

# **Question Answering Using Structured and Unstructured Data**

Doctoral thesis proposal

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## Abstract

Over more than half a century of research, the area of automatic Question Answering (QA) has progressed from small single domain systems to IBM Watson, who defeated best human competitors in the Jeopardy! TV show [43]. However, many of our questions are still left unanswered, and we still have a lot to do to move beyond 10 blue links in search results [38] as for most of the questions users still have to dig into the retrieved documents or post questions to the community question answering (CQA) websites. Questions come in different flavors, some are asking about a certain fact and can be answered with a short phrase, such as entity name, date or number. Such questions are typically referred to as *factoid*, as opposed to rest of the questions, which are often called *non-factoid*. In my thesis I focus on three topics in QA: 1). combination of structured and unstructured data to improve factoid question answering; 2). improving question summarization, candidate scoring and answer generation using recent advances in neural network research and better utilization of source web document structure; 3). interactions between a question answering system and real people.

Text document collections and knowledge bases (KB) are very effective in answering certain types of factoid questions, but they are also complimentary to each other. I propose to combine these data sources via semantic annotation of KB entity mentions, which effectively extends the knowledge base with additional unstructured information, often missing or complimentary to the KB data.

Non-factoid question answering is somewhat harder as it deals with a more diverse set of question and answer types. In my thesis I propose to improve performance of different stages of QA system pipeline by better utilization of the structure of a web page where a candidate answer is extracted from, and using deep learning techniques, inspired by recent successes in machine translation [8], text summarization [85], automatic caption generation [62] and answer sentence scoring [110].

The focus of the last part of the thesis is on the interaction between human and a search or question answering system. Unfortunately, there always be cases, when a machine cannot provide a good answer to the question. In such cases, a QA system may come back to the user with some suggestions on how a user can solve his search problem, or with a clarification question aiming at resolving certain ambiguities. Alternatively, a machine can consult with the crowd in order to get the answer or help it decide on certain alternatives.

In summary, the goal of the proposed research is to improve the performance of question answering over a variety of different questions a user might have, and to study some reply strategies in case a system fails to deliver a good response. I believe, that results of the proposed work will be useful for the future research in improving automatic question answering.

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# 1 Introduction

## 1.1 Motivation

It has long been a dream to communicate with a computer as with another human being using natural language speech and text. Nowadays, we are coming closer to this dream as natural language interfaces become more and more popular. Our phones are already reasonably good in recognizing speech, and personal assistants, such as Apple Siri, Google Now, Microsoft Cortana, Amazon Alexa, *etc.*, help us with everyday tasks and answer some of our questions. Chat bots are arguably considered “the next big thing”, and a number startups developing this kind of technologies has emerged in Silicon Valley and around the world<sup>1</sup>.

Questions are a natural way of communicating ones information needs. Users of modern search engines are already benefit from direct answers on search results page in response to some of their queries <sup>2</sup>. However, there is still a big number of questions, for which users have to dig into the “10 blue links” and mine answers from a pile of information contained in retrieved documents. Therefore, in my thesis I focus on helping users get answers to their questions by improving question answering methods and studying interactions between a human and a QA system.

It’s common to divide questions into *factoid* and *non-factoid*. Factoid questions are inquiring about certain facts and can be answered by a short phrase (or list), *i.e.* entity name, date or number. An example of a factoid question is “*What book did John Steinbeck wrote about the people in the dust bowl?*” (answer: “*The Grapes of Wrath*”). However, many other questions do not fall into this group, *i.e.* people often ask for recommendations, opinions, instructions, reasons, *etc.* The literature usually refer to all these questions by “non-factoid questions” umbrella term.

Nowadays, most of the question answering systems retrieve answers from certain data sources. By their nature, data sources can be classified into unstructured (*e.g.* raw natural language text), semi-structured (*e.g.* tables) and structured (*e.g.* knowledge bases). Each of these types has certain advantages and limitations (Table 1.1). Existing approaches often use either a single type of data sources, or combine them to a limited extend. Motivated by the fact that advantages and disadvantages of structured and unstructured data sources complement each other, In my thesis I propose to study methods of combining different data sources for joint reasoning for factoid and non-factoid questions.

Two major paradigms for factoid question answering are knowledge base question answering (KBQA) and text-based question answer (TextQA). Information contained in a huge volume of text data on the web can be relatively easily queried using terms and phrases from the original question in order to retrieve sentences that might contain the answer. However, each sentence encode very limited amount of information about mentioned entities and aggregating it over unstructured data is quite problematic. On the other hand, modern large scale knowledge bases, such as Freebase [17], dbPedia [6], YAGO [74], WikiData [108], aggregate information about millions of entities into a graph of [subject, predicate, object] RDF triples. The problem with KBs is that they are inherently incomplete and miss a lot of entities, facts and predicates. In addition, triple data

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<sup>1</sup><http://time.com/4194063/chatbots-facebook-messenger-kik-wechat/>

<sup>2</sup><https://www.stonetemple.com/rich-answers-in-search/>

Table 1.1: Pros and cons of structured and unstructured data sources for factoid and non-factoid question answering

	unstructured data	structured data
factoid questions	<p>Text</p> <ul style="list-style-type: none"> <li>+ easy to match against question text</li> <li>+ cover a variety of different information types</li> <li>- each text phrase encodes a limited amount of information about mentioned entities</li> </ul>	<p>Knowledge Bases</p> <ul style="list-style-type: none"> <li>+ aggregate all the information about entities</li> <li>allow complex queries over this data using special languages (e.g. SPARQL)</li> <li>- hard to translate natural language questions into special query languages</li> <li>- KBs are incomplete (missing entities, facts and properties)</li> </ul>
non-factoid questions	<p>Text</p> <ul style="list-style-type: none"> <li>+ contain relevant information to a big chunk of user needs</li> <li>- hard to extract semantic meaning of a paragraph to match against the question (lexical gap)</li> </ul>	<p>Question-Answer pairs</p> <ul style="list-style-type: none"> <li>+ easy to find a relevant answer by matching the corresponding questions</li> <li>- cover a smaller subset of user information needs</li> </ul>

representation format complicates retrieval of KB concepts relevant to question phrases. The focus of the proposed research in factoid question answering lies on the idea of combining structured KB and unstructured text data, which can help a QA system to overcome these drawbacks.

The main challenge in non-factoid question answering lies in the diversity of question and answer types. One of the most effective strategies is to reuse answers to previously asked questions, which could be found, for example, in CQA archives [92]. Unfortunately, it's not always possible to find a similar question, that has already been answered. Many information needs are unique or contain unique details, which makes it impossible to reuse old answers. Alternative strategies include ranking text passages extracted from retrieved web documents. One of the main challenges of this approach is estimating semantic similarity between the question and an answer candidate [96]. Therefore, one would benefit from knowing what kind of questions could a paragraph of text answer. This information can often be inferred from the structure of a web page, e.g. forums, FAQ pages, or estimated using title, subtitle and other page elements. Therefore, one of the questions I'm going to focus in my thesis is how to effectively use the structure of web page to predict whether an extracted passage of text answer the given question.

However, ranking isn't the only important part of the question answering pipeline. A system can only rank and return a good answer if it was able to retrieve relevant information from a collection. Non-factoid questions, especially those that people post on CQA websites are often long, which makes it problematic to use directly as search queries. Previous research has studied certain question transformation strategies [1, 22, 71], however the focus was on shorter factoid questions. In my thesis I would like to focus on the problem of query generation for non-factoid questions using some recent advances in deep learning. Another promising direction of research, which I'm going to explore in my thesis, is answer generation, *i.e.* by summarizing the information

a system could retrieve. Different answer candidates might be complimentary to each other, answer different parts of the question or have different opinions on the subject.

No matter how good a QA system we have, there will be cases, when it will be unable to answer a question user asked. It may be caused by various reasons, *e.g.* the question might be hard to answer with the existing data sources or it may be ambiguous. In such cases, it make sense to either appeal to another external resources, *e.g.* such as wisdom of a crowd, or interact with the asked and give him some suggestions on how to tackle her search problem or ask for some additional information.

## 1.2 Research Questions

Research questions I proposed addressed in my thesis are the following:

1. RQ1. How to effectively combine unstructured text and structured knowledge base data to improve factoid question answering?
2. RQ2. What kind of information about a web page can help scoring a passage extracted from it as a possible answer to the given question?
3. RQ3. How to build question and answer summarization models to improve candidate retrieval and answer generation for non-factoid question answering?
4. RQ4. How we can improve user experience with question answering systems for complex informational tasks?

## 1.3 Research Plan

### 1.3.1 Combining KB and Text Data for Factoid Question Answering (Chapter 3)

The goal is to study a problem of using multiple structured KB and unstructured data together to improve factoid question answering. Two major issues with KBQA is knowledge base incompleteness and complexity of translating natural language question into a structured query. Text documents on the other hand are easier to match against the question, contain more information than a typical knowledge base, but aggregating information across multiple statements and documents is complicated.

One way to improve the situation with knowledge base incompleteness is to extract missing information from other data sources, *e.g.* [24, 25, 36, 39, 50, 65]. I propose to explore one additional data source, that wasn't used for relation extraction before, namely question-answer pairs. Section 3.1 will describe our experiments and results in utilizing this data to improve knowledge base coverage. Unfortunately, relation extraction isn't perfect either and there are both precision and recall losses. Therefore, I propose to explore semantic annotation of entity mentions as a way to bridge the gap between KB entity graph and text documents. Such representation will allow us to do simple string matching on text documents and at the same time explore the knowledge about the mentioned entities in KB and vice versa. Section 3.2 describes the approach in more detail.

### 1.3.2 Using Web Page Information to Improve Passage Ranking in Non-factoid Question Answering (Chapter 4.1.2)

To answer RQ2 I'm planning to study what kind of information from web pages can be useful to predict whether a passage of text answer the given questions. First, I'll derive a dataset of questions from TREC LiveQA'15 with passages, labeled by TREC assessors, and extract the corresponding web pages. This allows us to set the problem as passage ranking problem using a set of passage and web page context features. I will design a set of features representing a passage and some key elements from the web page and train an answer ranking model. The feature ablation experiments will reveal the relative importance of different model components.

### 1.3.3 Question and Answer Summarization for Non-factoid Question Answering (Chapter 4.1.1)

The goal is to develop models for question summarization, which should improve candidate answer retrieval performance, and answer summarization to generate the final response of the system. The plan is to explore recent advances in deep learning for text summarization [85] and generation [62] and apply these techniques for the above mentioned problems. The effectiveness of these models will be evaluated using the data from TREC LiveQA'15 and tested inside this year challenge model.

### 1.3.4 User Interaction with a QA system (Chapter 5)

The goal is to explore some techniques of involving human in the question answering problem. I'm going to focus on three scenarios:

- showing users hints on how to approach her complex informational search task.
- communicating with the user by asking certain clarification questions for ambiguous questions
- involving crowdsourcing to help a QA system to answer the given question

### 1.3.5 Research Timeline

A tentative timeline for the work that needs to be done is shown below:

- Completing the work proposed in Sections 1.3.2 and 1.3.3 (4/2016 - 5/2016): develop individual components for question analysis, answer candidate retrieval and answer generation and integrate them into a system to participate in TREC LiveQA'16.
- Completing the work proposed in Section 1.3.1 (6/2016 - 7/2016): Develop a model to use annotation of entity mentions for factoid question answering and compare it against existing techniques. I'm also planning to develop a new QA dataset, which will include more diverse and realistic set of questions than existing KBQA datasets and larger than available TREC QA datasets.



- Completing the work proposed in Section 1.3.4 (4/2016 - 5/2016): Integrate a crowdsourcing module into my TREC LiveQA'16 system as one of the options, develop a model to predict ambiguous questions on a CQA website and propose certain clarification questions.
- Thesis writing (07/2016 - 08/2016)
- Thesis defense (08/2016)

## 1.4 Contributions and Implications

The key contributions of the proposed research are: 1. New hybrid KB-text question answering algorithm, that is based on graph search, which includes both KB links as well as text search edges to follow. 2. New labelled dataset for question answering (???) 3. New features for ranking answer candidates ???

## 2 Related Work

The field of automatic questions answering has a long history of research and dates back to the days when the first computers appear. By the early 60s people have already explored multiple different approaches to question answering and a number of text-based and knowledge base QA systems existed at that time [93, 94]. In 70s and 80s the development of restricted domain knowledge bases and computational linguistics theories facilitated the development of interactive expert and text comprehension systems [5, 91, 117, 116]. The modern era of question answering research was motivated by a series of Text Retrieval Conference (TREC<sup>1</sup>) question answering shared tasks, which was organized annually since 1999 [107]. A comprehensive survey of the approaches from TREC QA 2007 can be found in [32]. An interested reader can refer to a number of surveys to track the progress made in automatic question answering over the years [52, 4, 111, 64, 82, 3, 49].

