Question Answering over a Probabilistic Knowledge Base

Christan Grant, Kun Li, Yan Chen, Daisy Zhe Wang
University of Florida
Computer & Information Science & Engineering Department
Gainesville, Florida
{cgrant,kli,yang,daisyw} @ cise.ufl.edu

ABSTRACT

As knowledge bases gain appeal from large companies and organizations, the high volatility of facts is making *probabilistic* knowledge bases, knowledge bases with uncertainty attached to each fact, the next frontier. In this demonstration we a present question answering application over a large probabilistic knowledge bases. This demonstration allows users to interact with a large probabilistic knowledge base, one with primarily deterministic rules, and another with thousands of rules extracted from the web and a third from a continuously learning system. In addition, the use of a probabilistic knowledge base allows the system to quantify the truthfulness of evaluated questions by computing the joint probabilities of facts that support the answer to each questions. We leverage a popular question answering system for language translation and we perform all knowledge base computations — including, grounding and inference — inside of the PostgreSQL Relational Database Management System. We believe this demonstration to be the first to demonstrate such an application over a probabilistic knowledge bases.

1. INTRODUCTION

In recent years, the large increase of machine accessible data has lead researchers to develop sophisticated methods of organizing and using the information. In particular, the advancement of information extraction techniques has allowed millions of facts to be extracted from across the web. This is evidenced by the renewed interests in knowledge graphs and knowledge bases from companies and researchers [1, 5, 7, 11].

Knowledge graphs efficiently store and manage the linking of facts. Knowledge bases are equivalent to knowledge graphs but with and additional inference engine. Inference engines allow the discovery of facts that are not explicitly mentioned in the knowledge graph. Researchers currently pair probabilities with extracted facts and rules to represent the natural uncertainty found in language and extrac-
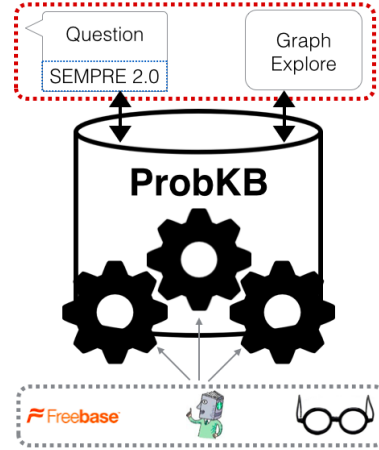

Figure 1: Question answering system architecture.

tion systems. These stores are called probabilistic knowledge bases [6]. When performing inference, probabilistic knowledge bases consider the uncertainty of facts upon evaluation.

This demonstration describes a question answering application developed to demonstrate a new probabilistic knowledge base begin developed in the data science research group at the University of Florida. Users will gain an understanding of the usefulness of a probabilistic knowledge base and the techniques developed for large-scale knowledge base management. The question answering application allows users to see example queries to a probabilistic knowledge base and also to understand how probabilistic knowledge bases work in general.

Further, we enumerate our contributions as follows:

- We develop a question answering architecture that leverages a probabilistic knowledge base for answer generation.

- We develop a trustworthiness value for each question answered over three difference knowledge bases.

- We describe an application for users to interact with a probabilistic knowledge base. Users can add and removing facts before to recompute answer trustworthiness.

2. BACKGROUND

In this section, we give the necessary background from the probabilistic knowledge base backed question answering

system. We first describe the set of data sets that underly this work. We then give a brief description of Markov Logic Networks followed by our definition of a probabilistic knowledgebase.

2.1 Data Set

In this demo, we use Freebase, Reverb, and NELL as the underlying knowledge bases. These knowledge bases store collection of facts as (subject, predicate, object) triples, representing facts related to real-world entities (people, places, and things). Each knowledge base differs in scale, schema and construction methods.

Freebase. Freebase is a web-scale, human-crafted, high precision knowledge base of well-known topics (entities) and facts [4]. As of current writing, it contains 47.5 million entities and 2.9 billion facts, spanning a variety of areas including People, Sports, Music, Internet, Books, etc, organized into domains. The Freebase KB is publicly accessible as RDF triples.

ReVerb. ReVerb is an automatic knowledge base construction system that extracts entities and facts from natural language text [8]. It is a universal schema extraction system, extracting both entities and predicates (relations). The extracted tuples are publicly available, and we use its ClueWeb extractions, which contains 14.7 million facts, annotated by their confidence and source URLs.

