Advanced Knowledge Base Debugging for Rulelog†

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Rulelog: Overview

- First KRR to meet central challenge:
  - rich -- higher order logic formulas, incl. as target for text interpretation
  - defeasible -- handle exceptions, change in K, change in world
  - tractable

- New rich logic: based on databases, not classical logic
  - Expressively extends normal declarative logic programs (LP)
  - Transforms into LP (the logic of DB’s (SQL, SPARQL) and pure Prolog)

- In draft as industry standard (RuleML submission to W3C RIF and …)
- Associated new reasoning techniques to implement it

- Prototyped in Vulcan’s SILK
  - Mostly open source: Flora-2 and XSB Prolog

- Applications: college-level science (e.g., AP Biology), legal analysis and reasoning (Regulation W), financial compliance (Financial Industry Business Ontology), health care treatment protocols, national intelligence, privacy
Rulelog: Overview

- Defeasibility based on *argumentation theories (AT)* [Wan, Grosof, Kifer, Fodor 2009]
  - Meta-rules specify principles of debate, thus when rules have exceptions
  - Prioritized conflict handling. Ensures consistent conclusions. Efficient, flexible, sophisticated defeasibility.

- **Restraint**: semantically clean *bounded rationality* [Grosof & Swift, AAAI-13]*
  - Leverages “undefined” truth value to represent “not bothering”
  - Extends well-foundedness in LP

- **Omniformity**: higher-order logic formula syntax, incl. hilog, rule id’s
  - Omni-directional disjunction. Skolemized existentials. [Grosof (invited), RuleML-2013]
  - Avoids general reasoning-by-cases (cf. unit resolution).

- Sound interchange of K with all major standards for sem. web K
  - Both FOL & LP, e.g.: RDF(S), OWL-DL, SPARQL, CL

- Reasoning techniques based on extending tabling in LP inferencing
  - Truth maintenance, justifications incl. why-not, trace analysis for KA debug, term abstraction, delay subgoals

For more info, see [Grosof et al, AAAI-13 Tutorial]* – largely about Rulelog

* preprint/prelim-v. already avail.
Rulelog: Overview

- Classical LP (well-founded semantics)
- Frames (F-logic) and Higher-order (Hilog)
  
  \[ \text{red('blood cell')} \#\# \text{eukaryotic(cell)}. \ // \text{subClassOf relationship in frame syntax} \]
- Omniformity: classical-logic formulas including existential and universal quantifiers
  
  \[
  @[\text{tag->r1, source->'A cell has a nucleus']} /* ==\Rightarrow \text{means strong implication */}
  \text{forall}(\?x1)^\text{(cell}(\?x1) ==\Rightarrow \text{exist}(\?x2)^\text{((nucleus}(\?x2) \text{and have}(\?x1, \?x2))))).
  \]
- Defeasibility with argumentation theories (rule identifiers, defaults, defeasible candidates, conflicts, overrides, refutation, rebuttal)
  
  \[
  @[\text{tag->r2, source->'A eukaryotic cell during anaphase has no nucleus']} \\
  \text{forall}(\?x1)^\text{(anaphase}(\?x1) ==\Rightarrow \text{forall}(\?x2)^\text{(eukaryotic(cell)}(\text{(during)})(\?x2, \?x1) ==\Rightarrow \text{neg exist}(\?x3)^\text{(nucleus}(\?x3) \text{and have}(\?x2, \?x3))))).
  \]
  \text{overrides(r2, r1).}
  \]
  
  \[
  @[\text{tag->r3, source->'A red blood cell has no nucleus']} \\
  \text{forall}(\?x1)^\text{(red('blood cell')}(\?x1) ==\Rightarrow \text{neg exist}(\?x2)^\text{(nucleus}(\?x2) \text{and have}(\?x1, \?x2))).
  \]
  \text{overrides(r3,r1).}
  \]
- Bounded rationality (radial restraint): radial depth limit for search
Debugging for Rulelog

• **Justify** answers
• Pinpoint **wrong or missing knowledge**
• Cope with potential **runaway** and **incompleteness** in inferencing

Via a set of techniques:
• Justifications: incl. of **why-not**. Leverages rule id’s.
• Profile: memory used, compute time, # rules, usage or rules
• Forestlog trace: view subgoaling and tables. Drill down.
• Terminyzer: analyze and diagnose non-termination
• SCC analysis of unstratified NAF loops
• Restraint (radial, skipping, unsafety) – valves that ensure tractability. **undefined** represents “not bothering”.

