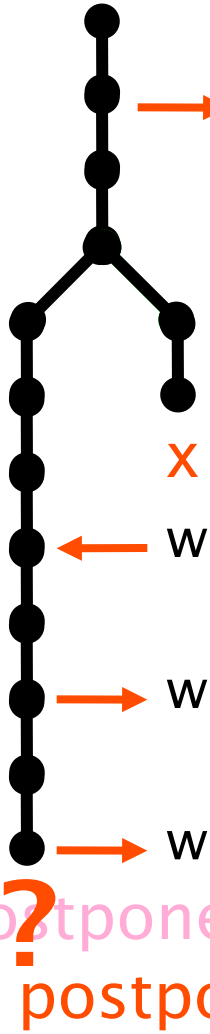

Continue in current branch with other inferences.

When the current branch is exhausted and a query is still waiting, postpone the branch.

Return to postponed branch when all other branches have been closed or postponed.

Waiting query returns...

- <result>: continue reasoning
- "no result": done, branch is model
- "wait": depends on configuration:
  either treat as "no result",
  or wait indefinitely until some waiting query returns <result> or "no result"

Webservices in Use

Webservices in Use

- Yahoo GeoPlanet
- Weather Service
- Currency Converter

- OpenCyc
- DBPedia
- SpassYago -- coming soon?

Webservices for Abductive Relaxation

logical query representation:

$false \leftarrow Q_1 \wedge \ldots \wedge Q_n$

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$false \leftarrow Q_1 \wedge ... \wedge Q_n$

1. add abductive relaxation clause:

$relAns(rel(c_1, x_1), ..., rel(c_m, x_m)) \leftarrow$
$Q_1' \wedge ... \wedge Q_n' \wedge kb(abduce(c_1), x_1) \wedge ... \wedge kb(abduce(c_m), x_m)$

where Q_1',..., Q_n' result from Q_1,..., Q_n by replacing each occurrence c_i of a constant with a fresh variable x_i.

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2. add trivial abduction unit clause:

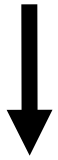
$kb(abduce(x), x) \leftarrow .$

"Who invented Coca-Cola?"

$$\mathit{false} \leftarrow \mathit{is}(x, \mathit{person}) \wedge \mathit{invent}(x, \mathit{cocacola}).$$

"Who invented Coca-Cola?"

false ← ***is*(*x*, *person*)** ∧ ***invent*(*x*, *cocacola*).**



E-KRHyper adds:

***relAns*(*rel*(*person*,*y*), *rel*(*cocacola*, *z*))** ←

***is*(*x*, *y*)** ∧ ***invent*(*x*, *z*)**

∧ ***kb*(*abduce*(*person*), *y*)** ∧ ***kb*(*abduce*(*cocacola*), *z*).**

***kb*(*abduce*(*x*), *x*)** ← .

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E-KRHyper adds:

$$\mathit{relAns}(\mathit{rel}(\mathit{person}, y), \mathit{rel}(\mathit{cocacola}, z)) \leftarrow$$
$$\mathit{is}(x, y) \wedge \mathit{invent}(x, z)$$
$$\wedge\ \mathit{kb}(\mathit{abduce}(\mathit{person}), y) \wedge \mathit{kb}(\mathit{abduce}(\mathit{cocacola}), z).$$

$$\mathit{kb}(\mathit{abduce}(x), x) \leftarrow .$$

- prover will run until proof is found or timeout
- if timeout, return any derived relAns-facts instead
- let user decide if abductive relaxations were acceptable(?)

false ⇐ is(x, person) ∧ invent(x, cocacola).

relAns(rel(person,y), rel(cocacola,z)) ⇐

is(x, y) ∧ invent(x, z) ∧ kb(abduce(person), y) ∧ kb(abduce(cocacola), z).

kb(abduce(x), x) ⇐ .

