SPASS-XDB
Automated Reasoning with World Knowledge

by

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Abstract
SPASS-XDB
Automated Reasoning with World Knowledge

Introduction

- Automated Theorem Proving - What is it?, What is it Good For?
- Motivation - Commonsense Reasoning
- Problem - Large Theories with (too) many axioms
- Solution - External Axioms

Design and Implementation

- System Design and Architecture
- SPASS-XDB Implementation
- External Sources

Testing and Application

- Testing
- SporcleAI
- New External Sources

Conclusion

The End - Any Questions?

And now, A Word from My Sponsor
Commonsense Reasoning

"Reasoning methods that exhibit the features of human thinking"

Application Domains

- Reasoning over ontologies
- Question answering
- Planning
- Education
- Personalization

The Nature of the Reasoning

- Large theories (many symbols, many axioms, many theorems)
- Human expectations (fast reasoning, friendly interfaces, world knowledge)
- Inconsistent, uncertain, imprecise, temporal, incomplete ... (aaaargh)
- Unnecessary axioms (how to choose the right few)
- Short and simple arguments (easy once you have the axioms)

Reasoning with World Knowledge

- Commonsense reasoning with the plethora of facts
- Example systems
  - SPASS-XDB, CYC, SigmaKEE, LogAnswer, NAGA, Open Mind, TrueKnowledge, Watson, HALO, ...
  - NOT Google, Wikipedia, Bing, WolframAlpha, ...
- Example deployments
  - TrueKnowledge, START, askHERMES, LogAnswer SporcleAI
Large Theories and World Knowledge

Large Theories

- Many functors and predicates, many (common) axioms, many theorems
- SUMO, Cyc, Mizar, YAGO, Wikipedia, WordNet, MeSH, DBPedia, CIA Factbook, GenBank ...
- Different challenges for ATP
  - Parsing and building data structures
  - Loading and preprocessing the common axioms only once
  - Selecting axioms that are likely to be useful
  - Extracting heuristics and lemmas from proofs

Infinite Theories

- Dynamic and computational sources of axioms
- Mathematica, HR, XchangeRates, Weather, AGInT, ...
- Infinite number of "axioms"

The State-of-the-Art in ATP

- Large theories only a recent focus
- Few systems can load and reason with millions of axioms
- No system can load an infinite number of axioms
External Axioms

This Work

- Accessing *external sources of axioms* from ATP
- Axioms not loaded/stored in the ATP system
- Axioms retrieved on demand from external sources
- Further challenges
  - Specifying availability of external axioms
  - Retrieving and integrating external axioms
  - Adapting ATP to axioms arriving during reasoning

Previous work

SPASS-XDB

- On-demand, asynchronous, retrieval of external axioms for a common ATP system design
- Unifying syntax and protocols, based on de facto standards (TPTP)
- Implemented in a state-of-the-art ATP system
- Implemented external sources - SQL, SPARQL, Prolog, WWW, Computation
- Testing and deployment to demonstrate capability
System Design and Architecture

The Nature of External Axioms

- External axioms are positive ground facts
- External axioms are consistent, certain, precise, non-temporal
- External axioms can be repeated
- Retrieval from external sources can be incomplete
- External sources are comparatively slow

ATP's Use of External Axioms

- External axioms requested on demand
- External axioms delivered in batches
- External axioms requested and delivered asynchronously
- No constraints on external source technology

System Architecture

- Based on SPASS' classic given-clause architecture
- Problem specification includes external specifications
- External axioms requested based on chosen clause literals
- Requests and deliveries are mediated
- External axioms integrated into the "Usable" list
- External requests are never duplicated
- TPTP-based syntax and protocols
SPASS-XDB Implementation

Algorithm

while (!Solved && (Usable || DeliveryPending || RequestQueue)) {
    repeat {
        Accept deliveries, add to Usable;
        Dequeue requests and send
        if (!Usable && DeliveryPending) sleep(1);
        until (Usable || !DeliveryPending);
        if (!Usable) break;
        Move ChosenClause from Usable to WorkedOff;
        Enqueue requests for negative literals of ChosenClause
        Do relaxed-extended inferencing with ChosenClause
    }

    Points to note

Controls on Retrieval

- Universal quantification in external specifications
- xdb(limit,*) terms
- xdb(group,*) terms
External Sources