Biology Reasoning Example

• Biology information about cells and nuclei:

  “A eukaryotic cell has a nucleus.”
  @[id->i1, tag->r1] forall(?x)^(?x(is(a(eukaryotic(cell)))) ===> ?x(has(a(nucleus))))

  “A red blood cell has no nucleus.”
  @[id->i2, tag->r2] forall(?x)^(?x(is(a(red(blood(cell)))))) ===> neg ?x(has(a(nucleus))))

  “A eukaryotic cell during anaphase has no nucleus.”
  @[id->i3, tag->r3] forall(?x)^(?x(is(a(eukaryotic(cell)(during(anaphase)))))) ===> neg ?x(has(a(nucleus))))

• Prioritization:

  \texttt{overrides(r2,r1);}
  \texttt{overrides(r3, r1);}

• Ontology information:

  @[strict] red(blood(cell)) :: eukaryotic(cell);
  cell52 : red(blood(cell));

  @[strict] eukaryotic(cell)(during(anaphase)) :: eukaryotic(cell);
  ?x(is(a(?c))) <==> ?x : ?c ;
  cell41(is(a(eukaryotic(cell)))) ;
  cell63(is(a(eukaryotic(cell)(during(anaphase)))))) ;

• Queries:

  ?- ?x(has(?y(nucleus))); // What has or doesn't have a nucleus?
  ?- cell41(has(a(nucleus))); // is true
  ?- neg cell52(has(a(nucleus))); // is true, and without the neg is false
Omniform (omni) transformation

Classical-logic formulas with quantifiers are transformed into directional rules:

// Source English text: “A eukaryotic cell has a nucleus.”

// Pretransform logical form
forall(?x1)^(?x1(is(a(eukaryotic(cell))) => ?x1(has(a(nucleus))))).

// Omni transform: logical equivalency
neg ?x1(is(a(eukaryotic(cell))) or ?x1(has(a(nucleus)))).

// Post Omni transform directional rules
?x1(has(a(nucleus))) :- ?x1(is(a(eukaryotic(cell))) .

neg ?x1(is(a(eukaryotic(cell)))) :- neg ?x1(has(a(nucleus))) .
Demo time: The Basic Panes/Views

Project Explorer – shows the LP files and folders, Activity View, Engine

The Editing Pane

Query View – type in queries and the answers are displayed below

The Console Pane, Justification Viewer, Ontology viewer, Search
Demo Time: Query Justification

?- neg cell52(has(a(nucleus)))) ; // True

- True literal
- False literal
- Fact
- True rule body (argument) supporting a literal
- Prioritization rule between two rule tags
- Refutation: another argument on the other side had a higher priority
- Live argument
- There are more arguments to see (pro, con, both)
Demo Time: NL Query Justification

- True literal
- False literal
- Fact
- True rule body (argument) supporting a literal
- Prioritization rule between two rule tags
- Refutation: another argument on the other side had a higher priority
- Live argument
- There are more arguments to see (pro, con, both)
Demo time: Syntax Errors

Parsing errors are displayed with a red X icon in the left column of the text editor window. Error details are displayed when the mouse is hovered over the red X icon, or in the Eclipse Problems View (Window -> Show View -> Other -> General -> Problems)
Demo time: Checkers and Warnings

Warnings are displayed with a yellow triangle icon on the left column of the text editor window. Hovering the mouse over a warning marker will give details. Double click on a warning marker to access a dialog allowing to ignore certain warnings.
Non-Termination Analysis