The main focus of research in automatic question answering was on factoid questions. However, recently we can observe an increased interest in non-factoid question answering, and as an indicator in 2015 TREC started a LiveQA shared task track<sup>2</sup>, in which the participant systems had to answer various questions coming from real users of Yahoo! Answers<sup>3</sup> in real time.

In the rest of the chapter I will describe related work in factoid (Section 2.1) and non-factoid (Section 2.2) question answering with the focus on data sources used.

### 2.1 Factoid question answering

Since the early days of automatic question answering researches explored different sources of data, which lead to the development of two major approaches to factoid question answering: text-based (TextQA) and knowledge base question answering (KBQA) [93]. We will first describe related work in TextQA (Section 2.1.1), then introduce KBQA (Section 2.1.2) and in Section 2.1.3 present existing techniques for combining different information sources together.

#### 2.1.1 Text-based question answering

A traditional approach to factoid question answering over text document collections, popularized by TREC QA task, starts by querying a collection with possibly transformed question and retrieving a set of potentially relevant documents, which are then used to identify the answer. Information retrieval for question answering has certain differences from traditional IR methods [63], which are usually based on keyword matches. A natural language question contains certain information, that is not expected to be present in the answer (*e.g.* the keyword *who*, *what*, *when*, *etc.*), and the answer statement might use language that is different from the question (lexical gap problem). On the other side, there is a certain additional information about expected answer statement, that a QA system might infer from the question (*e.g.* we expect to see in a number in response to the “how many” question). One way to deal with this problem is to transform the question in certain

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<sup>1</sup><http://trec.nist.gov>

<sup>2</sup><http://trec-liveqa.org/>

<sup>3</sup><http://answers.yahoo.com/>

ways before querying a collection [1, 22]. Raw text data might be extended with certain semantic annotations by applying part of speech tagger, semantic role labeling, named entity recognizer, *etc.* By indexing these annotations a question answering system gets an opportunity to query collection with additional attributes, inferred from the question [16, 130].

The next stage in TextQA is to select sentences, that might contain the answer. One of the mostly used benchmark datasets for the task, proposed in [113], is based on TREC QA questions and sentences retrieved by participating systems<sup>4</sup>. The early approaches for the task used simple keyword match strategies [57, 97]. However, in many cases keywords doesn't capture the similarity in meaning of the sentences very well and researches started looking on syntactic information. Syntactic and dependency tree edit distances and kernels allow to measure the similarity between the structures of the sentences [83, 90, 51, 129, 112]. Recent improvements on the answer sentence selection task come are associated with the deep learning techniques, *e.g.* recursive neural networks using sentence dependency tree [58], convolutional neural networks [133, 86], recurrent neural networks [103, 110]. Another dataset, called WikiQA [125], raises a problem of answer triggering, *i.e.* detecting cases when the retrieved set of sentences don't contain the answer.

To provide a user with the concise answer to his factoid question QA systems extract the actual answer phrase from retrieved sentences. This problem is often formulated as a sequence labeling problem, which can be solved using structured prediction models, such as CRF [129], or as a node labeling problem in an answer sentence parse tree [75].

Unfortunately, passages include very limited amount of information about the candidate answer entities, *i.e.* very often it doesn't include the information about their types (person, location, organization, or more fine-grained CEO, president, basketball player, *etc.*), which is very important to answer question correctly, *e.g.* for the question "*what country will host the 2016 summer olympics?*" we need to know that **Rio de Janeiro** is a city and **Brazil** is the country and the correct answer to the question. Therefore, a lot of effort has been put into developing answer type typologies [55, 54] and predicting and matching expected and candidate answer types from the available data [68, 69, 81]. Many approaches exploited external data for this task, I will describe some of this efforts in Section 2.1.3.

Very large text collections, such as the Web, contain many documents expressing the same information, which makes it possible to use a simpler techniques and rely on redundancy of the information. AskMSR QA system was one of the first to exploit this idea, and achieved very impressive results on TREC QA 2001 shared task [21]. The system starts by transforming a question into search queries, extracts snippets of search results from a web search engine, and consider word n-grams as answer candidates, ranking them by frequency. A recent revision of the AskMSR QA system [105] introduced several improvements to the original system, *i.e.* named entity tagger for candidate extraction, and additional semantic similarity features for answer ranking. It was also observed, that modern search engines are much better in returning the relevant documents for question queries and query generation step is no longer needed. Another notable systems, that used the web as the source for question answering are MULDER[66], Aranea [71], and a detailed analysis of what affects the performance of the redundancy-based question answering systems can be found in [70].

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<sup>4</sup>A table with all known benchmark results and links to the corresponding papers can be found on [http://aclweb.org/aclwiki/index.php?title=Question\\_Answering\\_\(State\\_of\\_the\\_art\)](http://aclweb.org/aclwiki/index.php?title=Question_Answering_(State_of_the_art))

### 2.1.2 Knowledge base question answering

Earlier in the days knowledge bases were relatively small and contained information specific to a particular domain, *e.g.* baseball statistics [48], lunar geology [117], geography [134]. However, one of the main challenges in KBQA is mapping between natural language phrases to the database concepts, which raises a problem of domain adaption of question answering systems.

Recent development of large scale knowledge bases (*e.g.* dbPedia [6], Freebase [17], YAGO [99], WikiData<sup>5</sup>) shifted the attention towards open domain question answering. Knowledge base question answering approaches can be evaluated on an annual Question Answering over Linked Data (QALD<sup>6</sup>) shared task, and some popular benchmark dataset, such as Free917 [27] and WebQuestions [11]. A survey of some of the proposed approaches can be found in [106].

A series of QALD evaluation campaigns has started in 2011, and since then a number of different subtasks have been offered, *i.e.* since QALD-3 includes a multilingual task, and QALD-4 formulated a problem of hybrid question answering. These tasks usually use dbPedia knowledge base and provide a training set of questions, annotated with the ground truth SPARQL queries. The hybrid track is of particular interest to the topic of this dissertation, as the main goal in this task is to use both structured RDF triples and free form text available in dbPedia abstracts to answer user questions.

The problem of lexical gap and lexicon construction for mapping natural language phrases to knowledge base concepts is one of the major difficulties in KBQA. The earlier systems were mainly trained from question annotated with the correct parse logical form, which is expensive to obtain. Such an approach is hard to scale to large open domain knowledge bases, which contain millions of entities and thousands of different predicates. An idea to extend a trained parser with additional lexicon, built from the Web and other resources, has been proposed by [28]. However, most of the parses of the question produce different results, which means that it is possible to use question-answer pairs directly [11]. PARALEX system ([42]) construct a lexicon from a collection of question paraphrases from WikiAnswers<sup>7</sup>. A somewhat backwards approach was proposed in ParaSempre model of [12], which ranks candidate structured queries by first constructing a canonical utterance for each query and then using a paraphrasing model to score it against the original question. Another approach to learn term-predicate mapping is to use patterns obtained using distant supervision [78] labeling of a large text corpus, such as ClueWeb [127]. Such labelled collections can also be used to train a KBQA system, as demonstrated by [84]. Such an approach is very attractive as it doesn't require any manual labeling and can be easily transferred to a new domain. However, learning from statements instead of question answer pairs has certain disadvantages, *e.g.* question-answer lexical gap and noise in distant supervision labeling. Modern knowledge bases also contain certain surface forms for their predicates and entities, which makes it possible to convert KB RDF triples into questions and use them for training [18]. Finally, many systems work with distributed vector representations for words and RDF triples and use various deep learning techniques for answer selection. A common strategy is to use a joint embedding of text and knowledge base concepts. For example, character n-gram text representation as input to a convolutional neural network can capture the gist of the question and help map phrases to entities and predicates [131]. Joint embeddings can be trained using multi-task learning, *e.g.* a system can learn to embed a question and candidate answer subgraph using question-answer pairs and question paraphrases at the same time ([18]). Memory Networks, developed by the

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<sup>5</sup><http://www.wikidata.org>

<sup>6</sup>[www.scit-ec.uni-bielefeld.de/qald/](http://www.scit-ec.uni-bielefeld.de/qald/)

<sup>7</sup><https://answers.wikia.com/>

Facebook AI Lab, can also be used to return triples stored in network memory in a response to the user question [19]. This approach uses embeddings of predicates and can answer relatively simple questions, that do not contain any constraints and aggregations. To extend deep learning framework to more complex questions, [35] use multi-column convolutional neural network to capture the embedding of the entity path, context and type.

As for the architecture of KBQA systems, two major approaches have been identified: semantic parsing and information extraction. Semantic parsing starts from question utterances and work to produce the corresponding semantic representation, *e.g.* logical form. The model of [11] uses a CCG parser, which can produce many candidates on each level of parsing tree construction. A common strategy is to use beam search to keep top-k options on each parsing level or agenda-based parsing [13], which maintains current best parses across all levels. An alternative information extraction strategy was proposed by [128], which can be very effective for relatively simple questions. A comparison of this approaches can be found in [127]. The idea of the information extraction approach is that for most of the questions the answer lies in the neighborhood of the question topic entity. Therefore, it is possible to use a relatively small set of query patterns to generate candidate answers, which are then ranked using the information about how well involved predicates and entities match the original question.

Question entity identification and disambiguation is the key component in such systems, they cannot answer the question correctly if the question entity isn't identified. Different systems used NER to tag question entities, which are then linked to a knowledge base using a lexicon of entity names [11, 12, 121]. However, NER can easily miss the right span and the whole system would fail to produce the answer. Recently, most of the state-of-the-art system on WebQuestions dataset used a strategy to consider a reasonable subset of token n-grams, each of which can map to zero or more KB entities, which are disambiguated on the answer ranking stage [126, 9, 104]. Ranking of candidates can be done using a simple linear classification model [126] or a more complex gradient boosted trees ranking model [9, 104].

Some questions contain certain conditions, that require special filters or aggregations to be applied to a set of entities. For example, the question “*who won 2011 heisman trophy?*” contains a date, that needs to be used to filter the set of heisman trophy winners, the question “*what high school did president bill clinton attend?*” requires a filter on the entity type to filter high schools from the list of educational institutions, and “*what is the closest airport to naples florida?*” requires a set of airports to be sorted by distance and the closest one to be selected. Information extraction approaches either needs to extend the set of candidate query templates used, which is usually done manually, or to attach such aggregations later in the process, after the initial set of entities have been extracted [104]. An alternative strategy to answer complex questions is to extend RDF triples as a unit of knowledge with additional arguments and perform question answering over n-tuples [132]. In [115] authors propose to start from single KB facts and build more complex logical formulas by combining existing ones, while scoring candidates using paraphrasing model. Such a a template-free model combines the benefits of semantic parsing and information extraction approaches.

### 2.1.3 Hybrid question answering

A natural idea of combining available information sources to improve question answering has been explored for a long time. WordNet lexical database [77] was among the first resources, that were adapted by QA community [56, 80], and it was used for such tasks as query expansion

and definition extraction. Wikipedia<sup>8</sup>, which can be characterized as an unstructured and semi-structured (infoboxes) knowledge base, quickly became a valuable resource for answer extraction and verification [2, 23]. Developers of the Aranea QA system noticed that structured knowledge bases are very effective in answering a significant portion of relatively simple questions [71]. They designed a set of regular expressions for popular questions that can be efficiently answered from a knowledge base and fall back to regular text-based methods for the rest of the questions.

One of the major drawbacks of knowledge bases is their incompleteness, which means that many entities, predicates and facts are missing from knowledge bases, which limits the number of questions one can answer using them. One approach to increase the coverage of knowledge bases is to extract information from other resources, such as raw text[78, 61, 50], web tables [24], *etc.* However, the larger the knowledge base gets, the more difficult it's to find a mapping from natural language phrases to KB concepts. Alternatively, open information extraction techniques ([39]) can be used to extract a surface form-based knowledge base, which can be very effective for question answering. Open question answering approach of [41] combines multiple structured (Freebase) and unstructured (OpenIE) knowledge bases together by converting them to string-based triples. User question can be first paraphrased using paraphrasing model learned from WikiAnswers data, then converted to a KB query and certain query rewrite rules can be applied, and all queries are ranked by a machine learning model.

SPOX tuples, proposed in [122], encode subject-predicate-object triples along with certain keywords, that could be extracted from the same place as RDF triple. These keywords encode the context of the triple and can be used to match against keywords in the question. The method attempts to parse the question and uses certain relaxations (removing SPARQL triple statements) along with adding question keyphrases as additional triple arguments. As an extreme case of relaxation authors build a query that return all entities of certain type and use all other question terms to filter and rank the returned list.