NELL. NELL is a never-ending knowledge extraction system [9]. It extracts facts and updates its knowledge base every day. As of current writing, it has extracted 84.6 million facts, of which 2.2 million are believed to have high confidence. Like ReVerb, each fact is annotated by its confidence and source URLs. It also contains information on which extraction algorithms are used to extract each fact.

In both ReVerb and NELL KBs, recent works have tried to mine *first-order inference rules*. An inference rule states causal relationships among facts, for example, we have

$$\text{bornIn}(x, y), \text{locatedIn}(y, z) \rightarrow \text{bornIn}(x, z).$$

This rule states that if a person x was born in location y, and location y is located within another location z, then person x is also born in location z. The Sherlock-Holmes system [12] mines 30,912 inference rules from ReVerb, and NELL also has 2 thousand rules with an inference engine as one of its extraction component.

2.2 Markov Logic Networks

Markov Logic Networks (MLNs) are the standard method of modeling uncertainty. MLNs are mare up of a weighted first-order formulae of the form $\{F_i, W_i\}$, where F_i is a logical expression and W_i is a weight specifying how likely it is that the formula is true.

For example, the MLN clauses below state two different sets of information.
0.96 bornInState (Obama, Hawaii)
1.40 $\forall x \in Person, \forall y \in State, \forall z \in Country :$
      $bornState(x, y) \wedge isState(y, z) \rightarrow bornCountry(x, z)$
The first clause states that that Obama was born in the state of Hawaii. The second formulate is an inference rule that states that if a person x is born in a state y, and a state y is in a part of a country z, then that person x is born in the country z. These formula do not necessitate that the formula apply. The weights of 0.96 and 1.40 specify the strength of the formula; stronger rules have a lower chance of being violated. Deterministic rules, or rules that can never be violated are given an infinite weights of ∞.

2.2.1 Grounding

MLNs are a template generating ground factor graphs. A factor graph is a set of factors $\Phi = \{\phi_1, \ldots, \phi_{|\Phi|}\}$, where each factor ϕ_i is a function $\phi_i(\mathbf{X}_i)$ over a vector of random variables $\mathbf{X}_i$. The random variables correspond to facts (F_i) and factors a correspond to rules.

We use the term grounding to refer to the processes of creating the factor graph from an MLN and a set of clauses. Each node in the factor graph is a ground atom and has a boolean variable that represents its truth value. We an perform the grounding step inside the database using a simple series of database queries [6].

For each possible grounding of formula F_i we create a ground factor $\phi_i(\mathbf{X}_i)$ with a value of 1 if the grounding is true, otherwise e^{W_i}. The marginal probability distribution of a set of grounded atoms $\mathbf{X}$ is defined as

$$P(\mathbf{X} = x) = \frac{1}{Z} \prod_i \phi_i(\mathbf{X}_i) = \frac{1}{Z}\exp\left(\sum_i W_i n_i(x)\right), \quad (1)$$

where $n_i(x)$ is the number of true groundings of rule F_i in x, W_i is its weight, and Z is the partition function. This probability gives use the probability of one particular state of a knowledge base.

2.3 Probabilistic Knowledge Bases

We use a definition of probabilistic knowledge bases derived in previous work [6]. A probabilistic knowledge base is a 5-tuples $\Gamma = (\mathcal{E}, \mathcal{C}, \mathcal{R}, \Pi, \mathcal{L})$, where
1. $\mathcal{E} = \{e_1, \ldots, e_{|\mathcal{E}|}\}$ is the set of entities. Each entitie $e \in \mathcal{E}$ refers to a real-world object.
2. $\mathcal{C} = \{c_1, \ldots, c_{|\mathcal{C}|}\}$ is the set of classes (or types). Each class $C \in \mathcal{C}$ maybe be a subset of $\mathcal{E} : C \subseteq \mathcal{E}$, or an unknown class.
3. $\mathcal{R} = \{R_1, \ldots, R_{|\mathcal{R}|}\}$ is the set of relations. Each $R \in \mathcal{R}$ defines a binary relation on $C_i, C_j \in \mathcal{C} : R :\subseteq C_i \times C_j$. We call C_i, C_j the domain and range of R and use $R(C_i, C_j)$ to denote the relation and its domain and range.
4. $\Pi = \{(r_1, w_1), \ldots, (r_{|\Pi|}, w_{\Pi})\}$ is a set of weighted facts. For each $(r, w) \in \Pi$, r is a tuple (R, x, y), where $R(C_i, C_j) \in \mathcal{R}, x \in C_i \in C, y \in C_j \in C$, and $(x, y) \in R$; $w \in \mathbb{R}$ is a weight indicating how likely it is that r is true.
5. $\mathcal{L} = \{(F_1, W_1), \ldots, (F_{|\mathcal{L}|}, W_{|\mathcal{L}|})\}$ is a set of weighted rules. For each $(F, W) \in \mathcal{L}$, F is a first-order logic clause, and $W \in \mathbb{R}$ us a weight indicating how likely the formula F holds.