- Knowledge bases are typically complex, large and unfriendly to domain knowledge experts who know little about engine’s evaluation strategy ➔ Non-termination happens more often, hard to debug

- Causes:
  - Loops:
    \[ p(?X) :- p(?X). \]
    - Solution: **tabling** caches calls and answers (evaluation terminates if there are finitely many subgoals and answers)
  - Infinitely many tabled subgoals:
    \[ p(?X) :- p(f(?X)). \]
    - The goals to be tabled: \( p(a), p(f(a)), p(f(f(a))), \ldots \)
    - Solution: **subgoal abstraction** to a threshold. E.g., for threshold = 2, then \( p(f(f(f(a)))) \) is abstracted to \( p(f(f(?X))), ?X = f(a) \)
  - **Infinitely many answers:**
    \[ p(a). \quad p(f(?X)) :- p(?X). \]
    - The answers to be derived: \( p(a), p(f(a)), \ldots \)
    - Solution: none (i.e., halting problem: whether a program has a finite number of answers is undecidable).
    - **Unexpected non-termination (bug):** we help the user to deal with the issue: find non-termination recursion and bounded rationality
Forest Logging

- Tabling needs no introduction.
- Forest logging is new:

<table>
<thead>
<tr>
<th>Events</th>
<th>Logs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calls to tabled subgoals</td>
<td>tc(child, parent, status, timestamp)</td>
</tr>
<tr>
<td>E.g. parent calls child</td>
<td>nc(child, parent, status, timestamp)</td>
</tr>
<tr>
<td></td>
<td>status = new, complete, incomplete</td>
</tr>
<tr>
<td>Answer derivations</td>
<td>na(ansr, sub, timestamp)</td>
</tr>
<tr>
<td>E.g. ansr is derived for sub</td>
<td>nda(ansr, sub, delayed_lits, timestamp)</td>
</tr>
<tr>
<td>Return answers to consumers</td>
<td>ar(ansr, child, parent, timestamp)</td>
</tr>
<tr>
<td>E.g. ansr for child is retuned</td>
<td>dar(ansr, child, parent, timestamp)</td>
</tr>
<tr>
<td>to parent</td>
<td></td>
</tr>
<tr>
<td>Subgoal completions</td>
<td>cmp(sub, scc_num, timestamp)</td>
</tr>
<tr>
<td>E.g. sub is completed</td>
<td>cmp(sub, ec, timestamp)</td>
</tr>
</tbody>
</table>

- **Bounded rationality** (radial restraint): radial depth limit for search
Non-Termination Analysis

• Unfinished subgoal: not all its answers have been derived.

\[ \text{unfinished}(\text{Child}, \text{Parent}, \text{Timestamp}) \leftarrow \]
\[ (\text{tc}(\text{Child}, \text{Parent}, \text{Stage}, \text{Timestamp}) ; \text{nc}(\ldots)), \]
\[ (\text{Stage} == \text{new} ; \text{Stage} == \text{incmp}), \]
\[ \text{not}_\text{exists}(\text{cmp}(\text{Child}, \text{SCCNum}, \text{Timestamp}1)). \]

Here, \text{not}_\text{exists} is the XSB well-founded negation operator, and it existentially quantifies \text{SCCNum} and \text{Timestamp}1.

• \text{Unfinished}(\text{child}, \text{parent}, \text{timestamp}) says that
  • Subgoal parent calls subgoal child
  • Neither child nor parent have been completely evaluated

• The sequence of unfinished call, sorted by timestamp, is the exact sequence of unfinished tabled subgoals causing a non-termination
More information

- Coherent Knowledge Systems (start-up by members of former SILK team): [http://coherentknowledge.com](http://coherentknowledge.com)
- SILK (Vulcan Inc.): [http://silk.semwebcentral.org](http://silk.semwebcentral.org)
- XSB Logic Programming and Deductive Database system (open source): [http://xsb.sourceforge.net](http://xsb.sourceforge.net)