Incremental Approach to Error Explanations in Ontologies

Inference Support for Semantic Annotations

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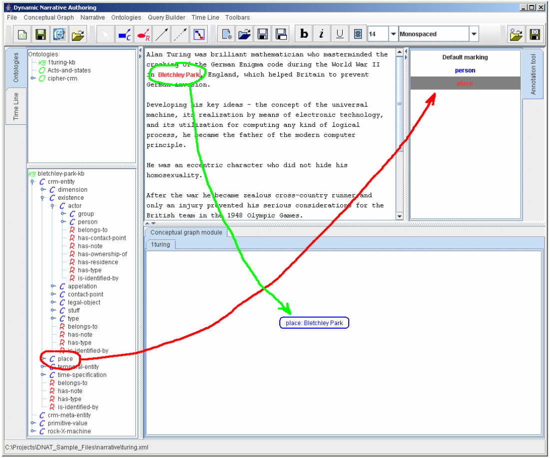
  - **Modeling error explanations** – the problem discussed in this work.

Motivation (2) – Document Annotation Tool

- ☺ frames and conceptual graphs : simple, human understandable.



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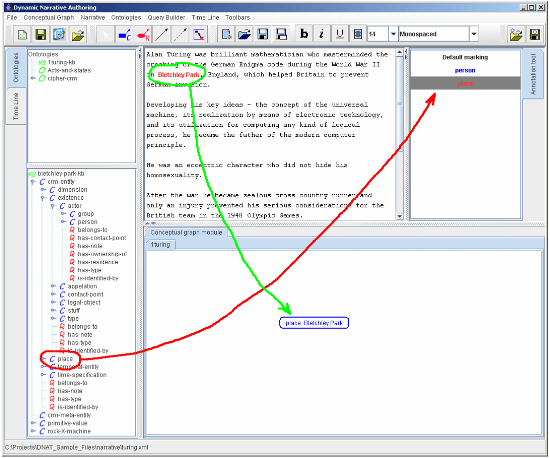

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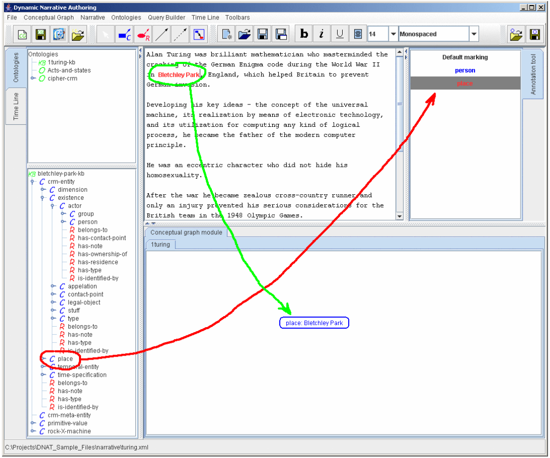

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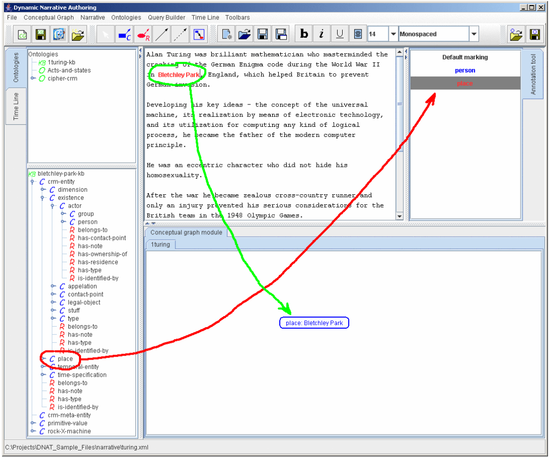

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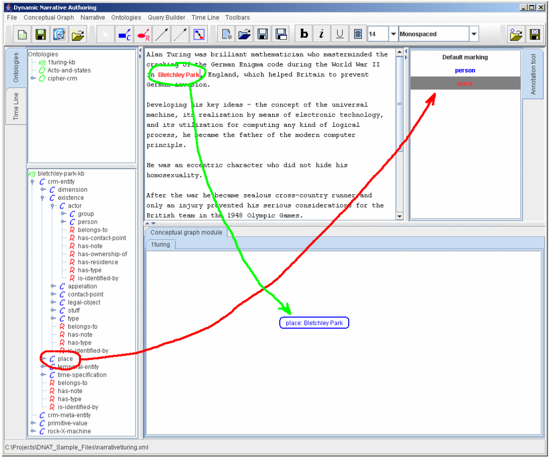
! **This lead us to use a description logic based approach.**



