Question-Answer Driven Semantic Role Labeling: Using Natural Language to Annotate Natural Language

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Abstract

This paper introduces the task of question-answer driven semantic role labeling (QA-SRL), where question-answer pairs are used to represent predicate-argument structure. For example, the verb “introduce” in the previous sentence would be labeled with the questions “What is introduced?”, and “What introduces something?”, each paired with the phrase from the sentence that gives the correct answer. Posing the problem this way allows the questions themselves to define the set of possible roles, without the need for pre-defined frame or thematic role ontologies. It also allows for scalable data collection by annotators with very little training and no linguistic expertise. We gather data in two domains, newswire text and Wikipedia articles, and introduce simple classifier-based models for predicting which questions to ask and what their answers should be. Our results show that non-expert annotators can produce high quality QA-SRL data, and also establish baseline performance levels for future work on this task.

1 Introduction

Semantic role labeling (SRL) is the widely studied challenge of recovering predicate-argument structure for natural language words, typically verbs. The goal is to determine “who does what to whom,” “when,” and “where,” etc. (Palmer et al., 2010; Johansson and Nugues, 2008). However, this intuition is difficult to formalize and fundamental aspects of the task vary across efforts, for example FrameNet (Baker et al., 1998) models a large set of interpretable thematic roles (AGENT, PATIENT, etc.) while PropBank (Palmer et al., 2005) uses a small set of verb-specific roles

Figure 1: QA-SRL annotations for a Wikipedia sentence.

(ARG0, ARG1, etc.). Existing task definitions can be complex and require significant linguistic expertise to understand,1 causing challenges for data annotation and use in many target applications.

In this paper, we introduce a new question-answer driven SRL task formulation (QA-SRL), which uses question-answer pairs to label verbal predicate-argument structure. For example, for the sentence in Figure 1, we can ask a short question containing a verb, e.g. “Who finished something?”, and whose answer is a phrase from the original sentence, in this case “UCD.” The answer tells us that “UCD” is an argument of “finished,” while the question provides an indirect label on the role that “UCD” plays. Enumerating all such pairs, as we will see later, provides a relatively complete representation of the original verb’s arguments and modifiers.

The QA-SRL task formulation has a number of advantages. It can be easily explained to non-expert annotators with a short tutorial and a few examples. Moreover, the formulation does not depend on any pre-defined inventory of semantic roles or frames, or build on any existing gram-

1The PropBank annotation guide is 89 pages (Bonial et al., 2010), and the FrameNet guide is 119 pages (Ruppenhofer et al., 2006). Our QA-driven annotation instructions are 5 pages.
mar formalisms. Nonetheless, as we will show, it still represents the argument and modifier attachment decisions that have motivated previous SRL definitions, and which are of crucial importance for semantic understanding in a range of NLP tasks, such as machine translation (Liu and Gildea, 2010) and coreference resolution (Ponzetto and Strube, 2006). The annotations also, perhaps surprisingly, capture other implicit arguments that cannot be read directly off of the syntax, as was required for previous SRL approaches. For example, in “It was his mother’s birthday, so he was going to play her favorite tune”, annotators created the QA pair “When would someone play something? His mother’s birthday” which describes an implicit temporal relation. Finally, QA-SRL data can be easily examined, proofread, and improved by anyone who speaks the language and understands the sentence; we use natural language to label the structure of natural language.

We present a scalable approach for QA-SRL annotation and baseline models for predicting QA pairs. Given a sentence and target word (the verb), we ask annotators to provide as many question-answer pairs as possible, where the question comes from a templated space of wh-questions and the answer is a phrase from the original sentence. This approach guides annotators to quickly construct high quality questions within a very large space of possibilities. Given a corpus of QA-SRL annotated sentences, we also train baseline classifiers for both predicting a set of questions to ask, and what their answers should be. The question generation aspect of QA-SRL is unique to our formulation, and corresponds roughly to identifying what semantic role labels are present in previous formulations of the task. For example, the question “Who finished something” in Figure 1 corresponds to the AGENT role in FrameNet. Table 1 also shows examples of similar correspondences for PropBank roles. Instead of pre-defining the labels, as done in previous work, the questions themselves define the set of possibilities.