- **Amazon**: Facts about products, especially books.
- **DBPedia**: Curated data from Wikipedia, from a SPARQL endpoint. Requires translation server for URLs.
- **Linked Movie Database**: Information about movies, from SPARQL + translation.
- **City information**: Latitude, longitude, etc., for a city, from Yahoo and GeoNames.
- **Mondial**: CIA Factbook geographic information, from an XML fact file.
- **YAGOSUMO**: About 14.5 million facts, compatible with SUMO. Stored in an SQL database.
- **Weather**: Weather for location, and city with weather, from Yahoo.
- **Xchange**: Converts one currency to another, from Time Genie
- **Arithmetic**: SOlutions to conjunctive requests, by Mathematica.
- **Babelfish**: Natural language translation, provided by Yahoo.
- **LookDifferent**: Checks for syntactic difference. Controlled implementation of UNA.
- **RegExp**: Matching regular expressions, in Perl.
- **PrintTTY**: Axioms with output as a side effect. No axioms with output for continued search.
- **Twitter**: Axioms with tweets as a side effect.
- **XDB Translator**: Aimed at internal translation of terms, but can be used explicitly.

- **Online Access**
Testing

Abraham Lincoln is a Mammal

- Prove that Abraham Lincoln is a mammal
- YAGOSUMO facts and SUMO ontology (internal)
- 188 requests queued, 175 sent, 266 axioms delivered, 1 axiom used
- 15s CPU, 18s WC. 5863 clauses derived.

An Early 18th Century Composer

- Name a composer born in the first half of the 18th century
- YAGOSUMO facts, Arithmetic
- 515 requests queued, 427 sent, 456 axioms delivered, 2 axioms used
- 18s CPU, 26s WC. 7600 clauses derived.

Prize Winning Curies

- Name all Nobel prizes won by members of the Curie family
- YAGOSUMO facts
- 32 requests queued, 32 sent, 31 axioms delivered, 11 axioms used
- 2s CPU, 14s WC. 10 clauses derived.

An OECD Capital at the Same Latitude as Moscow that could get Flooded

- Name an OECD country's capital that is at the same latitude as Moscow (to the nearest degree), that could get flooded
- Needs preemptive requests for axioms (\(-I\_ANo=0\))
- YAGOSUMO facts, Yahoo map services, Arithmetic, Syntactic difference SUMO ontology (internal)
- 230 requests queued, 227 sent, 321 axioms delivered, 11 axioms used
- 3s CPU, 19s WC. 1047 clauses derived.
Mentally Stimulating Diversions

- Questions by the people, for the people
- Automated player
- SPASS-XDB used a backend knowledge provider
- Online access

Architecture

- GreaseMonkey scripts
- SporcleAI server
- NLP by string hacking and ACE translation
- Two backend knowledge providers

Illustrative Results

<table>
<thead>
<tr>
<th>Quiz topic</th>
<th>Solutions</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>US state capitals</td>
<td>50/50</td>
<td>7:33/10:00</td>
</tr>
<tr>
<td>Countries of the world</td>
<td>149/195</td>
<td>7:45/15:00</td>
</tr>
<tr>
<td>Floodable world capitals</td>
<td>36/36</td>
<td>3:34/10:00</td>
</tr>
<tr>
<td>Words ending with `ACE'</td>
<td>15/16</td>
<td>0:21/4:00</td>
</tr>
<tr>
<td>Greek gods and goddesses</td>
<td>11/12</td>
<td>0:15/5:00</td>
</tr>
<tr>
<td>Actor by movie</td>
<td>6/30</td>
<td>6:00/6:00</td>
</tr>
</tbody>
</table>
New External Sources

Mathematica

- Built-in arithmetic does ground evaluation
- Mathematica as a source of arithmetic axioms
- Accepts conjoined requests, of all relevant literals
- Returns axiom for first literal
- Allows SPASS-XDB to enter TFA division of CASC

Web Search

- The obvious thing to do
- Query search engine, match results with template, build axiom
- Currently limited to unary and binary predicates
- Leverage search engines, and still provide answers
Conclusion, Current and Future Work

Contributions

- Analysis of issues of accessing external axioms from ATP
- Design, implementation, and testing of working system
- New capability for ATP

Current and Future Work

- Natural language (ACE) input and output (*Partly done!*)
- Ontology axiom selection using SInE (*Student failed!*)
- Automatic alignment of terminology between external sources (*Some parts done!*)
- Automatic configuration of control features (*Not done*)
- Theoretical properties for ATP system (*Not done*)
- Question answering using TPTP standards (*Externally done!*)
- Make it play *Trivial Pursuit!*