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    - **concept and role assertions** – $school(CVUT)$, $partOf(FEL, CVUT)$

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Example (Part of the Mad Cow Ontology)

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\begin{array}{rcl}
madCow & \equiv & cow \sqcap \exists eats.(brain \sqcap \exists partOf.sheep) \\
cow & \sqsubseteq & vegetarian \\
vegetarian & \equiv & animal \sqcap \forall eats.\neg animal \sqcap \forall eats.\neg(\exists partOf.animal) \\
animal & \sqsubseteq & \exists eats.\top \\
sheep & \sqsubseteq & animal \\
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animal \sqcup \exists partOf.animal & \sqsubseteq & \neg(plant \sqcup \exists partOf.plant)
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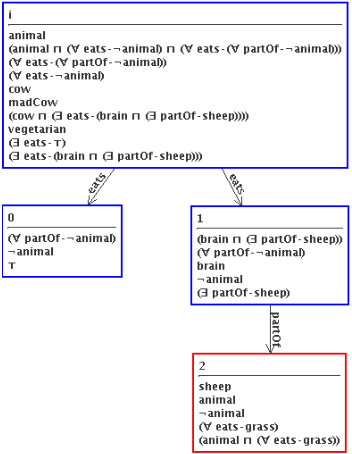
- *Tableau algorithms* prove consistency of given knowledge base by constructing a model for it using a set of inference rules.
- These algorithms terminate upon obtaining a clash-free model candidate – a completion graph – on which no more rules are applicable (consistent), or whenever each completion graph contains a clash (inconsistent).

Completion Graph Example

Testing satisfiability of the concept *madCow* a $\mathcal{SHIN}$ tableau reasoner may generate the following completion graph. The generated individual 2 contains a clash – individual 2 belongs to both *animal* and ¬*animal*.



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glass-box methods are fully integrated into the reasoner (Schlobach 2006, Kalyanpur 2006).

+ more efficient
- poor reusability, **no fully glass box approach exists for even simpler languages than $\mathcal{SHIN}$**

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- computing directly all MUPSes (*allMUPSesInc2*).

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Having 6 axioms numbered $1 \ldots 6$, a concept is unsatisfiable due to the MUPSes $\{\{1, 2, 4\}, \{2, 4, 5\}, \{3, 5\}, 6\}$. The algorithm works as follows :

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$\longleftarrow$	[**1**, 2, 3, ~~4, 5, 6~~]	$D = [4, 1]$	e=[4,3,2,1]

Algorithm for Single MUPS (*singleMUPSInc*)

- Initial axiom list P and an empty reasoner state e.
- "Feed" the reasoner with axioms one by one until an unsatisfiability is detected.
- When an unsatisfiability is detected, the search direction is changed, current reasoner state e is initialized with D, "overlapping" axioms are pruned (emphasized with strikeout) and the last axiom that caused the unsatisfiability (in bold) is put into the MUPS core D.

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- This algorithm can be used with Reiter's algorithm (Reiter 1987) to compute all MUPSes for given concept.

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: T is the list of already explored axioms ... satisfiable set

Algorithm for All MUPSes (2) – Example

Example

Having 3 axioms numbered $1, 2, 3$, a concept is unsatisfiable due to the MUPSes $\{\{1, 2\}, \{1, 3\}\}$. The algorithm works as follows :