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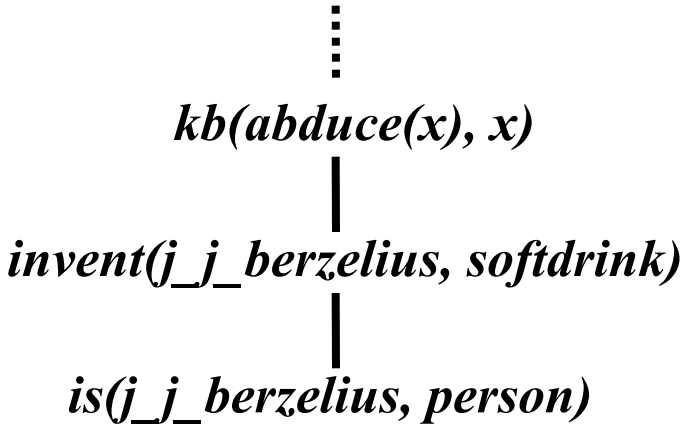

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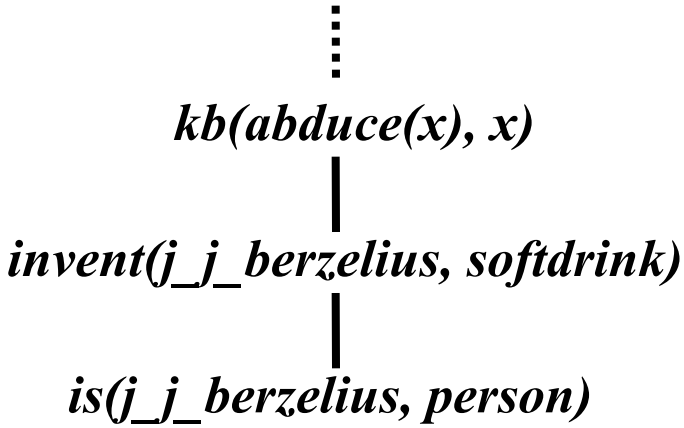

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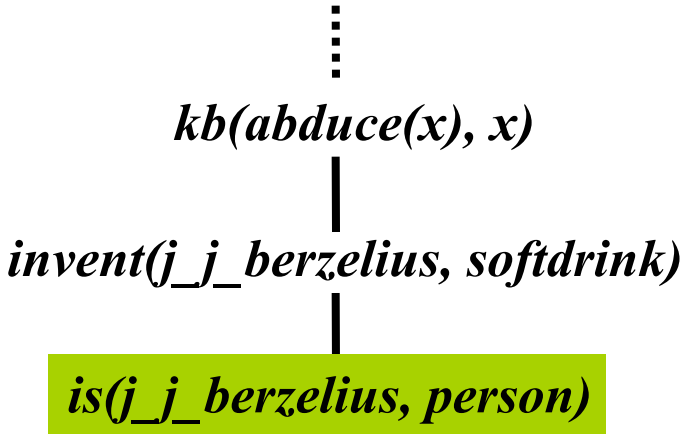

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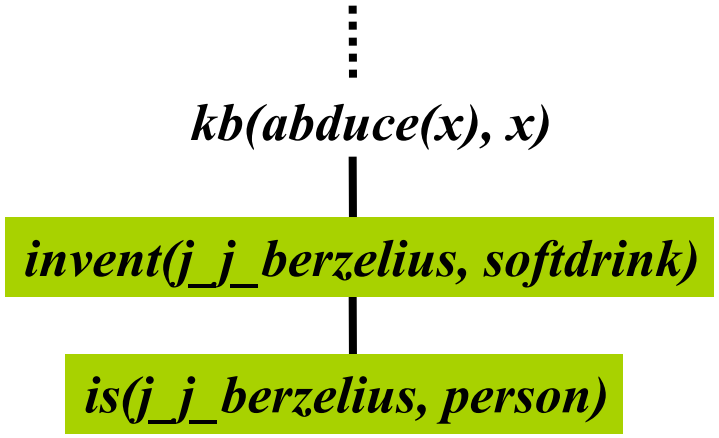

σ = {*x/j_j_berzelius*,
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relAns(rel(person,y), rel(cocacola,z)) ←
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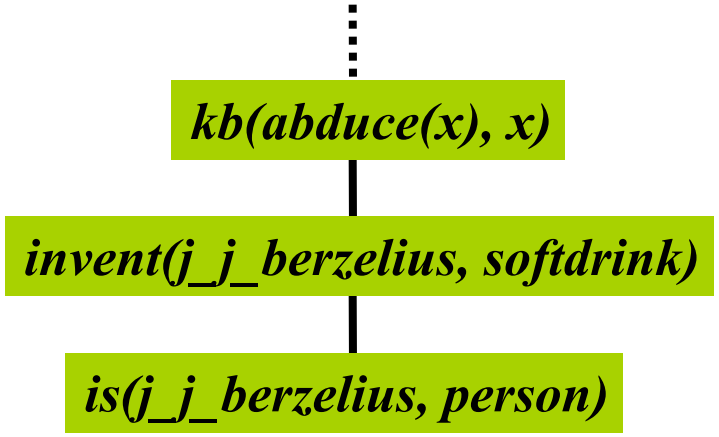