2.3.1 Question Answering

To answer questions, a mapping must be developed between a known natural language utterance and a subset of all possible facts. We assume that the knowledge base contains that complete set of facts necessary to find the answer to the question. Additionally, in order to quantify the truthfulness of each fact, it is important to enumerate the facts that support the final answer.

In this work, we leverage a question answering system named SEMPRE which uses supervised learning of question answer pairs to create a Lambda Dependency-Based Compositional Semantics language (λ-DCS) [2]. The translating to a logical form, such as a λ-DCS, allows the semantics to be executed and produce a denotation, or an answer to the utterance. The λ-DCS can be translated to a SPARQL

query for execution over Freebase of a similar knowledge base where it can be evaluated. SEMPRE just needs to be provided training examples specific to each source answer.

3. SYSTEM OVERVIEW

This demonstration describes a question answering systems that leverages a probabilistic knowledge base. To introduce this section, we first give a walk through of how a question is evaluated. We give a detailed description of how answers and truthfulness is generated. We then discuss the algorithm used to extract the underlying facts of the questions.

3.1 Walk through

A user user first enters a question q. We then leverage the SEMPRE system to translate the question into SPARQL, the de facto language for querying RDF data stores. The SQL-like formalism of SPARQL queries produces a set of subgraph expressions as triples. We can then use the SPARQL query $s(q)$ and extract the supporting triples $t_{s(q)}$ that underly the subgraph. These triples are in the form $\langle s, p, o \rangle$ and correspond to the facts that support the answer to the question. To obtain the $t_{s(q)}$, we can evaluate the SPARQL query and materialize each the intermediate triple. We can use $t_{s(q)}$ to search our probabilistic knowledge base of facts to obtain the closest matching facts. Each fact $f \in \mathcal{F}$ is of the form $R(A, B)$ and a triple $t_{s(q)}$ is equivalent to a fact f when $(s, p, o) = (A, R, B)$. Given the equivalent facts, we use an in-database inference algorithm to determine the joint probability that each fact is correct. This probability is a truthfulness score that can be paired with each answer to the question.

3.2 Truthfulness

When a user enters a natural language utterance q, we use the SEMPRE 2.0 system to transform the utterance to a logical form [3, 2]. We then translate the logical form to SPARQL for execution over a knowledge base $\mathcal{D}$; let $s(q, \mathcal{D})$, or equivalently, $s(q)$ be a function that transforms a natural language utterance to the SPARQL query. We then parse the SPARQL query and extract the intermediate triples $t_{s(q)} = \{\langle s, p, o \rangle_1, \ldots\}$. Like the SPARQL query, these triples only specify a template of the facts that are required to evaluate the utterance. We evaluate the SPARQL query over $\mathcal{D}$ to obtain an answer α, we map the query template to define the candidate set of triples $t_{s(q)}^{\alpha}$.

For each triples in $t_{s(q)}^{\alpha}$ we perform a look up in $\mathcal{D}'$ which may or may not be equivalent to the knowledge base $\mathcal{D}'$. If there is a exact match, the triple is mapped to a score of 1. If there is no exact match in $\mathcal{D}$, we estimate the probability of the triple appearing using a straight-forward application of the chain rule. The intuition behind this weighting is that if a fact does not exist we would like to compute the probability that the facts could exist. An equation representing this value is as follows,

$$\omega(s, p, o) = \begin{cases} 1 & \text{if } exists(\langle s, p, o \rangle) \\ \max(\omega(o, p, s), P(s, p, o)) & \text{otherwise,} \end{cases}$$
(2)

where $P(s, p, o) = P(s|p, o)P(p|o)P(o)$. We then estimate the joint probability of a fact existing given the rules.

