Probabilistic Logic Programming with Beta-Distributed Random Variables

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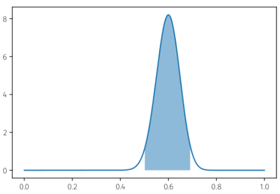
Objectives

- We want to harness the ability to reason about objects, attributes and relations (i.e. "unrest in the market area can cause a feud")
- We want to be able to reason about aleatoric uncertainties, i.e. probabilities
- We want to be able to reason about epistemic uncertainty, i.e. quantify the confidence of a learning process

Technical Challenges

- ProbLog [DeRat et al., 2007] implements the distribution semantics [Sato 1995] for dogmatic probabilities
- While this method can determine uncertain probabilities via a Monte Carlo approach
- We need to avoid computationally expensive simulations to determine epistemic uncertainty

Approach



$$P(q) := \sum_{\Lambda' \subseteq \Lambda, \Lambda' \models q} P_\Lambda(\Lambda') = \sum_{\Lambda' \subseteq \Lambda, \Lambda' \models q} \prod_{\lambda_i \in \Lambda'} p_i \cdot \prod_{\lambda_i \in \Lambda \setminus \Lambda'} (1 - p_i)$$

```
B(61,41)::asthma(X):-smokes(X).
B(9,1)::smokes(bill).
```

Let q(uery) be asthma(bill).
Let Z be the real distribution of q

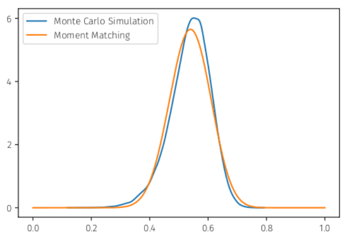
$Z = B(61, 41) \cdot B(9, 1)$

$\tilde{Z}$: Moment Matching Approximation

$\tilde{Z} \sim \text{Beta}(\overline{\alpha}, \overline{\beta})$ such that (given B(61,41) and Y = B(9,1)):

$E[\tilde{Z}] = E[X] \cdot E[Y]$

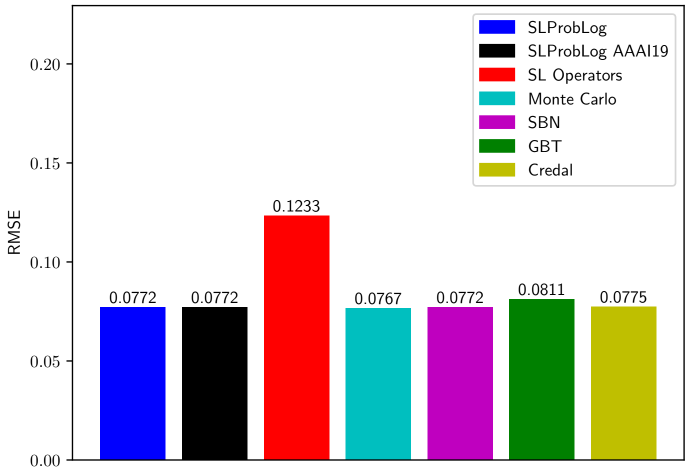
$\text{Var}(\tilde{Z}) = \text{Var}(X)E[Y]^2 + \text{Var}(Y)E[X]^2 + \text{Var}(X)\text{Var}(Y)$



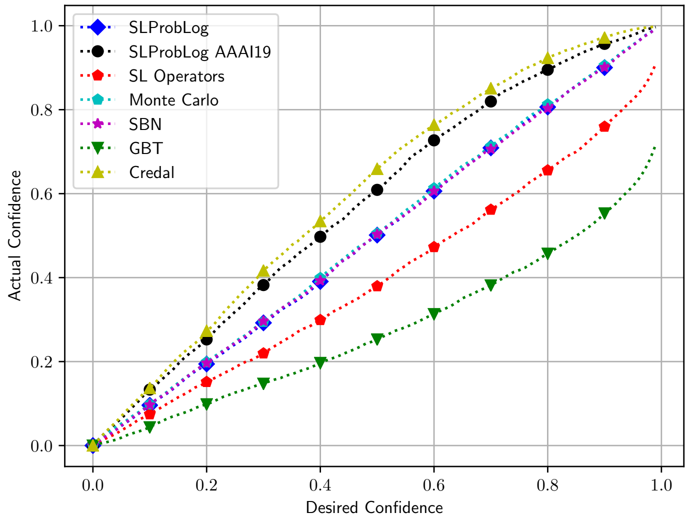
Military & Coalition Relevance

- To research and develop artificially intelligent agents (heterogeneous & distributed) that rapidly learn, adapt, reason & act in contested, austere & congested environments
- Reasoning with limited training data
- Characterization of both aleatoric and epistemic uncertainty
- Explanations of uncertainty for the user
- Further case studies can be found in [Kaplan et al. 2018]

Results



Best Smallest



Best closest to the diagonal

Summary & Future Work

Inferring the spread of possible probabilities of queries over a database of facts and rules in ProbLog format accounting for inherent uncertainty in learning over limited training data

Publication(s) & Impact

Kaplan L., Cerutti F., Sensoy M., Preece A., and Sullivan P. Uncertainty Aware AI ML: Why and How. Proceedings of the AAAI Fall Symposium. 2018 [DAIS-ITA RESEARCH]

Sato T. 1995. A statistical learning method for logic programs with distribution semantics. In Proceedings of ICLP-1995, 715–729.

De Raedt L., Kimmig A., and Toivonen H. 2007. Problog: A probabilistic prolog and its application in link discovery. In Proceedings IJCAI-2007, 2462–2467.

Cerutti F., Kaplan L., Kimmig A., and Sensoy M., *Probabilistic Logic Programming with Beta-Distributed Random Variables*. AAAI 2019 [DAIS-ITA RESEARCH]