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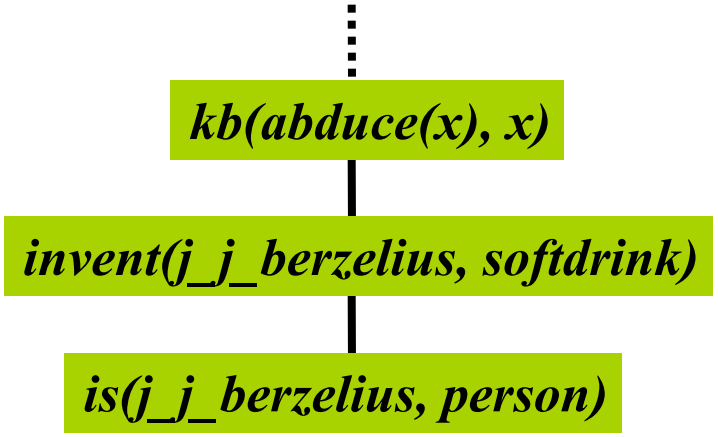

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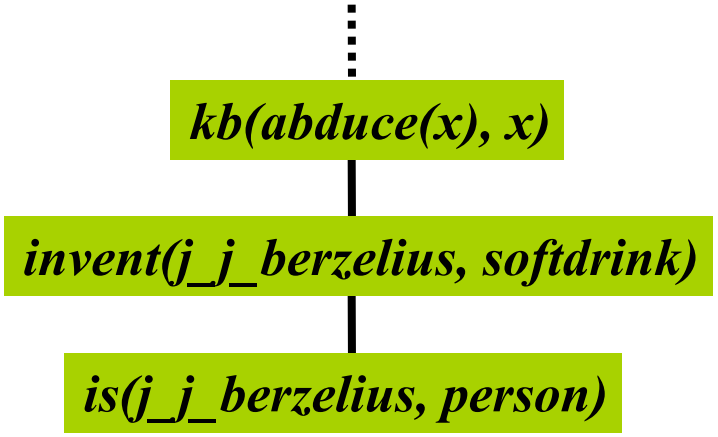

webservice request to ontology browser,

superclasses of *cocacola*?

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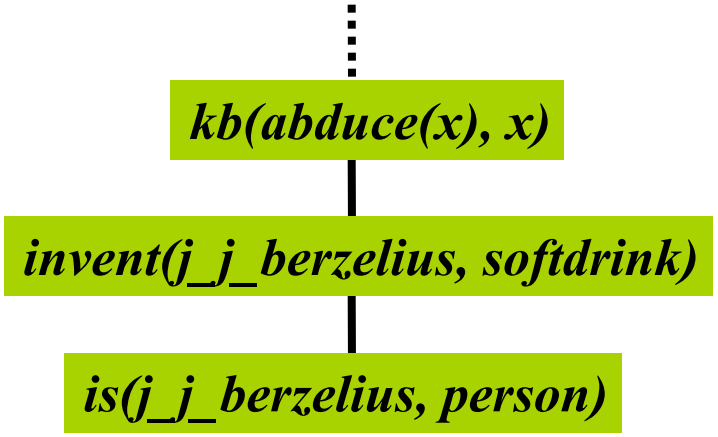

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response: *kb(abduce(cocacola),softdrink)*

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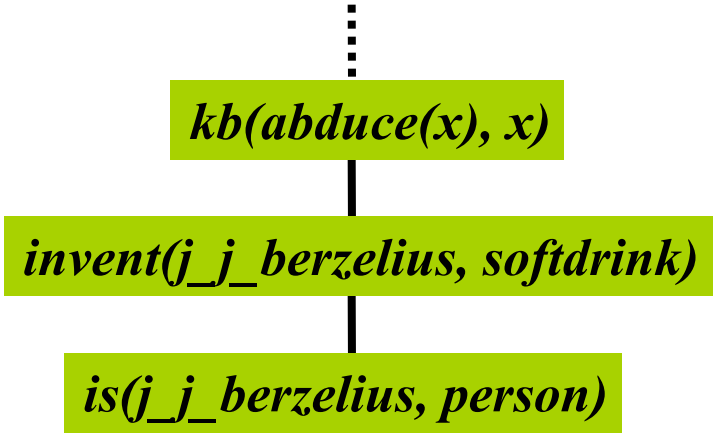