3.3 Fact Search

Given a candidate fact f of the form $\langle s, p, o \rangle$, we use the database to search for the top triples that are similar to f. Some sets of facts contain blank nodes or expect lists or sets of information. For example, the utterance "`Who are Justin Bieber's siblings?`" produces a SPARQL query that contains the following triples:

(1) $\langle$`justin_bieber, people.person.sibling_s, ?x1`$\rangle$

(2) $\langle$`?x1, people.sibling_relationship.sibling, ?x2`$\rangle$

(3) $\langle$`?x2, type.object.name, ?x2name`$\rangle$

The answers to the query are `Jazmyn_Bieber` and `Jaxon_Bieber`. The extracted query contains one answer variable, `?x2`, and one intermediate node, `?x1`. For each answer node we perform a depth first search to evaluate the probability of each set of triples that can construct the full subgraph. The maximum probability set of triples is returned as the trustworthiness of the answer.

Algorithm 1 Algorithm for discovering the truthfulness of the answer.

1: **procedure** TRUSTWORTHINESS($t_{s(q)}^{\alpha}, \mathcal{D}$)
2:     $G \leftarrow$ `CreateSubGraph`($t_{s(q)}^{\alpha}$)
3:     $Q \leftarrow$ `AllPairs`($G, t_{s(q)}^{\alpha}$) $\triangleright$ Subgraphs that contain all facts
4:     **for** path **in** Q **do**
5:        $S \leftarrow S \cup$ `Prob`(`Facts`(path)) $\triangleright$ Joint Probability of facts
6:     **end for**
7:     **return** $\max(S)$
8: **end procedure**

Algorithm 1 describes the algorithm for obtaining the truthfulness score. Given the evaluated triples, we first perform a topological sort to generate a subgraph containing all facts (Line 2). Next, we find all possible facts in the data that satisfy the subgraph (Line 3). We can then calculate the maximum joint probability of facts from each of the path (Lines 4 to 6).

4. RELATED WORK

Several existing research projects have aimed to extract answers from knowledge bases [13, 14]. In this work, we leverage existing research to demonstrate the utility of probabilistic knowledge bases. Previous methods rank answers by their compatibility to the question. This works additionally computes the joint probability of the underlying facts providing an additional dimension to the answer. Previous works only use deterministic rules they so they are not able to extract a similar trustworthiness score.

Nakashole and Mitchell [10] describe a system, called FactChecker that discovers whether facts are believable by observing the semantics and considering alternatives. In this work, we only uses the knowledge base and have no access to the source knowledge accuracy of the extractions and context. Such a constraint also separates this work from knowledge bases such as Knowledge Vault [7] that require source information in response to a user search.
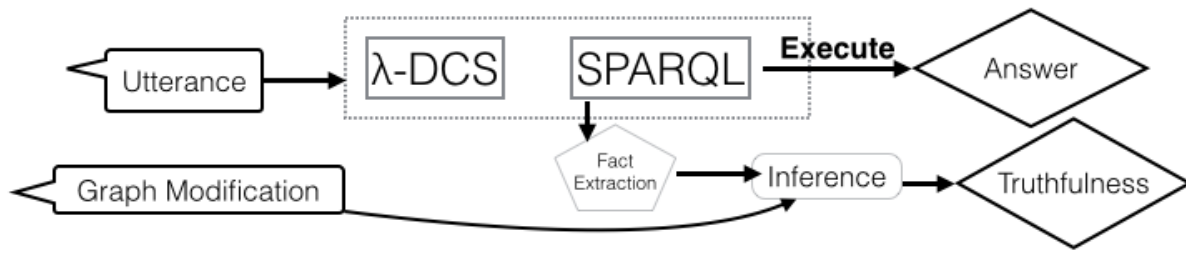
Figure 2: Probabilistic knowledge base assisted question answering demonstration pipeline.

5. DEMONSTRATION PLAN

During the demo, users will be given the work flow shown in Figure 2. An users may provide a natural language question to the interface of retrieve one of the pre-seeded utterances. This question is then translated to the λ-DCS and SPARQL using the SEMPRE system. The user is then shows the answer to the question, as computed by the SPARQL query and also the truthfulness result of the answer.

Alternatively, a user may interact with the knowledge base through a graphical interface. Users will be able to search through the set of existing facts or use a graph to explore connections between graphs. New probabilistic facts and rules can also be added to the system through the interface. Users can also remove or alter the existing facts and rerun queries or answer more questions. The status of queries and the underlying processes are displayed on the main interface.