$-1, [], [\mathbf{1}, 2, 3], []$

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-1, [], [1, 3], [1] \arrow[r, "{[3]}"'] \arrow[d, shift right, "{[1,3]}"'] & 0, [3], [\mathbf{1}], [3] \\
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-1, [], [1], [1] \arrow[u, shift right] & -1, [3], [], [3]
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-1, [], [1], [1] \arrow[u, shift right] & -1, [3], [], [3] \arrow[u, shift right] &
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$$
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$$
\begin{tikzcd}
-1, [], [1, {\color{red}2}, 3], [1] \arrow[rrr, "{[2]}"'] \arrow[d, shift right, "{[1],\ [1,2]}"'] & & & 0, [2], [{\color{red}1}, 3], [2] \arrow[d, "\cancel{[1,2]}"'] \\
-1, [], [1, {\color{red}3}], [1] \arrow[u, shift right] \arrow[r, shift right, "{[3]}"'] \arrow[d, shift right, "{[1,3]}"'] & 0, [3], [{\color{red}1}], [3] \arrow[l, shift right] \arrow[r, shift right, "\cancel{[1,3]}"'] \arrow[d, shift right, "\cancel{[1,3]}"'] & \text{found } [3,1] \arrow[l, shift right] & -1, [2], [3], [2] \arrow[d, "{[2,3]}"'] \\
-1, [], [1], [1] \arrow[u, shift right] & -1, [3], [], [3] \arrow[u, shift right] & & SAT
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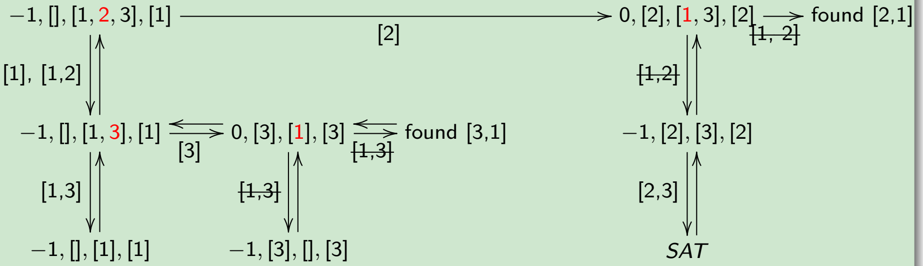

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Comparison of Incremental and Black Box Techniques

- Underlying reasoner is our impl. of the $\mathcal{SHIN}$ tableaux algorithm.

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- **allMUPSesInc2** is our modification of *allMUPSesInc1*
- Finding all MUPSes for all concepts in the miniTambis ontology (30/182 unsat. concepts) and the miniEconomy ontology[1](51/338 unsat. concepts):

algorithm	miniTambis (time [ms])	miniEconomy (time [ms])
Reiter + singleMUPSbb	67481	$> 15 min.$
Reiter + singleMUPSinc	**19875**	**19796**
allMUPSesInc1	8655	14110
allMUPSesInc2	**8516**	**13970**

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Comparison of Incremental Methods w.r.t. Axiom Ordering

- As we need to generate all permutations of the axiom set, we use two small ontologies.

[2] http://protege.stanford.edu/plugins/owl/owl-library/tambis-full

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tambisP	# of IT[4]	avg # of IT	var of IT
Reiter + singleMUPSinc	**268362**	**124.29**	**206.81**
allMUPSesInc1	75696	35.04	36.44
allMUPSesInc2	**61590**	**28.51**	**16.76**

madCowP	# of IT	avg # of IT	var of IT
Reiter + singleMUPSinc	**277200**	**55.00**	**8.00**
allMUPSesInc1	131040	26.00	0.00
allMUPSesInc2	**119520**	**23.04**	**0.50**

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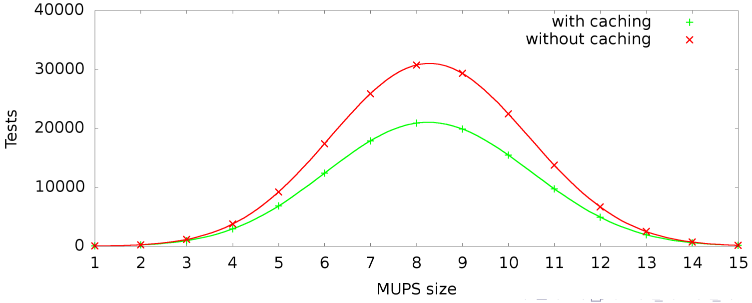
Evaluation of Caching

- For which knowledge bases is the caching gain significant ?