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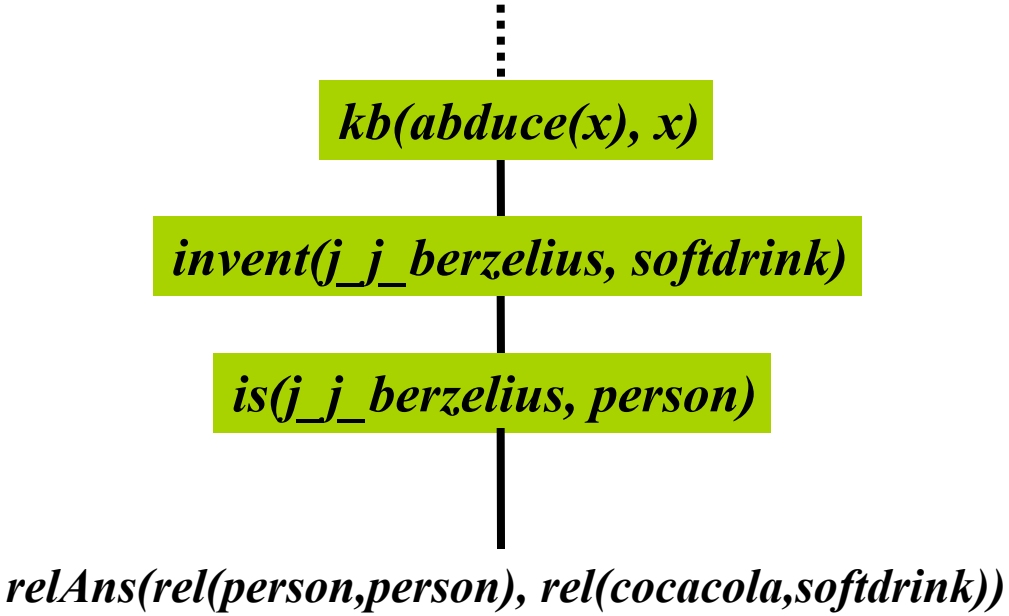
false ← *is(x, person)* ∧ *invent(x, cocacola).*

relAns(rel(person,y), rel(cocacola,z)) ←
is(x, y) ∧ *invent(x,z)* ∧ *kb(abduce(person),y)* ∧ *kb(abduce(cocacola), z)*

kb(abduce(x), x) ← .



webservice request to ontology browser,

superclasses of *cocacola*?
response: *kb(abduce(cocacola),softdrink)*

σ = {*x/j_j_berzelius*,
y/person,
z/softdrink}

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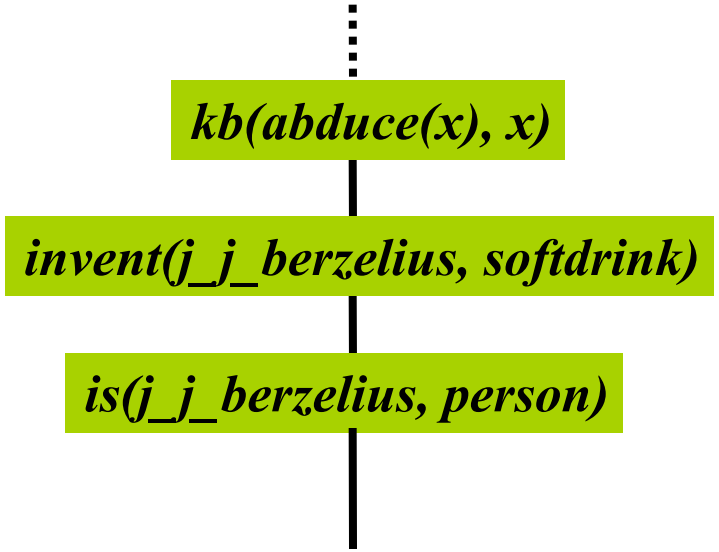

relAns(rel(person,person), rel(cocacola,softdrink))

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response: *kb(abduce(cocacola),softdrink)*

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z/softdrink}

"Who invented Coca-Cola?"
- "J.J. Berzelius, if 'soft drink' can replace 'Coca-Cola'." (No!)

Partitioning of Clause set

Compute dependency graphs in pre-processing

Test:

309 multi-literal clauses

10 061 units

Reduction of 20% of clauses and 10% of time

Issues for AD

Time-constraints

Relaxing queries

Abduction

Webservices

Confidence Measures

QA Forums

Forum users ask and answer questions.