However, by applying information extraction to raw text we inevitably lose certain portion of the information due to recall errors, and extracted data is also sometimes erroneous due to precision errors. In [120], authors propose to use textual evidence to do answer filtering in a knowledge base question answering system. On the first stage with produce a list of answers using traditional information extraction techniques, and then each answer is scored using its Wikipedia page on how well it matches the question. Knowledge bases can also be incorporated inside TextQA systems. Modern KBs contain comprehensive entity types hierarchies, which were utilized in QuASE system of [100] for answer typing. In addition, QuASE exploited the textual descriptions of entities stored in Freebase knowledge base as answer supportive evidence for candidate scoring. However, most of the information in a KB is stored as relations between entities, therefore there is a big potential in using all available KB data to improve question answering.

Another great example of a hybrid question answering system is IBM Watson, which is arguably the most important and well-known QA systems ever developed so far. It was designed to play the Jeopardy TV show<sup>9</sup>. The system combined multiple different approaches, including text-based, relation extraction and knowledge base modules, each of which generated candidate answers, which are then pooled together for ranking and answer selection. The full architecture of the system is well described in [43] or in the full special issue of the IBM Journal of Research and Development [44]. YodaQA [10] is an open source implementation of the ideas behind the IBM Watson system.

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<sup>8</sup><http://www.wikipedia.org>

<sup>9</sup><https://en.wikipedia.org/wiki/Jeopardy!>

## 2.2 Non-factoid question answering

During earlier days of research non-factoid questions received relatively little attention. TREC QA tasks started to incorporate certain categories of non-factoid questions, such as definition questions, during the last 4 years of the challenge. One of the first non-factoid question answering system was described in [96] and was based on web search using chunks extracted from the original question. The ranking of extracted answer candidates was done using a translation model, which showed better results than n-gram based match score.

The growth of the popularity of community question answering (CQA) websites, such as Yahoo! Answers, Answers.com, *etc.*, contributed to an increased interest of the community to non-factoid questions. Some questions on CQA websites are repeated very often and answers can easily be reused to answer new questions, [73] studies different types of CQA questions and answers and analyzes them with respect to answer re-usability. A number of methods for similar question retrieval have been proposed [14, 92, 37, 59]. WebAP is a dataset for non-factoid answer sentence retrieval, which was developed in [124]. Experiments conducted in this work demonstrated, that classical retrieval methods doesn't work well for this task, and multiple additional semantic (ESA, entity links) and context (adjacent text) features have been proposed to improve the retrieval quality.

Candidate answer passages ranking problem becomes even more difficult in non-factoid questions answering as systems have to deal with larger piece of text and need to "understand" what kind of information is expressed there. One of the first extensive studies of different features for non-factoid answer ranking can be found in [101], who explored information retrieval scores, translation models, tree kernel and other features using tokens and semantic annotations (dependency tree, semantic role labelling, *etc.*) of text paragraphs. Alignment between question and answer terms can serve as a good indicator of their semantic similarity. Such an alignment can be produced using a machine learning model with a set of features, representing the quality of the match [114]. Alignment and translation models are usually based on term-term similarities, which are often computed from a monolingual alignment corpus. This data can be very sparse, and to overcome this issue [46] proposed higher-order lexical semantic models, which estimates similarity between terms by considering paths of length more than 1 on term-term similarity graph. An alternative strategy to overcome the sparseness of monolingual alignment corpora is to use the discourse relations of sentences in a text to learn term association models [89].

Questions often have some metadata, such as categories on a community question answering website. This information can be very useful for certain disambiguations, and can be encoded in the answer ranking model [135]. The structure of the web page, from which the answers are extracted can be very useful as well. Wikipedia articles have a good structure, and the information encoded there can be extracted in a text-based knowledge base, which can be used for question answering [95]. Information extraction methods can also be useful for the more general case of non-factoid question answering. For example, there is a huge number of online forums, FAQ-pages and social media, that contain question-answer pairs, which can be extracted to build a collection to query when a new question arrives [30, 60, 123, 34, 67].

Most of the approaches from TREC LiveQA 2015 combined similar question retrieval and web search techniques [118, 87, 109]. Answers to similar questions are very effective for answering new questions [87]. However, we a CQA archive doesn't have any similar questions, we have to fall back to regular web search. The idea behind the winning system of CMU [109] is to represent each answer with a pair of phrases - clue and answer text. Clue is a phrase that should be similar to the given question, and the passage that follows should be the answer to this question.

## 2.3 User interactions

IN PROGRESS...

An interesting approach for knowledge base construction through dialog with the user has been proposed by [53].

A very nice crowdsourcing method to obtain answers to tail information needs was proposed by [15]. Question query-url pairs are first mined from query logs, and then the wisdom of a crowd is used to extract and save answers to these questions.

Certain questions cannot be answered by machines only due to reasons such as lack of the appropriate data. Crowdsourcing was explored as one of the options to bridge this knowledge gap and assist the machine in matching, ranking and result aggregation [45]. Wisdom of a crowd can also be exploited to answer more difficult quiz questions [7].

[20] retrieves Wikipedia statements that support user answers for opinion questions.

A number of works have focused on studying and estimating different factors of user satisfaction with question answering systems [79, 72]

Interactive TREC ciQA...

[33] analyzes how clarification questions can be detected and used to improve QA performance. As far as I understand, the clarification question comes from the same user, not the system.

## 2.4 Summary of Related Work

Most previous work in ...



## 3 Structured and Unstructured Data for Factoid Question Answering

There are multiple ways to marry unstructured and structured data for joint question answering: convert structured data to unstructured format or vice versa, convert all data to certain intermediate representation or to leave them as is and link the data sources. In my thesis I focus on two approaches: relation extraction for knowledge base completion, and semantic annotation of text for hybrid question answering.

### 3.1 Relation Extraction for Knowledge Base Completion

The information on the web is stored in multiple different forms, such as natural language statements, tables and infoboxes, images *etc.* In this work I focus on yet another source of information: question-answer pairs. Community question answering archives contain hundreds of millions of question and corresponding answers. Information expressed in these pairs might be hard to extract or not exist at all in other formats.

#### 3.1.1 Relation extraction from Question-Answer pairs

CQA websites, such as Yahoo! Answers<sup>1</sup>, Answers.com<sup>2</sup>, Quora<sup>3</sup> *etc.*, has gained a lot of popularity in the recent years, and their archives store hundreds of millions of user questions along with answers provided by the community. Many users' information needs are not unique and arise again and again, which makes it possible to reuse the information to answers new questions [92]. This idea makes CQA data attractive for knowledge base population. Although some of the facts mentioned in QnA pairs can also be found in some other text documents, another part might be unique (*e.g.* in Clueweb<sup>4</sup> about 10% of entity pairs with existing Freebase relations mentioned in Yahoo! Answers documents cannot be found in other documents [88]). Existing relation extraction techniques face some challenges when applied to CQA data, *i.e.* they typically consider sentences independently and ignore the discourse of a QnA pair text. However, frequently, it is impossible to understand the answer without knowing the question. For example, sometimes users simply give the answer to the question without stating it in a narrative sentence (*e.g.* “*What does "xoxo" stand for? Hugs and kisses.*”), or the provided answer might contain ellipsis, *i.e.* some important information is omitted (*e.g.* “*What's the capital city of Bolivia? Sucre is the legal capital, though the government sits in La Paz*”).

In this thesis we propose a novel model for relation extraction from CQA data, that uses discourse of a QnA pair to extract facts between entities mentioned in question and entities mentioned in answer sentences. The conducted experiments confirm that many of such facts

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<sup>1</sup><http://answers.yahoo.com/>

<sup>2</sup><http://www.answers.com>

<sup>3</sup><http://quora.com>

<sup>4</sup><http://www.lemurproject.org/clueweb12/>

cannot be extracted by existing sentence-based techniques and thus it is beneficial to combine their outputs with the output of our model.

Let us define the problem more formally. We target the problem of relation extraction from QnA data, which is a collection of  $(q, a)$  pairs, where  $q$  is a question text (can contain multiple sentences) and  $a$  is the corresponding answer text (can also contain multiple sentences). By relation instance  $r$  we mean an ordered binary relation between *subject* and *object* entities, which is commonly represented as  $[subject, predicate, object]$  triple. For example, the fact that Brad Pitt married Angelina Jolie can be represented as [Brad Pitt, married\_to, Angelina Jolie]. In this work we use Freebase, an open schema-based KB, where all entities and predicates come from the fixed alphabets  $E$  and  $P$  correspondingly. Let  $e_1$  and  $e_2$  be entities that are mentioned together in a text (*e.g.* in a sentence, or  $e_1$  in a question and  $e_2$  in the corresponding answer), we will call such an entity pair with the corresponding context a mention. The same pair of entities can be mentioned multiple times within the corpus, and for all mentions  $i = 1, \dots, n$  the goal is to predict the expressed predicate ( $z_i \in P$ ) or to say that none applies ( $z_i = \emptyset$ ). Individual mention predictions  $z_1, \dots, z_n$  are combined to infer a set of relations  $\mathbf{y} = \{y_i \in P\}$  between the entities  $e_1$  and  $e_2$ .

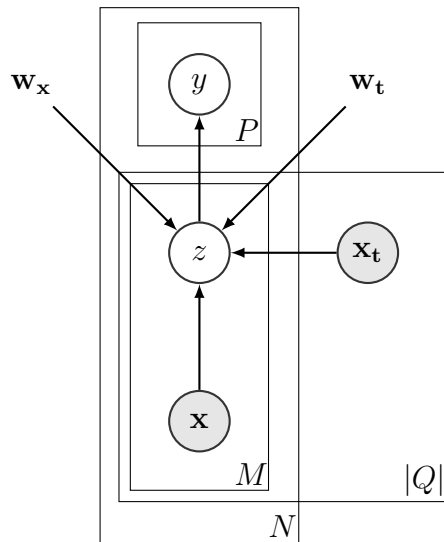


Figure 3.1: QnA-based relation extraction model plate diagram.  $N$  - number of different entity pairs,  $M$  - number of mentions of an entity pair,  $|Q|$  - number of questions where an entity pair is mentioned,  $\mathbf{x}$  and  $\mathbf{x}_t$  - mention-based and question-based features,  $\mathbf{w}$  and  $\mathbf{w}_t$  - corresponding feature weights, latent variables  $z$  - relation expressed in an entity pair mention, latent variables  $y$  - relations between entity pair

Our models for relation extraction from QnA data incorporates the topic of the question and can be represented as a graphical model (Figure 3.1). Each mention of a pair of entities is represented with a set of mention-based features  $x$  and question-based features  $x_t$ . A multinomial latent variable  $z$  represents a relation (or none) expressed in the mention and depends on the features and a set of weights  $w_x$  for mention-based and  $w_t$  for question-based features:

$$\hat{z} = \arg \max_{z \in P \cup \emptyset} p(z|x, x_t, w_x, w_t)$$

. To estimate this variable we use L2-regularized multinomial logistic regression model, trained

using the distant supervision approach for relation extraction [78], in which mentions of entity pairs related in Freebase are treated as positive instances for the corresponding predicates, and negative examples are sampled from mentions of entity pairs which are not related by any of the predicates of interest. Finally, to predict a set of possible relations  $\mathbf{y}$  between the pair of entities we take logical OR of individual mention variables  $\mathbf{z}$ , *i.e.*  $y_p = \bigvee_{i=1}^M [z_i = p, p \in P]$ , where  $M$  is the number of mentions of this pair of entities.

### Sentence-based baseline model

Existing sentence-based relation extraction models can be applied to individual sentences of a QnA pair and will work well for complete statements, *e.g.* “Who did Brad Pitt marry? Brad Pitt and Angelina Jolie married at secret ceremony”. In sentence-based scenario, when the set of question-based features is empty, the above model corresponds to the Mintz++ baseline described in [102], which was shown to be superior to the original model of [78], is easier to train than some other state of the art distant supervision models and produces comparable results.