Experiments demonstrate high quality data annotation with very little annotator training and establish baseline performance levels for the task. We hired non-expert, part-time annotators on Upwork (previously oDesk) to label over 3,000 sentences (nearly 8,000 verbs) across two domains (newswire and Wikipedia) at a cost of approximately $0.50 per verb. We show that the data is high quality, rivaling PropBank in many aspects including coverage, and easily gathered in non-newswire domains. The baseline performance levels for question generation and answering reinforce the quality of the data and highlight the potential for future work on this task.

In summary, our contributions are:

- We introduce the task of question-answer driven semantic role labeling (QA-SRL), by using question-answer pairs to specify verbal arguments and the roles they play, without predefining an inventory of frames or semantic roles.
- We present a novel, lightweight template-based scheme (Section 3) that enables the high quality QA-SRL data annotation with very little training and no linguistic expertise.
- We define two new QA-SRL sub-tasks, question generation and answer identification, and present baseline learning approaches for both (Sections 4 and 5). The results demonstrate that our data is high-quality and supports the study of better learning algorithms.

2 Related Work

The success of syntactic annotation projects such as the Penn Treebank (Marcus et al., 1993) has led to numerous efforts to create semantic annotations for large corpora. The major distinguishing features of our approach are that it is not tied to any linguistic theory and that it can be annotated by non-experts with minimal training.

Existing SRL task formulations are closely related to our work. FrameNet (Baker et al., 1998) contains a detailed lexicon of verb senses and thematic roles. However, this complexity increases the difficulty of annotation. While the FrameNet project is decades old, the largest fully annotated corpus contains about 3,000 sentences (Chen et al., 2010). We were able to annotate over 3,000 sentences within weeks. PropBank (Kingsbury and Palmer, 2002), NomBank (Meyers et al., 2004) and OntoNotes (Hovy et al., 2006) circumvent the need for a large lexicon of roles, by defining...
ing the core semantic roles in a predicate-specific manner. This means that frames need to be created for every verb, and it requires experts to distinguish between different senses and different roles.

Our work is also related to recent, more general semantic annotation efforts. Abstract Meaning Representation (Banaru et al., 2013) can be viewed as an extension of PropBank with additional semantic information. Sentences take 8-13 minutes to annotate—which is slower than ours, but the annotations are more detailed. Universal Cognitive Conceptual Annotation (UCCA) (Abend and Rappoport, 2013) is an attempt to create a linguistically universal annotation scheme by using general labels such as argument or scene. The UCCA foundational layer does not distinguish semantic roles, so *Frogs eat herons* and *Herons eat frogs* will receive identical annotation — thereby discarding information which is potentially useful for translation or question answering. They report similar agreement with PropBank to our approach (roughly 90%), but annotator training time was an order-of-magnitude higher (30-40 hours). The Groningen Meaning Bank (Basile et al., 2012) project annotates text by manually correcting the output of existing semantic parsers. They show that some annotation can be crowdsourced using “games with a purpose” — however, this does not include its predicate-argument structure, which requires expert knowledge of their syntactic and semantic formalisms. Finally, Reisinger et al. (2015) study crowdsourcing semantic role labels based on Dowty’s protoroles, given gold predicate and argument mentions. This work directly complements our focus on labeling predicate-argument structure.