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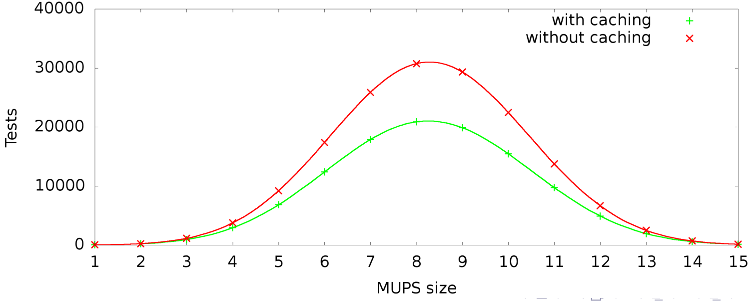

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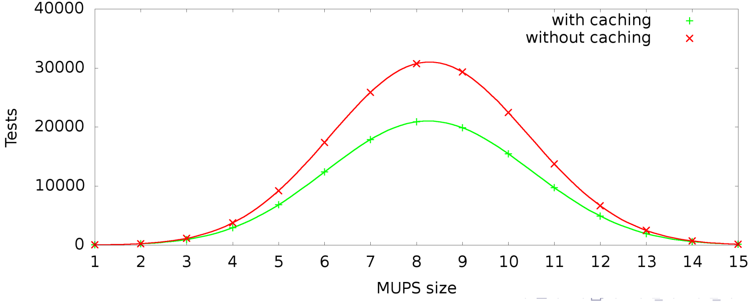

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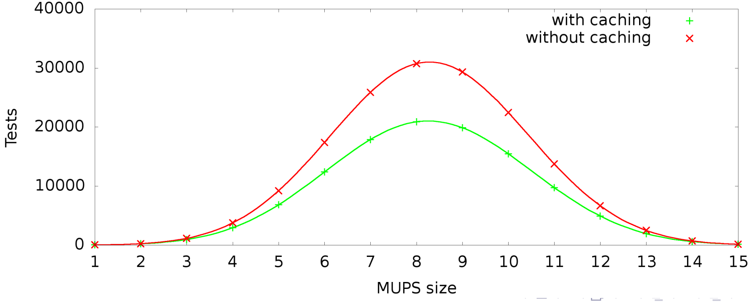
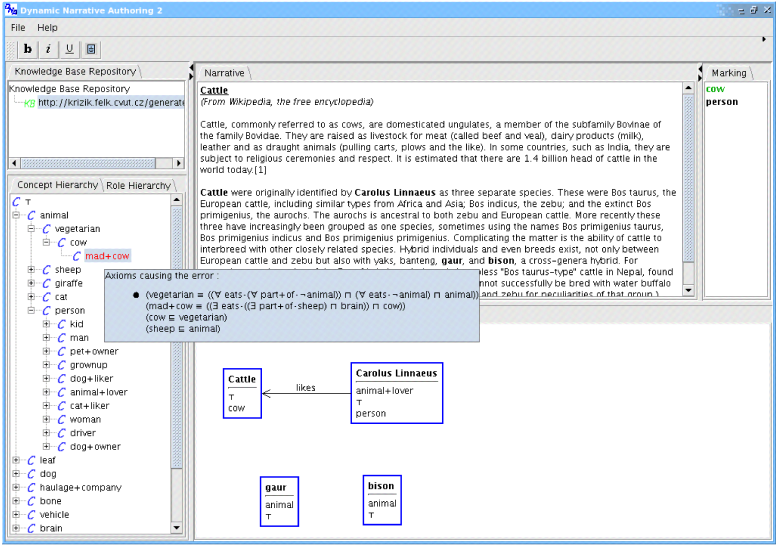
- **The caching is most efficient (about 30% gain) when the MUPSes are approximately medium-sized w.r.t. the number of axioms.**



Annotation Tool Prototype



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- Two novel promising **incremental algorithms** for error explanations were proposed and implemented.**Comparing to the black box methods they proved to be more efficient and robust to axiom ordering**.
- The "single MUPS" versions are less efficient than the "all MUPS" versions, but **"single MUPS" versions provide error explanations for free** (using Reiter's algorithm), while "all MUPS" versions provide only conflict sets.
- An inference services based on the proposed algorithms was **implemented in the new annotation tool prototype**, providing the user with explanations for given concept unsatisfiability.

Future Work

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Example

$reign(Person, Time, Location)$ generates a concept *Reign*, and three new properties `reignPerson`, `reignTime` and `reignLocation`. New axioms are generated that state these properties to be *functional*, to have corresponding domain and range and to allow only syntactically valid n-ary relations.

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    - To develop error explanation techniques for this n-ary description logic.

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