### Sentence-based model with question features

Table 3.1: Examples of features used for relation extraction for “*When was Mariah Carey born? Mariah Carey was born 27 March 1970*”

Sentence-based model	
Dependency path between entities	[PERSON]→nsubjpass(born)tmod←[DATE]
Surface pattern	[PERSON] be/VBD born/VBN [DATE]
Question features for sentence-based model	
Question template	when [PERSON] born
Dependency path from a verb to the question word	(when)→advmod(born)
Question word + dependency tree root	when+born
QnA-based model	
Question template + answer entity type	Q: when [PERSON] born A:[DATE]
Dependency path from question word to entity	Q:(when)→advmod(born)nsubj←[PERSON]
and answer entity to the answer tree root	A: (born)tmod←[DATE]
Question word, dependency root and answer pattern	Q: when+born A:born [DATE]

In many cases an answer statement is hard to interpret correctly without knowing the corresponding question. To give the baseline model some knowledge about the question, we include question features (Table 3.1), which are based on dependency tree and surface patterns of a question sentence. This information can help the model to account for the question topic and improve predictions in some ambiguous situations.

### QnA-based model

The QnA model for relation extraction is inspired by the observation, that often an answer sentence do not mention one of the entities at all, *e.g.*, “*When was Isaac Newton born? December 25, 1642*”

*Woolsthorpe, England*". To tackle this situation we make the following assumption about the discourse of a QnA pair: an entity mentioned in a question is related to entities in the corresponding answer and the context of both mentions can be used to infer the relation predicate. Our QnA-based relation extraction model takes an entity from a question sentence and entity from the answer as a candidate relation mention, represents it with a set features (Table 3.1) and predicts a possible relation between them similar to sentence-based models. The features are conjunctions of various dependency tree and surface patterns of question and answer sentences, designed to capture their topics and relation.

## Experiments

For experiments we used 2 publicly available CQA datasets: Yahoo! Answers WebScope dataset<sup>5</sup> and a crawl of WikiAnswers<sup>6</sup> collected by [41]. The Yahoo! Answers dataset contains 4,483,032 questions (3,894,644 in English) with the corresponding answers collected on 10/25/2007. The crawl of WikiAnswers has 30,370,994 question clusters, tagged by WikiAnswers users as paraphrases, and only 3,386,256 them have answers. From these clusters we used all possible pairs of questions and corresponding answers (19,629,443 pairs in total).

Table 3.2: Yahoo! Answers and WikiAnswers datasets statistics

	Y!A	WA
Number of QnA pairs	3.8M	19.6M
Average question length (in chars)	56.67	47.03
Average answer length (in chars)	335.82	24.24
Percent of QnA pairs with answers that do not have any verbs	8.8%	18.9%
Percent of QnA pairs with at least one pair of entities related in Freebase	11.7%	27.5%
Percent of relations between entity pairs in question sentences only	1.6 %	3.1%
Percent of relations between entity pairs in question and answer sentences only	28.1%	46.4%
Percent of relations between entity pairs in answer sentences only	38.6%	12.0%

For each QnA pair we applied tokenization, sentence detection, named entity tagger, parsing and coreference resolution from Stanford CoreNLP [76]. Our cascade entity linking approach is similar to [29] and considered all noun phrase and named entity mentions as candidates. First all named entity mentions are looked up in Freebase names and aliases dictionary. The next two stages attempt to match mention text with dictionary of English Wikipedia concepts [98] and its normalized version. Finally for named entity mentions we try spelling correction using Freebase entity names dictionary. We didn't disambiguate entities and instead took top-5 ids for each coreference cluster (using the  $p(entity|phrase)$  score from the dictionary or number of existing Freebase triples). All pairs of entities (or entity and date) in a QnA pair that are directly related<sup>7</sup> in Freebase were annotated with the corresponding relations.

Table 3.2 gives some statistics on the datasets used in this work. The analysis of answers that do not have any verbs show that  $\sim 8.8\%$  of all QnA pairs do not state the predicate in the answer text.

<sup>5</sup><http://webscope.sandbox.yahoo.com/catalog.php?datatype=1>

<sup>6</sup><http://wiki.answers.com/>

<sup>7</sup>We also consider some paths that come through a mediator node, e.g./people/person/spouse.s./people/marriage/spouse

The percentage is higher for WikiAnswers, which has shorter answers on average. Unfortunately, for many QnA pairs we were unable to find relations between the mentioned entities (for many of them no or few entities were resolved to Freebase). Among those QnA pairs, where some relation was annotated, we looked at the location of related entities. In Yahoo! Answers dataset 38.6% (12.0% for WikiAnswers) of related entities are mentioned in answer sentences and can potentially be extracted by sentence-based model, and 28.1% (46.4% for WikiAnswers) between entities mentioned in question and answer sentences, which are not available to the baseline model and our goal is to extract some of them.

For our experiments we use a subset of 29 Freebase predicates that have enough unique instances annotated in our corpus, *e.g.* date of birth, profession, nationality, education institution, date of death, disease symptoms and treatments, book author, artist album, *etc.* We train and test the models on each dataset separately. Each corpus is randomly split for training (75%) and testing (25%). Knowledge base facts are also split into training and testing sets (50% each). QnA and sentence-based models predict labels for each entity pair mention, and we aggregate mention predictions by taking the maximum score for each predicate. We do the same aggregation to produce a combination of QnA- and sentence-based models, *i.e.*, all extractions produced by the models are combined and if there are multiple extractions of the same fact we take the maximum score as the final confidence. The precision and recall of extractions are evaluated on a test set of Freebase triples, *i.e.* an extracted triple is considered correct if it belongs to the test set of Freebase triples, which are not used for training (triples used for training are simply ignored). Note, that this only provides a lower bound on the model performance as some of the predicted facts can be correct and simply missing in Freebase.

Figure 3.2 shows Precision-Recall curves for QnA-based and sentence-based baseline models and some numeric results are given in Table 3.3. As 100% recall we took all pairs of entities that can be extracted by either model. It is important to note, that since some entity pairs occur exclusively inside the answer sentences and some in pairs of question and answer sentences, none of the individual models is capable of achieving 100% recall, and maximum possible recalls for QnA- and sentence-based models are different.

Table 3.3: Extraction results for QnA- and sentence-based models on both datasets

	Yahoo! Answers			WikiAnswers		
	QnA	Sentence	Combined	QnA	Sentence	Combined
F-1 score	0.219	0.276	0.310	0.277	0.297	0.332
Number of correct extractions	3229	5900	7428	2804	2288	3779
Correct triples not extracted by other model	20.5%	56.5%	-	39.4%	25.8%	-

Results demonstrate that from 20.5% to 39.4% of correct triples extracted by the QnA-based model are not extracted by the baseline model, and the combination of both models is able to achieve higher precision and recall. Unfortunately, comparison of sentence-based model with and without question-based features (Figure 3.2) didn't show a significant difference.

## Analysis

To get an idea of typical problems of QnA-based model we sampled and manually judged extracted high confidence examples that are not present in Freebase (and thus are considered incorrect for precision-recall analysis).

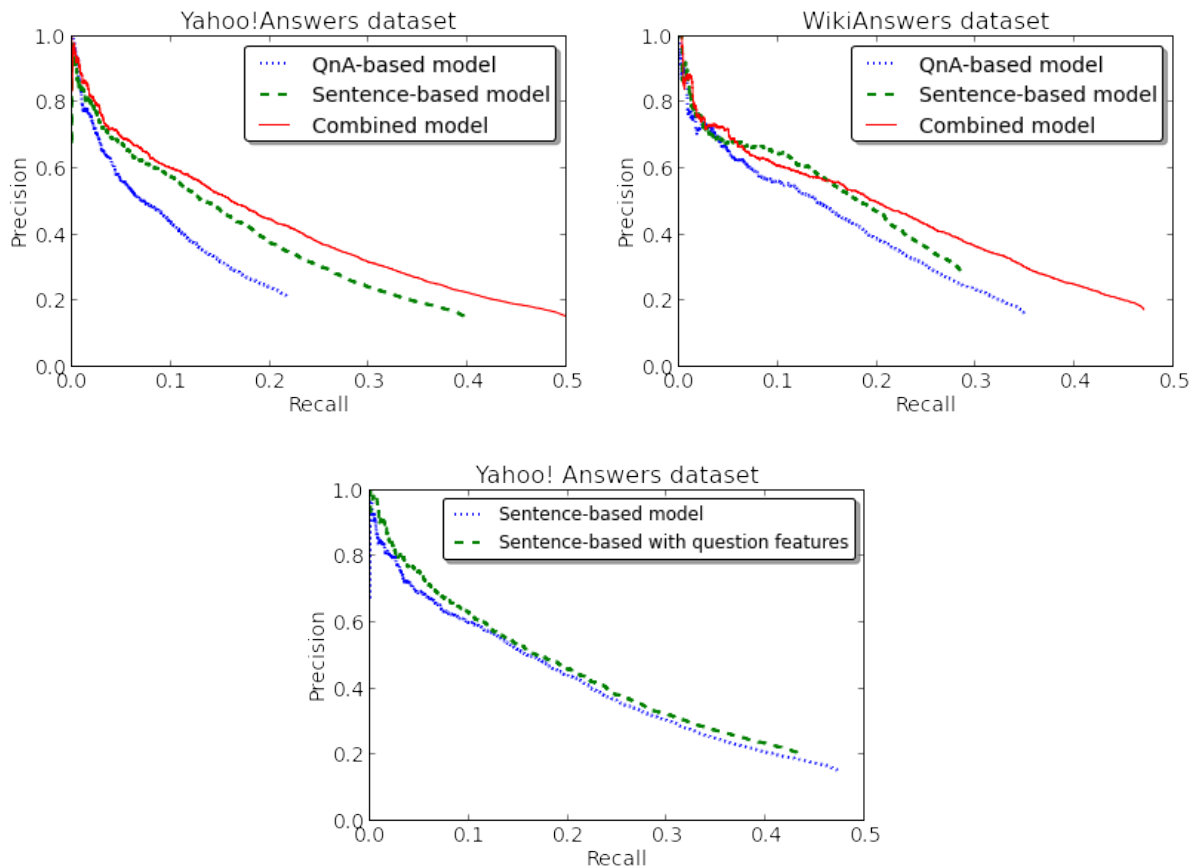


Figure 3.2: Precision-Recall curves for QnA-based vs sentence-based models and sentence-based model with and without question features

The major reason (40%) of false positive extractions is errors in entity linking. For example: “*Who is Tim O’Brien? He was born in Austin on October 1, 1946*”. The model was able to correctly extract [Tim O’Brien, date\_of\_birth, October 1, 1946], however Tim O’Brien was linked to a wrong person. In a number of cases (16%) our discourse model turns out to be too simple and fails for answers, that mention numerous additional information, e.g. “*How old is Madonna really? ...Cher was born on 20 May 1946 which makes her older than Madonna...*”. A possible solution would be to either restrict QnA-based model to cases when no additional information is present or design a better discourse model with deeper analysis of the answer sentence and its predicates and arguments. Some mistakes are due to distant supervision errors, for example for the music.composition.composer predicate our model extracts singers as well as composers (which are in many cases the same).

Of course, there are a number of cases, when our extractions are indeed correct, but are either missing (33%) or contradicting with Freebase (8%). An example of an extracted fact, that is missing in Freebase is “*Who is Wole Soyinka? He studied at the University College, Ibadan(1952-1954) and the University of Leeds (1954-1957)*”, and [Wole Soyinka, institution, University of Leeds] is currently not present in Freebase. Contradictions with Freebase occur because of different precision levels (“pianist” vs “jazz pianist”, city vs county, etc.), different calendars used for dates or “incorrect” information provided by the user. An example, when existing and extracted relation instance are different in precision is: “*Who is Edward Van Vleck? Edward Van Vleck was a mathematician born in Middletown, Connecticut*” we extract [Edward Van Vleck, place\_of\_birth,

Middletown], however the Freebase currently has USA as his place of birth.

The problem of “incorrect” information provided in the answer is very interesting and worth special attention. It has been studied in CQA research, *e.g.* [? ], and an example of such QnA pair is: “*Who is Chandrababu Naidu? Nara Chandra Babu Naidu (born April 20, 1951)*”. Other authoritative resources on the Web give April 20, 1950 as Chandrababu Naidu’s date of birth. This raises a question of trust to the provided answer and expertise of the answerer. Many questions on CQA websites belong to the medical domain, *e.g.* people asking advices on different health related topics. How much we can trust the answers provided to extract them into the knowledge base? We leave this question to the future work.

Finally, we have seen that only a small fraction of available QnA pairs were annotated with existing Freebase relations, which shows a possible limitation of Freebase schema. A promising direction for future work is automatic extraction of new predicates, which users are interested in and which can be useful to answer more future questions.

## Conclusion

In this section we described a model for relation extraction from QnA data, which is capable of predicting relations between entities mentioned in question and answer sentences. We conducted experiments on 2 publicly available CQA datasets and showed that our model can extract triples not available to existing sentence-based techniques and can be effectively combined with them for better coverage of a knowledge base population system.