The demo application is developed using AngularJS to be completely compatible with desktop and mobile devices. We also loaded the data sets described in Section 2.1 into a PostgreSQL DBMS. We trained SEMPRE models for question answering on each of the three knowledge bases. We translate the SPARQL queries to relational format using OpenRDF and Apache Jena SDB. We install the database and web server on docker system container, so any modifications by demo can be quickly rolled back to the initial state.

6. ACKNOWLEDGMENTS

7. REFERENCES

[1] K. Bellare, C. Curino, A. Machanavajihala, P. Mika, M. Rahurkar, and A. Sane. Woo: A scalable and multi-tenant platform for continuous knowledge base synthesis. *Proceedings of the VLDB Endowment*, 6(11):1114–1125, 2013.

[2] J. Berant, A. Chou, R. Frostig, and P. Liang. Semantic parsing on freebase from question-answer pairs. In *EMNLP*, pages 1533–1544, 2013.

[3] J. Berant, A. Chou, R. Frostig, and P. Liang. Semantic parsing on Freebase from question-answer pairs. In *Empirical Methods in Natural Language Processing (EMNLP)*, 2013.

[4] K. Bollacker, C. Evans, P. Paritosh, T. Sturge, and J. Taylor. Freebase: a collaboratively created graph database for structuring human knowledge. In *Proceedings of the 2008 ACM SIGMOD international conference on Management of data*, pages 1247–1250. ACM, 2008.

[5] K.-W. Chang, W.-t. Yih, B. Yang, and C. Meek. Typed tensor decomposition of knowledge bases for relation extraction. In *Proceedings of the 2014 Conference on Empirical Methods in Natural Language Processing (EMNLP)*, pages 1568–1579, 2014.

[6] Y. Chen and D. Z. Wang. Knowledge expansion over probabilistic knowledge bases. In *Proceedings of the 2014 ACM SIGMOD international conference on Management of data*, pages 649–660. ACM, 2014.

[7] X. Dong, E. Gabrilovich, G. Heitz, W. Horn, N. Lao, K. Murphy, T. Strohmann, S. Sun, and W. Zhang. Knowledge vault: A web-scale approach to probabilistic knowledge fusion. In *Proceedings of the 20th ACM SIGKDD international conference on Knowledge discovery and data mining*, pages 601–610. ACM, 2014.

[8] A. Fader, S. Soderland, and O. Etzioni. Identifying relations for open information extraction. In *Proceedings of the Conference of Empirical Methods in Natural Language Processing (EMNLP '11)*, Edinburgh, Scotland, UK, July 27-31 2011.

[9] T. Mitchell, W. Cohen, E. Hruschka, P. Talukdar, J. Betteridge, A. Carlson, B. Dalvi, M. Gardner, B. Kisiel, J. Krishnamurthy, N. Lao, K. Mazaitis, T. Mohamed, N. Nakashole, E. Platanios, A. Ritter, M. Samadi, B. Settles, R. Wang, D. Wijaya, A. Gupta, X. Chen, A. Saparov, M. Greaves, and J. Welling. Never-ending learning. In *Proceedings of the Twenty-Ninth AAAI Conference on Artificial Intelligence (AAAI-15)*, 2015.

[10] N. Nakashole and T. Mitchell. Languageaware truth assessment of fact candidates. In *Proceedings of the 52nd Annual Meeting of the Association for Computational Linguistics (ACL)*, 2014.

[11] F. Niu, C. Zhang, C. Ré, and J. W. Shavlik. Deepdive: Web-scale knowledge-base construction using statistical learning and inference. *VLDS*, 12:25–28, 2012.

[12] S. Schoenmackers, O. Etzioni, D. S. Weld, and J. Davis. Learning first-order horn clauses from web text. In *Proceedings of the 2010 Conference on Empirical Methods in Natural Language Processing*, pages 1088–1098. Association for Computational Linguistics, 2010.

[13] M. Yahya, K. Berberich, S. Elbassuoni, M. Ramanath, V. Tresp, and G. Weikum. Natural language questions for the web of data. In *Proceedings of the 2012 Joint*

Conference on Empirical Methods in Natural Language Processing and Computational Natural Language Learning, pages 379–390. Association for Computational Linguistics, 2012.

[14] X. Yao and B. Van Durme. Information extraction over structured data: Question answering with freebase. In *Proceedings of ACL*, 2014.