Processing Markov Logic Networks with GPUs

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Introduction

- Markov logic "combines first-order logic and Markov networks. A knowledge base in Markov logic is a set of first-order [logic] formulas with weights"
- Weights establish *soft constraints*: worlds that violate a formula are less likely but still possible.
- Markov logic networks have been widely adopted and are used to:
  - Refine Wikipedia's Infobox Ontology.
  - Carry out collective semantic role labelling.
  - Perform Natural Language Processing.
- Inference is divided into a *grounding* phase and a *search* phase.

MLN program example

```
ENGLISH AND FIRST-ORDER LOGIC            CLAUSAL FORM (Datalog syntax)          WEIGHT
--------------------------------------------------------------------------------------
Friends of friends are friends:
   Fr(x,y) & Fr(y,z) => Fr(x,z)          Fr(x,z) :- Fr(x,y), Fr(y,z)               0.7
Smoking causes cancer:
   Sm(x) => Ca(x)                        Ca(x) :- Sm(x)                            1.5
If two people are friends and one
smokes, then so does the other:
   Fr(x,y) & Sm(x) => Sm(y)              Sm(y) :- Fr(x,y), Sm(x)                   1.1
```

```
EVIDENCE            PROCESSING OF VALID GROUNDINGS                              RESULTS
--------------------------------------------------------------------------------------
Fr(John,Anna)       Fr(John,Anna) & Fr(Anna,Bob) => Fr(John,Bob)       0.92 Ca(John)
Fr(Anna,Bob)        Sm(Anna) => Ca(Anna)                               0.59 Ca(Anna)
Fr(Gary,Frank)      Fr(John,Anna) & Sm(John) => Sm(Anna)               0.58 Ca(Bob)
Sm(John)
                    PROCESSING OF INVALID GROUNDINGS
                    ---------------------------------
                    Fr(John, Anna) & Fr(Gary, Frank) => {}
                    Sm(Gary) => Ca(Gray)
                    Fr(Gary, Frank) & Sm(Gary) => Sm(Frank)
```

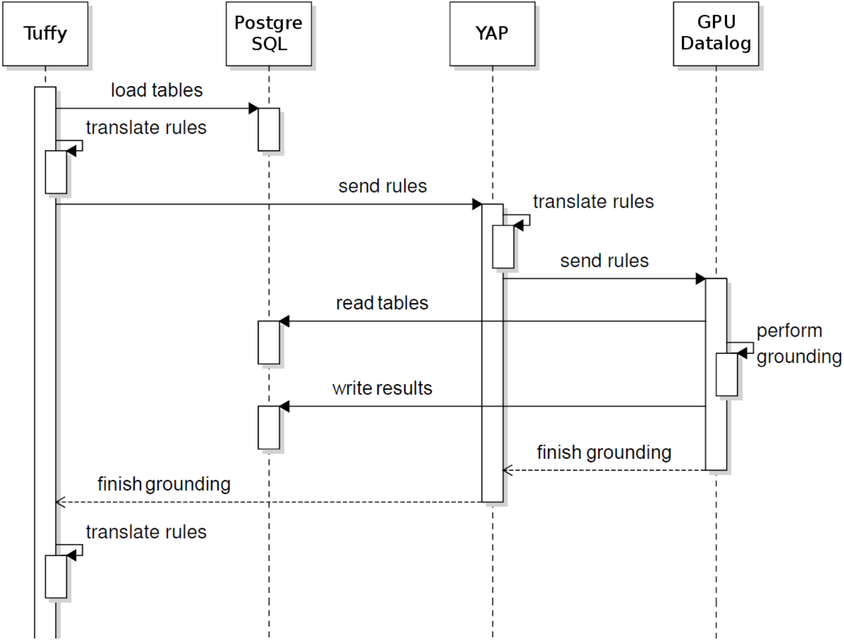
Tuffy and other MLN systems

- Alchemy was the first MLN system. Includes various algorithms for inference and learning.
- Tuffy relies on PostgreSQL to perform the grounding using a bottom-up approach, based on SQL queries and accelerated with query optimizations by the RDBMS.
- RockIt treats inference as an integer linear programming problem. Currently outperforms all other systems.