Users can grade answers or answerers.

QA-systems like LogAnser usually give the best answer they can find - even if it is poor.

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If 18% of questions are answered correctly,
then almost 82% get wrong answers.

High risk that forum users perceive LogAnswer as a nuisance!

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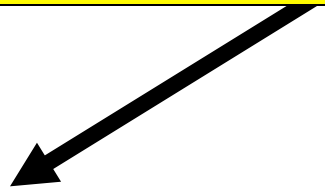
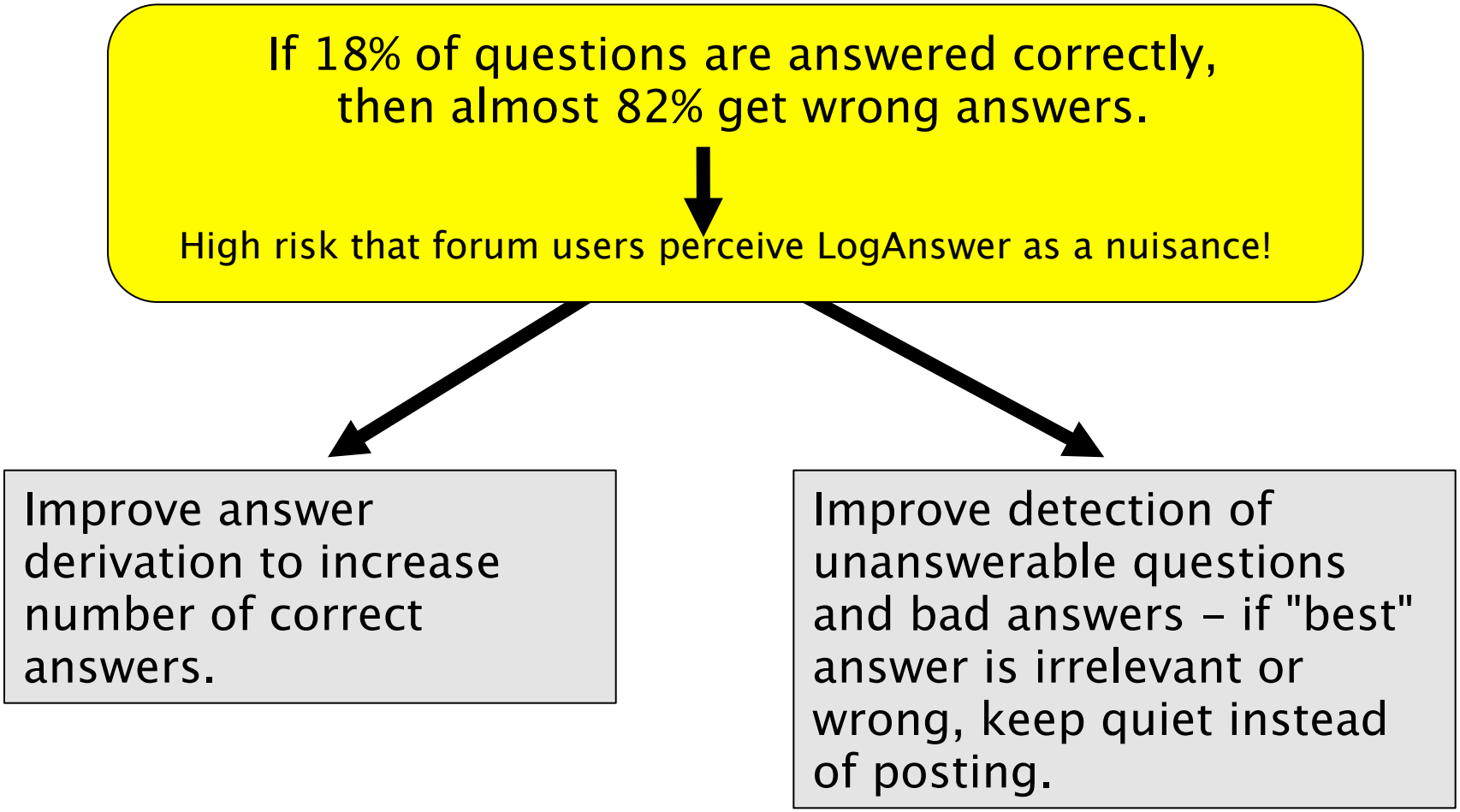


Improve answer derivation to increase number of correct answers.

QA-systems like LogAnser usually give the best answer they can find – even if it is poor.