The idea of expressing the meaning of natural language in terms of natural language is related to natural logic (MacCartney and Manning, 2007), in which they use natural language for logical inference. Similarly, we model predicate-argument structure of a sentence with a set of question-
Table 2: Fields in our question annotation template, with descriptions, example values, and the total number of possible values for each. WH* and TRG* are required; all other fields can be left empty.

| Field | Description                               | Example of Values          | No. Values |
|-------|-------------------------------------------|----------------------------|------------|
| WH*   | Question words (wh-words)                 | who, what, when, why, how, how much | 7          |
| AUX   | Auxiliary verbs                           | is, have, could, is n’t    | 36         |
| SBJ   | Place-holding words for the subject position | someone, something         | 2          |
| TRG*  | Some form of the target word              | built, building, been built | 12         |
| OBJ1  | Place-holding words for the object position | someone, something         | 2          |
| PP    | Frequent prepositions (by, to, for, with, about) and prepositions (unigrams or bigrams) that occur in the sentence | to, for, from, by       | 10         |
| OBJ2  | Similar to OBJ1, but with more options    | someone, something, do, do something, doing something | 9          |

Table 3: Four example questions written with our question annotation template.

| WH | AUX | SBJ | TRG* | OBJ1 | PP | OBJ2 |
|----|-----|-----|------|------|----|------|
| Who | built | someone | something |  |
| What | had | someone | said |  |
| What | was | someone | expected | to | do |  |
| Where | might | something | rise | from |  |

3 QA-based Semantic Dataset

This section describes our annotation process in more detail, and discusses agreement between our annotations and PropBank. Table 1 shows examples provided by non-expert annotators.4

3.1 Annotation Task Design

We annotate verbs with pairs of questions and answers that provide information about predicate-argument structure. Given a sentence $s$ and a verbal predicate $v$ in the sentence, annotators must produce a set of wh-questions that contain $v$ and whose answers are phrases in $s$.

To speed annotation and simplify downstream processing, we define a small grammar over possible questions. The questions are constrained with a template with seven fields, $q \in WH \times AUX \times SBJ \times TRG \times OBJ1 \times PP \times OBJ2$, each associated with a list of possible options. Descriptions for each field are shown in Table 2. The grammar is sufficiently general to capture a wide-range of questions about predicate-argument structure—some examples are given in Table 3.

The precise form of the question template is a function of the verb $v$ and sentence $s$, for two of the fields. For the TRG field, we generate a list of inflections forms of $v$ using the Wiktionary dictionary. For the PP field, the candidates are all the prepositions that occurred in the sentence $s$, and some frequently-used prepositions - by, to, for, with, and about. We also include preposition bi-grams (e.g., out for) from $s$.

Answers are constrained to be a subset of the words in the sentence but do not necessarily have to be contiguous spans. We also allow questions to have multiple answers, which is useful for annotating graph structured dependencies such as those in examples 3 and 6 in Table 1.

3.2 Data Preparation

We annotated over 3000 sentences (nearly 8,000 verbs) in total across two domains: newswire (PropBank) and Wikipedia. Table 4 shows the full data statistics. In the newswire domain, we sampled sentences from the English training data of CoNLL-2009 shared task (Hajić et al.,

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4Our dataset is freely available at: https://dada.cs.washington.edu/qasrl.
Table 4: Annotated data statistics.

| Dataset          | Sentences | Verbs | QAs   |
|------------------|-----------|-------|-------|
| newswire-train   | 744       | 2020  | 4904  |
| newswire-dev     | 249       | 664   | 1606  |
| newswire-test    | 248       | 652   | 1599  |
| Wikipedia-train  | 1174      | 2647  | 6414  |
| Wikipedia-dev    | 392       | 895   | 2183  |
| Wikipedia-test   | 393       | 898   | 2201  |

(1241 sentences) of our QA-SRL dataset and the PropBank dataset.

For each PropBank predicate that we have annotated with our scheme, we compute the agreement between the PropBank arguments and the QA-SRL answers. We ignore modality, reference, discourse and negation roles, as they are outside the scope of our current annotation. An annotated answer is judged to match the PropBank argument if either (1) the gold argument head is within the annotated answer span, or (2) the gold argument head is a preposition and at least one of its children is within the answer span.