## 3.2 Semantic Text Annotations for Hybrid Question Answering

Converting unstructured information into structured form by extracting knowledge from text suffers from certain quality losses. Existing relation extraction tools aren’t perfect, in particular due to recall losses a lot of information is left behind. Moreover, extractions contain certain level of incorrect information due to precision losses. These errors cap the upper bound on the question answering system performance.

Here I propose to utilize the synergy of structured and unstructured data, and exploit the advantages of each of them to overcome the limitations of the other. More particularly, I propose to annotate and index mentions of knowledge base entities in text documents. Such a representation induces a special kinds of edges to the knowledge base, and allows one to traverse this edges in both directions. These links open up many opportunities for QA reasoning, *e.g.* retrieving all the information about the entity by going from a mention to a KB entity, finding relations between entities by retrieving text passages that mention both of them, extracting candidate evidence by retrieving passages that mention question and answer entities along with some question terms, and so on.

— THE NEXT PIECE IS OLDER, NEED TO REVIEW

Question answering from text corpora typically starts by retrieving a set of potentially relevant documents using the question (or some transformation of the question [1]) as the query, and then extracting entities, phrases, sentences or paragraphs believed to be the answer to the question. However, the information available in the retrieved pieces of text is very limited and often not enough to decide whether it can be the answer to the given question. For example, below is one

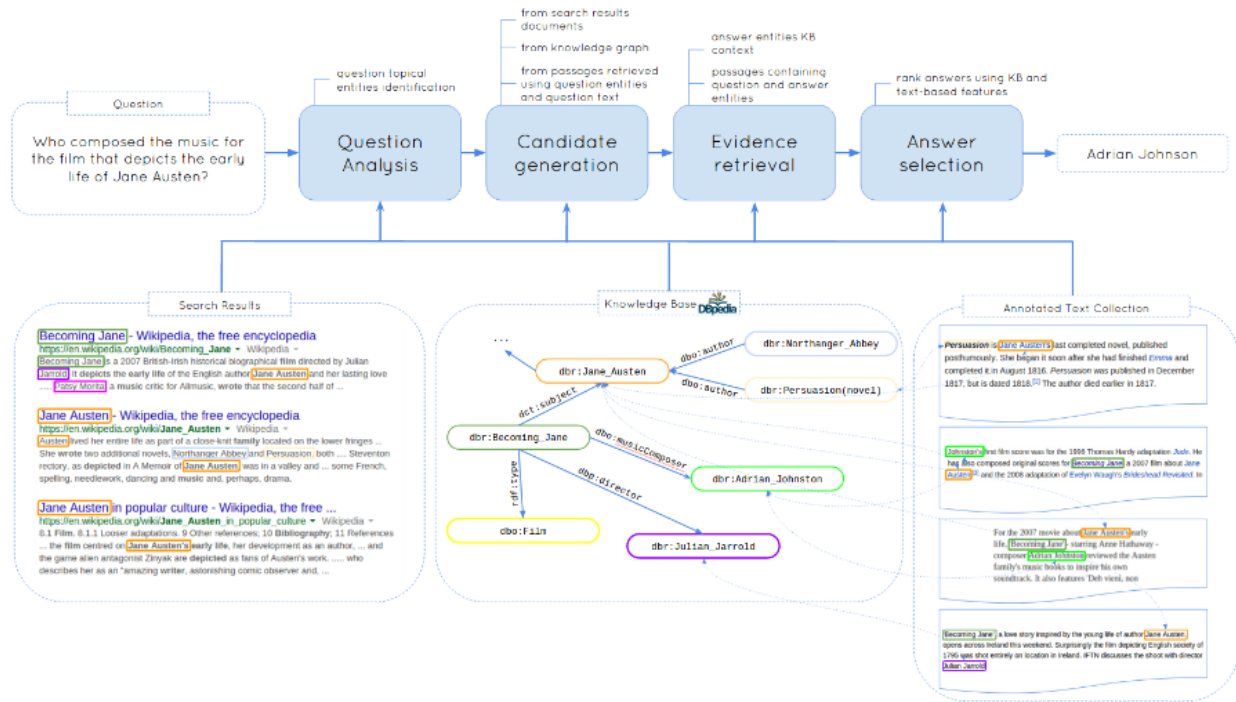


Figure 3.3: Architecture of a hybrid factoid question answering system, that uses a combination of structured knowledge base and unstructured text data

of the questions from TREC QA 2007 dataset:

“What republican senators supported the nomination of Harriet Miers to the Supreme Court?”

A candidate answer sentence “Minority Leader Harry Reid had already offered his open support for Miers.” mentions a senator “Harry Reid” and clearly says about his support of the nomination. However, “Harry Reid” is not a correct answer to the question because he is a member of the Democratic party. This information is not available in the answer candidate sentence, but it is present as one of the properties in Freebase: [Harry Reid, political\_party, Democratic party]<sup>8</sup>. Therefore, by looking into the knowledge available about the mentioned entities a QA system can make a better judgment about the candidate answer.

### 3.2.1 Approach

The architecture of the hybrid QA model I propose is presented on Figure 3.3. Here are the main stages of the question answering process:

- **Pre-processing**: identify mentions of KB entities in text document collection and index the documents text and mentions in separate fields
- **Topical entity identification**: search the text collection using question (or reformulated question [1]) as a query and use an approach similar to [31] to detect question topical entities

<sup>8</sup>Actually, in Freebase the entities are connected by a path of length 2 through a mediator node. The predicates on the path are: /government/politician/party and /government/political\_party\_tenure/party



- **Candidate generation from text:** extract candidate answer (or intermediate answer) entities with evidence from the retrieved text documents using existing techniques, e.g. [105].
- **Candidate generation from KB:** explore the KB neighborhood of question topical entities and entities extracted from text documents on the previous step
- **Candidate generation from KB & Text:** use entity and text index to find entities mentioned near question topical entity and question terms in the document collection
- **KB evidence extraction:** match neighborhood of answer entities (entity type and other entities) against the question to get additional evidence
- **Text evidence extraction:** estimate the similarity between the collection text fragments mentioning question and answer entities and the question text
- **Rank candidate:** rank candidate answers using evidence extracted from the KB as well as from text

Let’s consider an example question “*Who composed the music for the film that depicted the early life of Jane Austen?*” from the QALD dataset<sup>9</sup> (Figure 3.3). Even though it’s quite easy to identify the “**Jane Austen**” entity in the question, the knowledge base (dbPedia in this example) cannot help us to determine which movie is being referred to. However, there are a lot of documents on the web, that do mention the “**Becoming Jane**” movie and say what is it about. Unfortunately, extracting the name of the composer from these documents is quite challenging, but this task can be easily accomplished by checking the value of the `musicComposer` property in the knowledge base. At the end, for each candidate answer entity, we have all the KB information and passages that mention this entity as evidence to help with the correct answer selection.

### 3.2.2 Evaluation

#### Knowledge base QA

I THINK HERE WE CAN INCLUDE OUR RESULTS ON TEXT2KB.

Most of the recent work on knowledge base question answering and semantic parsing have been evaluated on the WebQuestions dataset [11], which contains a collection of question text and correct answer entities. The questions were collected using Google Suggest API and answers crowdsourced using Amazon Mechanical Turk<sup>10</sup>. The proposed approach will be compared against the previous results<sup>11</sup> on this dataset. Again, web can be used as a text collection which can be queried using Bing Search API. Relation extraction patterns can be mined using distant supervision from ClueWeb collection using publicly available dataset of Freebase annotations [47].

**New factoid question answering dataset.** However, WebQuestions dataset has certain limitations, e.g. questions mined using Google Suggest API have very similar structure and lexicon, and to find the answer to the mined questions users were asked to use the question entity Freebase profile page, which only include entities connected directly with a predicate or through a mediator node. Therefore most of the state-of-the-art results on the dataset use a small number of predefined logical form patterns. On the other hand CQA websites have a fraction of factoid questions with

<sup>9</sup><http://greententacle.techfak.uni-bielefeld.de/cunger/qald/>

<sup>10</sup><http://mturk.com/>

<sup>11</sup><http://goo.gl/sePBja>

provided text answers. Here I propose to use to construct a new dataset for question answering over Freebase by selecting a subset of QnA pairs with at least one entity in question and answer and some reasonable filtering heuristics and manual validation using crowdsourcing (e.g. through Amazon Mechanical Turk). Existing systems need to be retrained and tested on the new dataset to compare against the proposed model.

## Text-based QA

WE WILL ANNOTATE TREC DATASETS WITH ENTITIES!!!!

TREC QA datasets served as a benchmark for various question answering systems. Therefore, to evaluate the proposed approach for question answering over text enriched with the structured data I propose to test it on dataset derived from TREC QA and compare against existing strong baselines, including the most related approaches [41, 100]. The proposed system can use the web as the corpus and query it using Bing Search API<sup>12</sup>. Freebase and Reverb extractions [40] are examples of schema-based and open knowledge bases that can be used for the experiments. The metrics used for evaluation typically include accuracy and mean reciprocal rank (MRR).

For non-factoid question answering this year TREC pioneered a new question answering track - TREC LiveQA<sup>13</sup>, which targets questions asked by real users of Yahoo! Answers website. This year the deadline for system submission was on August 31 and my system trained on CQA QnA pairs participated in the challenge. The results will be available on the TREC Conference in November 2015. Organizers plan to continue with another TREC LiveQA task next year and this is going to be a good estimation of the effectiveness of the proposed techniques on hard real user questions.

## 3.3 Summary

In this section we considered two different ways of combining unstructured and structured data to improve factoid question answering. Relation extraction from question-answer pairs aims at filling some gaps in KB fact coverage, whereas semantic annotations of text documents provides a way to incorporate information available in unstructured text documents for reasoning along with KB data to improve the performance of factoid question answering.

Factoid questions represent just a part of user information needs. Many problems require more elaborate response, such as a sentence, list of instructions or in general a passage of text. Such questions are usually referred to as non-factoid questions and they will be the focus of the next Chapter.

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<sup>12</sup><https://datamarket.azure.com/dataset/bing/searchweb>

<sup>13</sup><http://trec-liveqa.org/>

## 4 Non-factoid Question Answering

In this chapter I summarize the proposed work in developing a non-factoid question answering system. In particular, Section 4.1 described the general architecture of the system, and the following chapters describe the proposed improvements to different stages of the pipeline.

### 4.1 The architecture of the system

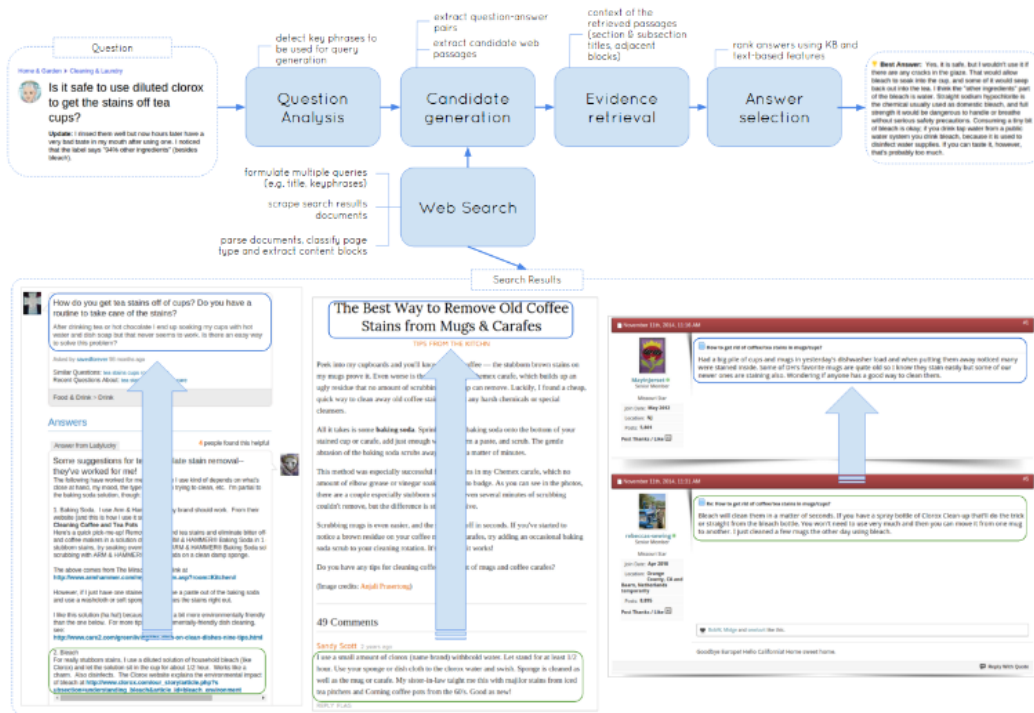


Figure 4.1: Using web page structure information for non-factoid question answering

The architecture of the system I develop is somewhat standard and contains 4 main stages: question analysis, candidate generation, evidence retrieval and answer selection. Figure 4.1 depicts the question-answering pipeline.