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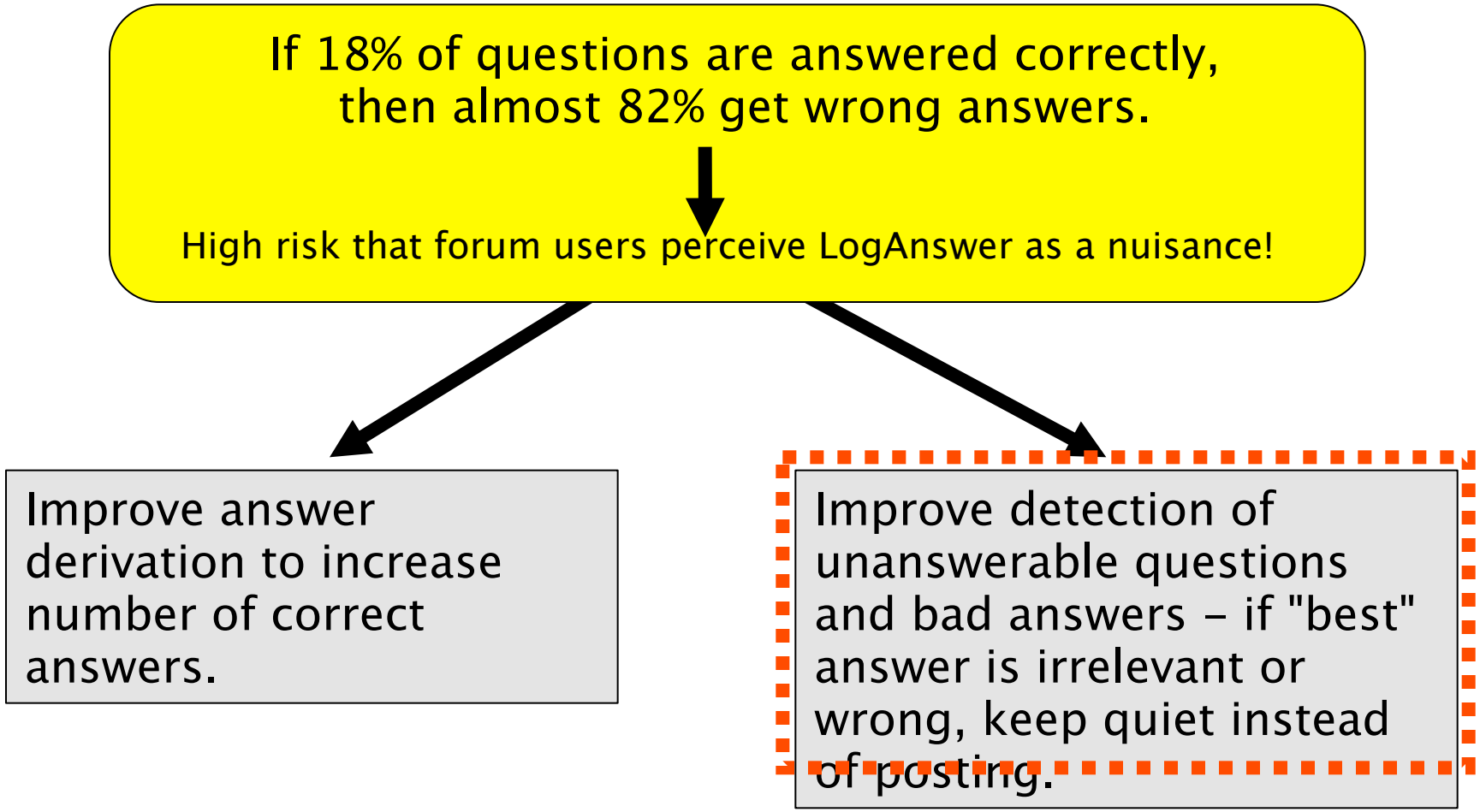

Block question categories:

Some categories contain mostly unanswerable questions.

- celebrities: **"What is the phone number of Justin Bieber?"**
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Block question types:

Some questions ask for opinions, recognizable by keywords.

- **"What do you think of...?"**
- **"What is the best/worst/most beautiful...?"**

External Ontologies

- Cyc is too large for ATP:

  3.3 million formulas in the TPTP-version of OpenCyc, requires 15 minutes to load and 7GB RAM in E-KRHyper.

  - Use query-based axiom selection methods.
  - No equational reasoning for Cyc-axioms.
  - Only use some parts of Cyc (i.e. subclass-assertions).