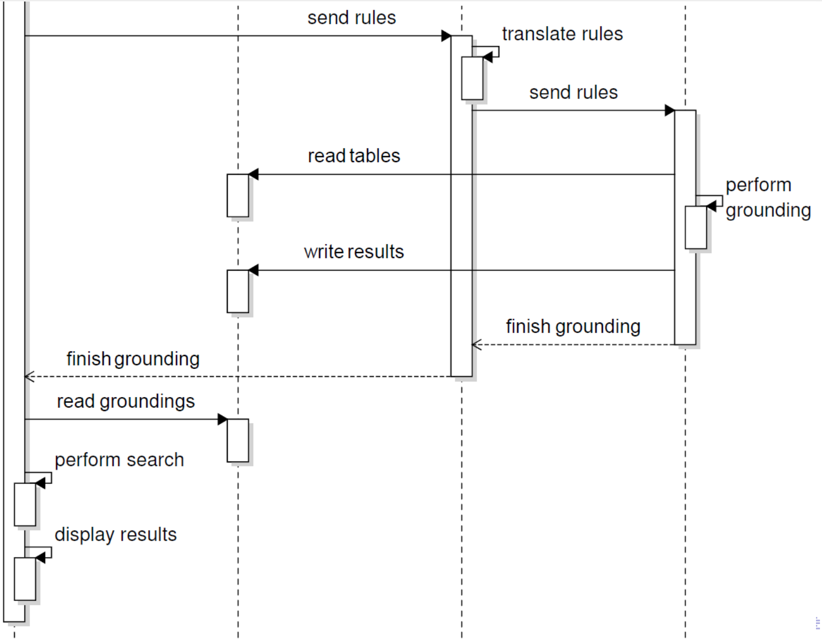
Tu2GPU - Our GPU-based Markov Logic Platform

- Its main components are: Tuffy, YAP Prolog and GPU-Datalog.
- GPU-Datalog evaluates Datalog programs with a bottom-up approach using GPU kernels that implement relational algebra operations.
- Includes several optimizations like operator weaving, automatic memory management, among others.
- It was extended with: management of negation, comparison predicates and a PostgreSQL interface.

Tu2GPU-Datalog sequence diagram I

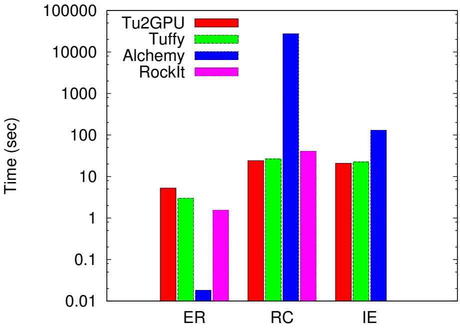


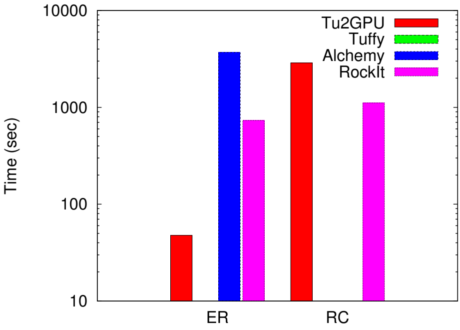
Tu2GPU-Datalog sequence diagram II



Results

- Applications: Entity Resolution (ER), Relational Classification (RC) and Information Extraction (IE).
- Left plot shows performance using Tuffy's example data. Right plot uses bigger, randomly generated data.
- Empty spaces mean that the system did not finish after several hours.





Analysis on bigger data

- For ER, our random data and its recursive clauses generate more recursive steps, 24 vs 2 in the original data.
- GPU-Datalog was designed around these recursive applications. Other systems struggled with costly joins.
- For RC, the search phase alone takes an astounding 43 minutes. The rest of the process approximately 3 minutes.
- During this phase, 5.5M active tuples where used. In contrast, ER uses only 252K tuples.

Conclusions

- Our system accelerates the grounding step in MLNs by combining Tuffy with our GPU-Datalog engine.
- Its performance is on par or better than other well-known MLN systems.
- Results show that the benefit of performing the grounding phase on the GPU outweighs the overhead of using a database and of GPU I/O.
- Our system can be greatly improved by also performing the search phase in the GPU.

Thanks