#### 4.1.1 Question Analysis

Questions that users post to CQA websites often contain title and body and can be relatively long and contain multiple important and not so important context information and details. The success of the retrieval-based question answering system depends on the information it finds in a collection. Extra long search queries are not very efficient and can return few or zero results. Therefore, there is a problem of summarizing the user question. Some strategies often used include considering first part of the question, *e.g.* title of the question only. However, often the most important part

of the question isn't the title, or the title doesn't contain all the crucial information, *e.g.*

**Title:** *Diet please please help asap?*

**Body:** *I want to lose weight, at least 4 stone but I don't know what I should eat :( what should I have for breakfast lunch and dinner? Should I exercise a little? Please help!!*

To summarize the question I propose to use recent advances in the field of deep learning, in particular a model similar to [85]. In more detail, I propose to train neural network based summarization model to generate the summary of the question, which will be used as a query to retrieve similar questions. Such a model can be specifically trained to maximize retrieval performance on a collection of question-answer pairs, retrieved by systems in LiveQA TREC 2015 and labeled by NIST assessors.

### 4.1.2 Structure of the Web Page for Candidate Generation and Scoring

The diversity and complexity of non-factoid questions pose additional challenges for automatic question answering systems. To answer such questions a system often needs to provide a whole paragraph of text, *e.g.* TREC LiveQA'15 limits the answers to a maximum of 1000 characters. Therefore, a candidate answer becomes much longer, which requires additional attention on candidate generation and ranking stages.

Existing techniques usually extract one or more consecutive sentences not exceeding the maximum answer length, pool them together and rank using certain feature representation, by large ignoring the context information from the page where the answer was extracted from. In the system I develop I propose to utilize the structure of the web page for both candidate generation and scoring.

To generate better candidates I'm going to utilize the structure of retrieved web pages. The previous analysis showed [87], that many search results retrieved for the question are FAQs, forums or other community question answering websites. From such resources it's beneficial to extract question answer pairs, which can be done either by designing wrapper for popular websites, utilizing semantic annotations, such as <https://schema.org> or by applying some of the automatic question-answer extraction methods [30]. For other resources, page segmentation techniques, similar to [26], can split a page into semantically information blocks, which will help to make sure that candidate don't contain disjoint and unreadable information.

After a candidate passage is extracted, we need to score it as a potential answer. Often, a passage taken out of context is hard to understand even for human. Therefore, I propose to include the context information, *i.e.* some features, representing the web page where the passage was taken from and its location there (*e.g.* adjacent passages, which are often related [124]).

### 4.1.3 Answer Summarization

Unlike factoid questions, where evidence from all retrieved passages is usually aggregates, a traditional non-factoid question-answering system simply returns the top scoring passage as the answer. However, such an answer can contain a lot of redundant or irrelevant information, whereas other good candidate passages may contain supplemental information or different opinion. Therefore, an idea to summarize passages and generate the final answer sounds natural in this scenario. The winning approach from TREC LiveQA'15 included a combination strategy, that simply put to-

gether multiple top scoring passages while the answer doesn't exceed the maximum length [109]. In my thesis I'm planning to explore the answer summarization problem in more detail. More specifically, I propose to explore deep learning techniques, that lie in the core of recent successes in text generation, *e.g.* image caption generation and machine translation models [8, 119]. Answer summarization problem can be posed as answer generation problem using recurrent neural network, that has information about the question and retrieved passages, and it can be trained using existing CQA question-answer pairs and retrieved passages, that can be assumed as the source of the answers. Alternative and simpler approach is to solve this problem as sequential answer selection problem, where a model is trained to predict the next sentence in the answer. Such a model can be trained on a collection of questions and answer sentences, which will provide the model information on both answer discourse coherence and relevance.

## 4.2 Evaluation

Evaluation of complete non-factoid question answering systems is complicated due to the variability of answer language, the quality of which is impossible to estimate using manually created answer patterns (as is the case for factoid TREC QA dataset). A manual judgment of answers is needed, and luckily TREC LiveQA 2016 is offering such an opportunity. The model I'm developing will participate in the shared task, which will allow us to evaluate it against other competing approaches.

The analysis of individual components can be performed using labeled data from TREC LiveQA 2015, which includes passages extracted from Yahoo! Answers as well as regular web documents. In more detail, the performance of the answer summarization module will be estimated by similar questions retrieval performance, *e.g.* Precision @ N since we are interested in retrieving more relevant answers in TopN rather than good ranking within the retrieved group. To make results reproducible a collection of Yahoo! Answers QnA pairs from the WebScope<sup>1</sup> and Lucene IR library will be used for question retrieval.

The dataset to evaluate the effectiveness of using web page structure for answer scoring will be derived from TREC LiveQA 2015 labels, which include a big number of passages, that were generated from regular web pages. Therefore, the problem of evaluation of answer scoring methods can be posed as passage ranking problem and metrics, such as Precision@1, can be used as a quality measure.

Finally, the answer summarization module is the most difficult to evaluate, because it's result is a free form text, the quality of which needs to be manually labeled. Therefore, for this task I will refer to the wisdom of a crowd and use Amazon Mechanical Turk to label the quality of answers and compare to the top scoring passages for the same question.

## 4.3 Summary

The proposed research directions target various aspects of non-factoid question answering pipeline and can help improve both precision and recall of existing systems. The results of this work can help to move in the direction of systems, that produce a natural language response by analyzing

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<sup>1</sup><http://webscope.sandbox.yahoo.com/catalog.php?datatype=1>

the information available on the web. In the next chapter, I will describe the proposed work and results on interactions between a question answering system and users.

## 5 Human Interaction with Question Answering Systems

Modern automatic question answering systems are still far from AI machines, that we often imagine or see in the movies. Many user information needs are still left unanswered by existing automatic question answering systems. For example, only 36% of answers of a winning approach from TREC LiveQA 2015 shared task were judged good or excellent. Therefore, in this chapter I will discuss the research on interactions between a human and a question answering system.

More specifically, Section 5.1 describes results on studying the effect of hints on user behavior for solving complex informational tasks. In Section 5.3 I propose research on using crowdsourcing for improving the performance of a question answering system. And Section 5.2 shifts the focus towards a dialogue between a user and a QA system, in particular towards clarification questions, that are often needed to understand user's question.

### 5.1 Search Hints for Complex Informational Tasks

SUMMARIZE SEARCH HINTS PAPER.

### 5.2 Clarification Questions

Today, we are observing a possible shift towards natural language interfaces, which will enable richer interaction between a human and computer, in particular question answering. Most of the existing systems are one-sided, *i.e.* they operate by returning an answer in a response to a user question. A richer model will inevitably lead to a dialogue rather than request-response kind of communication. There are many practical aspects of maintaining a dialogue for question-answering. For example, many questions that user ask allow multiple interpretations, *e.g.* "FIND GOOD EXAMPLE". In such cases a machine could ask a clarification questions to disambiguate certain aspects of the question and provide her with a reasonable response, instead of returning something non-relevant in the first place and force the user to think why did it happen.

Of course, this task is very challenging, and as a first step I propose to study what kind of clarifications do real people typically ask.

### 5.3 Using the Wisdom of a Crowd for Question Answering

This is our experiment for LiveQA answer crowdsourcing.

## 6 Summary and Discussion

In my thesis I propose several pieces of work towards improving user satisfaction with question answering systems. I plan to consider factoid and non-factoid questions, as usually classified in the community, separately, because certain techniques and data sources are most useful for one type of questions and not another.

The research I'm propose to conduct for improving factoid question answering targets a problem of combining information available in different data sources, *i.e.* structured knowledge bases and unstructured text documents. Semantic annotations of entity mentions in documents create additional connections between knowledge base entities, which should improve KB coverage and allow a system to answer more questions and with better precision. However, such an approach have certain potential limitations.

- A set of additional links for some entities is likely to be big, which makes it impossible to explore them all. Information extraction approaches on the other hand aggregate information over the whole collection, although the extraction process itself brings extra noise.
- ....

For non-factoid question answering I propose several improvements, targeting different stages of the question answering process. Question to query generation neural network model, trained to improve the document retrieval performance, should increase the recall of the question answering system by identifying the key phrases that needed to be search for. The answer passage scoring module should achieve a better precision by analyzing the structure of the answer origin web page, and detecting question-answer pairs and other key structural elements. Finally, the proposed direction in automatic answer summarization is a way to increase the quality of answers by combining evidence from multiple different data sources, possibly providing additional information and alternative opinions. Possible limitations of the proposed directions and approaches are:

- question to query generation model can be retrieval engine specific, which may force the model to be retrained after certain changes in the retrieval algorithm. An alternative strategy is to integrate a similar question summarization module into the retrieval engine itself.
- web page structure?...
- summarization?... The problem is that it might not work well...

Finally, I touch a user aspect of question answering, in particular user assistance with hints in case a system failed to respond to user information needs, clarification questions, which is one of the first steps in dialog-based question answering and finally using the wisdom of a crowd to improve the performance of question answering systems.

- Hints
- Clarifications
- Crowdsourcing



# Bibliography

- [1] E. Agichtein, S. Lawrence, and L. Gravano. Learning search engine specific query transformations for question answering. In *Proceedings of the Tenth International World Wide Web Conference, WWW 10*, pages 169–178, 2001.
- [2] D. Ahn, V. Jijkoun, G. Mishne, K. Müller, M. de Rijke, and K. Schlobach. Using wikipedia at the trec qa track. In *The Thirteenth Text Retrieval Conference (TREC 2004)*, 2005.
- [3] A. M. N. Allam and M. H. Haggag. The question answering systems: A survey. *International Journal of Research and Reviews in Information Sciences (IJRRIS)*, 2(3), 2012.
- [4] A. Andrenucci and E. Sneiders. Automated question answering: Review of the main approaches. In *null*, pages 514–519. IEEE, 2005.
- [5] I. Androutsopoulos, G. D. Ritchie, and P. Thanisch. Natural language interfaces to databases—an introduction. *Natural language engineering*, 1(01):29–81, 1995.
- [6] S. Auer, C. Bizer, G. Kobilarov, J. Lehmann, R. Cyganiak, and Z. Ives. *Dbpedia: A nucleus for a web of open data*. Springer, 2007.
- [7] B. I. Aydin, Y. S. Yilmaz, Y. Li, Q. Li, J. Gao, and M. Demirbas. Crowdsourcing for multiple-choice question answering. In *AAAI*, pages 2946–2953, 2014.
- [8] D. Bahdanau, K. Cho, and Y. Bengio. Neural machine translation by jointly learning to align and translate. *ICLR*, 2015.
- [9] H. Bast and E. Haussmann. More accurate question answering on freebase. In *CIKM*, 2015.
- [10] P. Baudiš. Yodaqa: a modular question answering system pipeline. In *POSTER 2015-19th International Student Conference on Electrical Engineering*, pages 1156–1165, 2015.
- [11] J. Berant, A. Chou, R. Frostig, and P. Liang. Semantic parsing on freebase from question-answer pairs. In *Proceedings of the 2013 Conference on Empirical Methods in Natural Language Processing*, pages 1533–1544, 2013.
- [12] J. Berant and P. Liang. Semantic parsing via paraphrasing. In *Proceedings of the 52nd Annual Meeting of the Association for Computational Linguistics, ACL 2014*, pages 1415–1425, 2014.
- [13] J. Berant and P. Liang. Imitation learning of agenda-based semantic parsers. *Transactions of the Association for Computational Linguistics*, 3:545–558, 2015.
- [14] D. Bernhard and I. Gurevych. Combining lexical semantic resources with question & answer archives for translation-based answer finding. In *Proceedings of the Joint Conference of the 47th Annual Meeting of the ACL and the 4th International Joint Conference on Natural Language Processing of the AFNLP: Volume 2-Volume 2*, pages 728–736. Association for Computational Linguistics, 2009.
- [15] M. S. Bernstein, J. Teevan, S. Dumais, D. Liebling, and E. Horvitz. Direct answers for search queries in the long tail. In *Proceedings of the SIGCHI conference on human factors in computing systems*, pages 237–246. ACM, 2012.
- [16] M. W. Bilotti, P. Ogilvie, J. Callan, and E. Nyberg. Structured retrieval for question answering. In *Proceedings of the 30th annual international ACM SIGIR conference on Research and development in information retrieval*, pages 351–358. ACM, 2007.