We measure the macro-averaged precision and recall of our annotation against PropBank, with the proportion of our QA-pairs that are match a PropBank relation, and the proportion of PropBank relations covered by our annotation. The results are shown in Table 5, and demonstrate high overall agreement with PropBank. Agreement for core arguments is especially strong, showing much of the expert linguist annotation in PropBank can be recovered with our simple scheme. Agreement for adjuncts is lower, because the annotated QAs often contain inferred roles, especially for why, when and where questions (See examples 4, 7 and 8 in Table 1). These inferred roles are typically correct, but outside of the scope of PropBank annotations; they point to exciting opportunities for future work with QA-SRL data. On the other hand, the adverbial arguments in PropBank are sometimes neglected by annotators, thus becoming a major source of recall loss.

Table 6 shows the overlap between our annotated question words and PropBank argument labels. There are many unsurprising correlations— who questions are strongly associated with PropBank, with the proportion of our QA-pairs that are match a PropBank relation, and the proportion of PropBank relations covered by our annotation. The results are shown in Table 5, and demonstrate high overall agreement with PropBank. Agreement for core arguments is especially strong, showing much of the expert linguist annotation in PropBank can be recovered with our simple scheme. Agreement for adjuncts is lower, because the annotated QAs often contain inferred roles, especially for why, when and where questions (See examples 4, 7 and 8 in Table 1). These inferred roles are typically correct, but outside of the scope of PropBank annotations; they point to exciting opportunities for future work with QA-SRL data. On the other hand, the adverbial arguments in PropBank are sometimes neglected by annotators, thus becoming a major source of recall loss.

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Figure 2: Inter-annotator agreement measured on 100 newswire sentences and 108 Wikipedia sentences, comparing the total number of annotators to the number of unique QA pairs produced and the number of agreed pairs. A pair is considered agreed if two or more annotators produced it.

Table 6: Co-occurrence of wh-words in QA-SRL annotations and role labels in PropBank.

| WHO | WHAT | WHEN | WHERE | WHY | HOW | MUCH |
|-----|------|------|-------|-----|-----|------|
| A0  | 1575 | 414  | 3     | 5   | 17  | 28   |
| A1  | 285  | 2481 | 4     | 25  | 20  | 23   |
| A2  | 85   | 364  | 2     | 49  | 17  | 51   |
| A3  | 11   | 62   | 7     | 8   | 4   | 16   |
| A4  | 2    | 30   | 5     | 11  | 2   | 4    |
| A5  | 0    | 0    | 0     | 1   | 0   | 2    |
| ADV | 5    | 44   | 9     | 2   | 25  | 27   |
| CAU | 0    | 3    | 1     | 0   | 23  | 1    |
| DIR | 0    | 6    | 1     | 13  | 0   | 4    |
| EXT | 0    | 4    | 0     | 0   | 0   | 5    |
| LOC | 1    | 35   | 10    | 89  | 0   | 13   |
| MNR | 5    | 47   | 2     | 8   | 4   | 108  |
| PNC | 2    | 21   | 0     | 1   | 39  | 7    |
| PRD | 1    | 1    | 0     | 0   | 0   | 1    |
| TMP | 2    | 51   | 341   | 2   | 11  | 20   |

Bank agents (A0), and where and when questions correspond to PropBank temporal and locative roles, respectively. Some types of questions are divided much more evenly among PropBank roles, such as How much. These cases show how our questions can produce a more easily interpretable annotation than PropBank labels, which are predicate-specific and can be difficult to understand without reference to the frame files.

Together, these results suggest that non-experts can annotate much of the information contained in PropBank, and produce a more easily interpretable annotation.

### 3.5 Inter-Annotator Agreement

To judge the reliability of the data, we measured agreement on a portion of the data (100 sentences in the newswire domain and 108 sentences in the Wikipedia domain) annotated by five annotators.

Measuring agreement is complicated by the fact that the same question can be asked in multiple ways—for example “Who resigned?” and “Who resigned from something?”—and annotators may choose different, although usually highly overlapping, answer spans. We consider two QA pairs to be equivalent if (1) they have the same wh-word and (2) they have overlapping answer spans. In this analysis, Who and What are considered to be the same wh-word.