- [17] 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 International Conference on Management of Data, SIGMOD '08*, pages 1247–1250, New York, NY, USA, 2008. ACM.
- [18] A. Bordes, S. Chopra, and J. Weston. Question answering with subgraph embeddings. In *Proceedings of the 2014 Conference on Empirical Methods in Natural Language Processing, EMNLP 2014*, pages 615–620, 2014.
- [19] A. Bordes, N. Usunier, S. Chopra, and J. Weston. Large-scale simple question answering with memory networks. *arXiv preprint arXiv:1506.02075*, 2015.
- [20] L. Braunstein, O. Kurland, D. Carmel, I. Szpektor, and A. Shtok. Supporting human answers for advice-seeking questions in cqa sites. In *Advances in Information Retrieval*, pages 129–141. Springer, 2016.
- [21] E. Brill, S. Dumais, and M. Banko. An analysis of the askmsr question-answering system. In *Proceedings of the ACL-02 conference on Empirical methods in natural language processing-Volume 10*, pages 257–264. Association for Computational Linguistics, 2002.
- [22] E. Brill, J. Lin, M. Banko, S. Dumais, and A. Ng. Data-intensive question answering. In *Proceedings of TREC 2001*, January 2001.
- [23] D. Buscaldi and P. Rosso. Mining knowledge from wikipedia for the question answering task. In *Proceedings of the International Conference on Language Resources and Evaluation*, pages 727–730, 2006.
- [24] M. J. Cafarella, A. Halevy, D. Z. Wang, E. Wu, and Y. Zhang. Webtables: Exploring the power of tables on the web. *Proc. VLDB Endow.*, 1(1):538–549, Aug. 2008.
- [25] M. J. Cafarella, J. Madhavan, and A. Halevy. Web-scale extraction of structured data. *SIGMOD Rec.*, 37(4):55–61, Mar. 2009.
- [26] D. Cai, S. Yu, J.-R. Wen, and W.-Y. Ma. Vips: a visionbased page segmentation algorithm. Technical report, Microsoft technical report, MSR-TR-2003-79, 2003.
- [27] Q. Cai and A. Yates. Large-scale semantic parsing via schema matching and lexicon extension. In *ACL (1)*, pages 423–433. Citeseer, 2013.
- [28] Q. Cai and A. Yates. Large-scale semantic parsing via schema matching and lexicon extension. In *Proceedings of the 51st Annual Meeting of the Association for Computational Linguistics, ACL 2013*, pages 423–433, 2013.
- [29] A. X. Chang, V. I. Spitzkovsky, E. Agirre, and C. D. Manning. Stanford-ubc entity linking at tac-kbp, again. In *Proceedings of Text Analysis Conference, TAC'11*, 2011.
- [30] G. Cong, L. Wang, C.-Y. Lin, Y.-I. Song, and Y. Sun. Finding question-answer pairs from online forums. In *Proceedings of the 31st annual international ACM SIGIR conference on Research and development in information retrieval*, pages 467–474. ACM, 2008.
- [31] M. Cornolti, P. Ferragina, M. Ciaramita, H. Schütze, and S. Rüd. The smaph system for query entity recognition and disambiguation. In *Proceedings of the first international workshop on Entity recognition & disambiguation*, 2014.
- [32] H. T. Dang, D. Kelly, and J. J. Lin. Overview of the trec 2007 question answering track. In *TREC*, volume 7, page 63. Citeseer, 2007.
- [33] M. De Boni and S. Manandhar. An analysis of clarification dialogue for question answering. In *Proceedings of the 2003 Conference of the North American Chapter of the Association for Computational Linguistics on Human Language Technology-Volume 1*, pages 48–55. Association for Computational Linguistics, 2003.
- [34] S. Ding, G. Cong, C.-Y. Lin, and X. Zhu. Using conditional random fields to extract contexts and answers of questions from online forums. In *ACL*, volume 8, pages 710–718. Citeseer, 2008.

- [35] L. Dong, F. Wei, M. Zhou, and K. Xu. Question answering over freebase with multi-column convolutional neural networks. In *Proceedings of the 53rd Annual Meeting of the Association for Computational Linguistics and the 7th International Joint Conference on Natural Language Processing*, volume 1, pages 260–269, 2015.
- [36] 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*, KDD '14, pages 601–610, New York, NY, USA, 2014. ACM.
- [37] H. Duan, Y. Cao, C.-Y. Lin, and Y. Yu. Searching questions by identifying question topic and question focus. In *ACL*, pages 156–164, 2008.
- [38] O. Etzioni. Search needs a shake-up. *Nature*, 476(7358):25–26, 2011.
- [39] O. Etzioni, M. Banko, S. Soderland, and D. S. Weld. Open information extraction from the web. *Commun. ACM*, 51(12):68–74, Dec. 2008.
- [40] A. Fader, S. Soderland, and O. Etzioni. Identifying relations for open information extraction. In *Proceedings of the 2011 Conference on Empirical Methods in Natural Language Processing, EMNLP 2011*, pages 1535–1545, 2011.
- [41] A. Fader, L. Zettlemoyer, and O. Etzioni. Open question answering over curated and extracted knowledge bases. In *Proceedings of the 20th ACM International Conference on Knowledge Discovery and Data Mining*, KDD '14, pages 1156–1165, New York, NY, USA, 2014. ACM.
- [42] A. Fader, L. S. Zettlemoyer, and O. Etzioni. Paraphrase-driven learning for open question answering. In *ACL*. Citeseer, 2013.
- [43] D. Ferrucci, E. Brown, J. Chu-Carroll, J. Fan, D. Gondek, A. A. Kalyanpur, A. Lally, J. W. Murdock, E. Nyberg, J. Prager, et al. Building watson: An overview of the deepqa project. *AI magazine*, 31(3):59–79, 2010.
- [44] D. Ferrucci, E. Brown, J. Chu-Carroll, J. Fan, D. Gondek, A. A. Kalyanpur, A. Lally, J. W. Murdock, E. Nyberg, J. Prager, et al. This is watson. *IBM Journal of Research and Development*, 56, 2012.
- [45] M. J. Franklin, D. Kossmann, T. Kraska, S. Ramesh, and R. Xin. Crowddb: Answering queries with crowdsourcing. In *Proceedings of the 2011 ACM SIGMOD International Conference on Management of Data*, SIGMOD '11, pages 61–72, New York, NY, USA, 2011. ACM.
- [46] D. Fried, P. Jansen, G. Hahn-Powell, M. Surdeanu, and P. Clark. Higher-order lexical semantic models for non-factoid answer reranking. *Transactions of the Association for Computational Linguistics*, 3:197–210, 2015.
- [47] E. Gabrilovich, M. Ringgaard, and A. Subramanya. Facc1: Freebase annotation of clueweb corpora, 2013.
- [48] B. F. Green Jr, A. K. Wolf, C. Chomsky, and K. Laughery. Baseball: an automatic question-answerer. In *Papers presented at the May 9-11, 1961, western joint IRE-AIEE-ACM computer conference*, pages 219–224. ACM, 1961.
- [49] P. Gupta and V. Gupta. A survey of text question answering techniques. *International Journal of Computer Applications*, 53(4), 2012.
- [50] R. Gupta, A. Halevy, X. Wang, S. E. Whang, and F. Wu. Biperpedia: An ontology for search applications. *Proc. VLDB Endow.*, 7(7):505–516, Mar. 2014.
- [51] M. Heilman and N. A. Smith. Tree edit models for recognizing textual entailments, paraphrases, and answers to questions. In *Human Language Technologies: The 2010 Annual Conference of the North American Chapter of the Association for Computational Linguistics*, pages 1011–1019. Association for Computational Linguistics, 2010.
- [52] L. Hirschman and R. Gaizauskas. Natural language question answering: the view from here. *natural*

*language engineering*, 7(4):275–300, 2001.

- [53] B. Hixon, P. Clark, and H. Hajishirzi. Learning knowledge graphs for question answering through conversational dialog. In *Proceedings of the the 2015 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies, Denver, Colorado, USA*, 2015.
- [54] E. Hovy, U. Hermjakob, and D. Ravichandran. A question/answer typology with surface text patterns. In *Proceedings of the Second International Conference on Human Language Technology Research, HLT '02*, pages 247–251, San Francisco, CA, USA, 2002. Morgan Kaufmann Publishers Inc.
- [55] E. H. Hovy, L. Gerber, U. Hermjakob, M. Junk, and C.-Y. Lin. Question answering in webclopedia. In *TREC*, volume 52, pages 53–56, 2000.
- [56] E. H. Hovy, U. Hermjakob, and C.-Y. Lin. The use of external knowledge of factoid qa. In *TREC*, volume 2001, pages 644–52, 2001.
- [57] A. Ittycheriah, M. Franz, and S. Roukos. Ibm’s statistical question answering system-trec-10. In *TREC*, 2001.
- [58] M. Iyyer, J. L. Boyd-Graber, L. M. B. Claudino, R. Socher, and H. Daumé III. A neural network for factoid question answering over paragraphs. In *EMNLP*, pages 633–644, 2014.
- [59] J. Jeon, W. B. Croft, and J. H. Lee. Finding similar questions in large question and answer archives. In *Proceedings of the 14th ACM International Conference on Information and Knowledge Management, CIKM '05*, pages 84–90, New York, NY, USA, 2005. ACM.
- [60] V. Jijkoun and M. de Rijke. Retrieving answers from frequently asked questions pages on the web. In *Proceedings of the 14th ACM International Conference on Information and Knowledge Management, CIKM '05*, pages 76–83, New York, NY, USA, 2005. ACM.
- [61] V. Jijkoun, M. De Rijke, and J. Mur. Information extraction for question answering: Improving recall through syntactic patterns. In *Proceedings of the 20th international conference on Computational Linguistics*, page 1284. Association for Computational Linguistics, 2004.
- [62] A. Karpathy and L. Fei-Fei. Deep visual-semantic alignments for generating image descriptions. In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*, pages 3128–3137, 2015.
- [63] M. Keikha, J. H. Park, W. B. Croft, and M. Sanderson. Retrieving passages and finding answers. In *Proceedings of the 2014 Australasian Document Computing Symposium*, page 81. ACM, 2014.
- [64] O. Kolomiyets and M.-F. Moens. A survey on question answering technology from an information retrieval perspective. *Information Sciences*, 181(24):5412–5434, Dec. 2011.
- [65] N. Kushmerick. *Wrapper induction for information extraction*. PhD thesis, University of Washington, 1997.
- [66] C. Kwok, O. Etzioni, and D. S. Weld. Scaling question answering to the web. *ACM Transactions on Information Systems (TOIS)*, 19(3):242–262, 2001.
- [67] B. Li, X. Si, M. R. Lyu, I. King, and E. Y. Chang. Question identification on twitter. In *Proceedings of the 20th ACM international conference on Information and knowledge management*, pages 2477–2480. ACM, 2011.
- [68] X. Li and D. Roth. Learning question classifiers. In *19th International Conference on Computational Linguistics, COLING 2002*, 2002.
- [69] X. Li and D. Roth. Learning question classifiers: the role of semantic information. *Natural Language Engineering*, 12(3):229–249, 2006.
- [70] J. Lin. An exploration of the principles underlying redundancy-based factoid question answering. *ACM Transactions on Information Systems (TOIS)*, 25(2):6, 2007.
- [71] J. Lin and B. Katz. Question answering from the web using knowledge annotation and knowl-

- edge mining techniques. In *Proceedings of the twelfth international conference on Information and knowledge management*, pages 116–123. ACM, 2003.
- [72] Y. Liu, J. Bian, and E. Agichtein. Predicting information seeker satisfaction in community question answering. In *Proceedings of the 31st Annual International ACM SIGIR Conference on Research and Development in Information Retrieval*, SIGIR '08, pages 483–490, New York, NY, USA, 2008. ACM.
  - [73] Y. Liu, S. Li, Y. Cao, C.-Y. Lin, D. Han, and Y. Yu. Understanding and summarizing answers in community-based question answering services. In *Proceedings of the 22Nd International Conference on Computational Linguistics - Volume 1*, COLING '08, pages 497–504, Stroudsburg, PA, USA, 2008. Association for Computational Linguistics.
  - [74] F. Mahdisoltani, J. Biega, and F. Suchanek. Yago3: A knowledge base from multilingual wikipe-dias. In *7th Biennial Conference on Innovative Data Systems Research*. CIDR Conference, 2014.
  - [75] C. Malon and B. Bai. Answer extraction by recursive parse tree descent. *ACL 2013*, page 110, 2013.
  - [76] C. D. Manning, M. Surdeanu, J. Bauer, J. Finkel, S. J. Bethard, and D. McClosky. The Stan-ford CoreNLP natural language processing toolkit. In *Proceedings of 52nd Annual Meeting of the Association for Computational Linguistics: System Demonstrations*, pages 55–60, 2014.
  - [77] G. A. Miller. Wordnet: a lexical database for english. *Communications of the ACM*, 38(11):39–41, 1995.
  - [78] M. Mintz, S. Bills, R. Snow, and D. Jurafsky. Distant supervision for relation extraction without labeled data. In *ACL 2009, Proceedings of the 47th Annual Meeting of the Association for Com-putational Linguistics and the 4th International Joint Conference on Natural Language Processing of the AFNLP*, pages 1003–1011, 2009.
  - [79] C.-S. Ong, M.-Y. Day, and W.-L. Hsu. The measurement of user satisfaction with question answer-ing systems. *Information & Management*, 46(7):397–403, 2009.
  - [80] M. Pasca and S. Harabagiu. The informative role of wordnet in open-domain question answering. In *Proceedings of NAACL-01 Workshop on WordNet and Other Lexical Resources*, pages 138–143, 2001.
  - [81] J. Prager, J. Chu-Carroll, E. W. Brown, and K. Czuba. Question answering by predictive annota-tion. In *Advances in Open Domain Question Answering*, pages 307–347. Springer, 2006.
  - [82] J. M. Prager. Open-domain question-answering. *Foundations and trends in information retrieval*, 1(2):91–231, 2006.
  - [83] V. Punyakanok, D. Roth, and W.-t. Yih. Mapping dependencies trees: An application to question answering. In *Proceedings of AI&Math 2004*, pages 1–10, 2004.
  - [84] S. Reddy, M. Lapata, and M. Steedman. Large-scale semantic parsing without question-answer pairs. *TACL*, 2:377–392, 2014.
  - [85] A. M. Rush, S. Chopra, and J. Weston. A neural attention model for abstractive sentence sum-marization. In *Proceedings of the 2015 Conference on Empirical Methods in Natural Language Processing*, pages 379–389, Lisbon, Portugal, September 2015. Association for Computational Lin-guistics.
  - [86] C. d. Santos, M. Tan, B. Xiang, and B. Zhou. Attentive pooling networks. *arXiv preprint arXiv:1602.03609*, 2016.
  - [87] D. Savenkov. Ranking answers and web passages for non-factoid question answering: Emory uni-versity at trec liveqa. In *Proceedings of TREC*, 2015.
  - [88] D. Savenkov, W.-L. Lu, J. Dalton, and E. Agichtein. Relation extraction from community generated question-answer pairs. In *NAACL-HLT 2015 Student Research Workshop (SRW)*, page 96, 2015.
  - [89] R. Sharp, P. Jansen, M. Surdeanu, and P. Clark. Spinning straw into gold: Using free text to train

- monolingual alignment models for non-factoid question answering. In *Proceedings of the Conference of the North American Chapter of the Association for Computational Linguistics-Human Language Technologies (NAACL HLT)*, 2015.
- [90] D. Shen, G.-J. M. Kruijff, and D. Klakow. Exploring syntactic relation patterns for question answering. In *Natural Language Processing-IJCNLP 2005*, pages 507–518. Springer, 2005.
  - [91] E. H. Shortliffe and B. G. Buchanan. A model of inexact reasoning in medicine. *Mathematical biosciences*, 23(3):351–379, 1975.
  - [92] A. Shtok, G. Dror, Y. Maarek, and I. Szpektor. Learning from the past: Answering new questions with past answers. In *Proceedings of the 21st International Conference on World Wide Web, WWW '12*, pages 759–768, New York, NY, USA, 2012. ACM.
  - [93] R. F. Simmons. Answering english questions by computer: A survey. *Communications of ACM*, 8(1):53–70, Jan. 1965.
  - [94] R. F. Simmons. Natural language question-answering systems: 1969. *Commun. ACM*, 13(1):15–30, Jan. 1970.
  - [95] P. Sondhi and C. Zhai. Mining semi-structured online knowledge bases to answer natural language questions on community qa websites. In *Proceedings of the 23rd ACM International Conference on Conference on Information and Knowledge Management*, pages 341–350. ACM, 2014.
  - [96] R. Soricut and E. Brill. Automatic question answering using the web: Beyond the factoid. *Information Retrieval*, 9(2):191–206, 2006.
  - [97] M. M. Soubbotin and S. M. Soubbotin. Patterns of potential answer expressions as clues to the right answers. In *TREC*, 2001.
  - [98] V. I. Spitkovsky and A. X. Chang. A cross-lingual dictionary for english wikipedia concepts. In *LREC*, pages 3168–3175, 2012.
  - [99] F. M. Suchanek, G. Kasneci, and G. Weikum. Yago: a core of semantic knowledge. In *Proceedings of the 16th international conference on World Wide Web*, pages 697–706. ACM, 2007.
  - [100] H. Sun, H. Ma, W.-t. Yih, C.-T. Tsai, J. Liu, and M.-W. Chang. Open domain question answering via semantic enrichment. In *Proceedings of the 24th International Conference on World Wide Web, WWW '15*, pages 1045–1055, Republic and Canton of Geneva, Switzerland, 2015. International World Wide Web Conferences Steering Committee.
  - [101] M. Surdeanu, M. Ciaramita, and H. Zaragoza. Learning to rank answers to non-factoid questions from web collections. *Computational Linguistics*, 37(2):351–383, 2011.
  - [102] M. Surdeanu, J. Tibshirani, R. Nallapati, and C. D. Manning. Multi-instance multi-label learning for relation extraction. In *Proceedings of the 2012 Joint Conference on Empirical Methods in Natural Language Processing and Computational Natural Language Learning, EMNLP-CoNLL '12*, pages 455–465, Stroudsburg, PA, USA, 2012. Association for Computational Linguistics.
  - [103] M. Tan, B. Xiang, and B. Zhou. Lstm-based deep learning models for non-factoid answer selection. *arXiv preprint arXiv:1511.04108*, 2015.
  - [104] W. tau Yih, M.-W. Chang, X. He, and J. Gao. Semantic parsing via staged query graph generation: Question answering with knowledge base. In *Proceedings of the Joint Conference of the 53rd Annual Meeting of the ACL and the 7th International Joint Conference on Natural Language Processing of the AFNLP. ACL Association for Computational Linguistics*, July 2015.
  - [105] C. Tsai, W.-t. Yih, and C. Burges. Web-based question answering: Revisiting askmsr. Technical report, Technical Report MSR-TR-2015-20, Microsoft Research, 2015.
  - [106] C. Unger, A. Freitas, and P. Cimiano. An introduction to question answering over linked data. In *Reasoning Web. Reasoning on the Web in the Big Data Era*, pages 100–140. Springer, 2014.
  - [107] E. M. Voorhees. The trec question answering track. *Natural Language Engineering*, 7(04):361–378, 2001.

- [108] D. Vrandečić and M. Krötzsch. Wikidata: a free collaborative knowledgebase. *Communications of the ACM*, 57(10):78–85, 2014.
- [109] D. Wang and E. Nyberg. Cmu oaq at trec 2015 liveqa: Discovering the right answer with clues. In *Proceedings of TREC*, 2015.
- [110] D. Wang and E. Nyberg. A long short-term memory model for answer sentence selection in question answering. In *Proceedings of the 53rd Annual Meeting of the Association for Computational Linguistics and the 7th International Joint Conference on Natural Language Processing of the Asian Federation of Natural Language Processing, ACL 2015*, pages 707–712, 2015.
- [111] M. Wang. A survey of answer extraction techniques in factoid question answering. *Computational Linguistics*, 1(1), 2006.
- [112] M. Wang and C. D. Manning. Probabilistic tree-edit models with structured latent variables for textual entailment and question answering. In *Proceedings of the 23rd International Conference on Computational Linguistics*, pages 1164–1172. Association for Computational Linguistics, 2010.
- [113] M. Wang, N. A. Smith, and T. Mitamura. What is the jeopardy model? a quasi-synchronous grammar for qa. In *EMNLP-CoNLL*, volume 7, pages 22–32, 2007.
- [114] Z. Wang and A. Ittycheriah. Faq-based question answering via word alignment. *arXiv preprint arXiv:1507.02628*, 2015.
- [115] Z. Wang, S. Yan, H. Wang, and X. Huang. Large-scale question answering with joint embedding and proof tree decoding. In *Proceedings of the 24th ACM International on Conference on Information and Knowledge Management*, pages 1783–1786. ACM, 2015.
- [116] R. Wilensky, D. N. Chin, M. Luria, J. Martin, J. Mayfield, and D. Wu. The berkeley unix consultant project. *Computational Linguistics*, 14(4):35–84, 1988.
- [117] W. A. Woods and R. Kaplan. Lunar rocks in natural english: Explorations in natural language question answering. *Linguistic structures processing*, 5:521–569, 1977.
- [118] G. Wu and M. Lan. Leverage web-based answer retrieval and hierarchical answer selection to improve the performance of live question answering. In *Proceedings of TREC*, 2015.
- [119] K. Xu, J. Ba, R. Kiros, A. Courville, R. Salakhutdinov, R. Zemel, and Y. Bengio. Show, attend and tell: Neural image caption generation with visual attention. *arXiv preprint arXiv:1502.03044*, 2015.
- [120] K. Xu, Y. Feng, S. Reddy, S. Huang, and D. Zhao. Enhancing freebase question answering using textual evidence. *arXiv preprint arXiv:1603.00957*, 2016.
- [121] K. Xu, S. Zhang, Y. Feng, and D. Zhao. Answering natural language questions via phrasal semantic parsing. In *Natural Language Processing and Chinese Computing*, pages 333–344. Springer, 2014.
- [122] M. Yahya, K. Berberich, S. Elbassuoni, and G. Weikum. Robust question answering over the web of linked data. In *Proceedings of the 22nd ACM international conference on Conference on information & knowledge management*, pages 1107–1116. ACM, 2013.
- [123] J.-M. Yang, R. Cai, Y. Wang, J. Zhu, L. Zhang, and W.-Y. Ma. Incorporating site-level knowledge to extract structured data from web forums. In *Proceedings of the 18th International Conference on World Wide Web, WWW '09*, pages 181–190, New York, NY, USA, 2009. ACM.
- [124] L. Y. Yang, Q. Ai, D. Spina, R.-C. Chen, L. Pang, W. B. Croft, J. Guo, and F. Scholer. Beyond factoid qa: Effective methods for non-factoid answer sentence retrieval. In *Proceedings of ECIR'16*, 2016.
- [125] Y. Yang, W.-t. Yih, and C. Meek. Wikiqa: A challenge dataset for open-domain question answering. In *Proceedings of the 2015 Conference on Empirical Methods in Natural Language Processing*, pages 2013–2018. Citeseer, 2015.
- [126] X. Yao. Lean question answering over freebase from scratch. In *Proceedings of NAACL Demo*, 2015.

- [127] X. Yao, J. Berant, and B. Van Durme. Freebase qa: Information extraction or semantic parsing? *ACL 2014*, page 82, 2014.
- [128] X. Yao and B. V. Durme. Information extraction over structured data: Question answering with freebase. In *Proceedings of the 52nd Annual Meeting of the Association for Computational Linguistics, ACL 2014*, pages 956–966, 2014.
- [129] X. Yao, B. Van Durme, C. Callison-Burch, and P. Clark. Answer extraction as sequence tagging with tree edit distance. In *HLT-NAACL*, pages 858–867. Citeseer, 2013.
- [130] X. Yao, B. Van Durme, and P. Clark. Automatic coupling of answer extraction and information retrieval. In *ACL (2)*, pages 159–165, 2013.
- [131] W.-t. Yih, X. He, and C. Meek. Semantic parsing for single-relation question answering. In *ACL (2)*, pages 643–648. Citeseer, 2014.
- [132] P. Yin, N. Duan, B. Kao, J. Bao, and M. Zhou. Answering questions with complex semantic constraints on open knowledge bases. In *Proceedings of the 24th ACM International on Conference on Information and Knowledge Management*, pages 1301–1310. ACM, 2015.
- [133] L. Yu, K. M. Hermann, P. Blunsom, and S. Pulman. Deep learning for answer sentence selection. *arXiv preprint arXiv:1412.1632*, 2014.
- [134] J. M. Zelle and R. J. Mooney. Learning to parse database queries using inductive logic programming. In *Proceedings of the national conference on artificial intelligence*, pages 1050–1055, 1996.
- [135] G. Zhou, T. He, J. Zhao, and P. Hu. Learning continuous word embedding with metadata for question retrieval in community question answering. In *Proceedings of ACL*, pages 250–259, 2015.