Figure 2 shows how the number of different QA pairs (both overall and agreed) increases with number of annotations. A QA pair is considered to be agreed upon if it is proposed by at least two of the five annotators. After five annotators, the number of agreed QA pairs starts to asymptote. A single annotator finds roughly 80% of the agreed QA pairs that are found by five annotators, suggesting that high recall can be achieved with a single stage of annotation. To further improve precision, future work should explore a second stage of annotation where annotators check each other’s work, for example by answering each other’s questions.

### 4 Question Generation

Given a sentence $s$ and a target verb $v$, we want to automatically generate a set of questions containing $v$ that are answerable with phrases from $s$. This task is important because generating answerable questions requires understanding the predicate-argument structure of the sentence.

essence, questions play the part of semantic roles in our approach.6

We present a baseline that breaks down question generation into two steps: (1) we first use a classifier to predict a set of roles for verb \( v \) that are likely present in the sentence, from a small, heuristically defined set of possibilities and then (2) generate one question for each predicted role, using templates extracted from the training set.

**Mapping Question Fields to Semantic Roles**

To generate questions, we first have to decide the primary role we want to target; each question’s answer is associated with a specific semantic role. For example, given the sentence *UCD finished the 2006 championship* and target verb *finished*, we could ask either: (Q1) *Who finished something?* or (Q2) *What did someone finish?*. Q1 targets the role associated with the person doing the finishing, while Q2 focuses on the thing being finished. To generate high quality questions, it is also often necessary to refer to roles other than the primary role, with pronouns. For example, Q2 uses “someone” to refer to the finisher.

Although it is difficult to know a priori the ideal set of possible roles, our baseline uses a simple discrete set, and introduces heuristics for identifying the roles a question refers to. The roles \( \mathcal{R} \) include:

\[
\mathcal{R} = \{ \text{R0}, \text{R1}, \text{R2}[^p], w, w[^p] \}
\]

\( w \in \{ \text{Where}, \text{When}, \text{Why}, \text{How}, \text{HowMuch} \} \)

\( p \in \text{Prepositions} \)

We then normalize the annotated questions by mapping its fields **WH**, **SBJ**, **OBJ1** and **OBJ2** to the roles \( r \in \mathcal{R} \), using a small set of rules listed in Table 7. In our example, the **WH** field of the Q1 (Who) and the **SBJ** of Q2 (someone) are both mapped to role R0. The **WH** of Q2 (What) and the **OBJ1** of Q1 (something) are mapped to role R1. Some roles can be subclassed with prepositions. For example, the **WH** field of the question *What did something rise from?* is mapped to R2[from].

In most cases, R0 is related to the A0/AGENT roles in PropBank/FrameNet, and R1/R2 are related to A1/PATIENT roles. Since our questions are defined in a templated space, we are able to do this mapping heuristically with reasonable accuracy. In the future, we might try to induce the set of possible roles given each target verb, following the semantic role induction work of Titov and Klementiev (2012) and Lang and Lapata (2011), or use crowdsourcing to label proto-roles, following Reisinger et al. (2015).

**Predicting Question Roles**

Given this space of possible roles, our first step in generation is to determine which roles are present in a sentence, and select the pronouns that could be used to refer to them in the resulting questions. We formulate this task as a supervised multi-label learning problem. We define the set of possible labels \( \mathcal{L} \) by combining the roles in \( \mathcal{R} \) with different pronoun values:

\[
\mathcal{L} = \{ \text{role:val} \mid \text{role} \in \mathcal{R} \}
\]

\( \text{val} \in \{ \phi, \text{someone}, \text{something}, \text{do something}, \text{doing something} \} \)

For example, to support the generation of the questions *Who finished something?* and *What did someone finish?*, we need to first predict the labels R0:someone and R1:something. Adjunct roles, such as *When* and *How*, always take an empty pronoun value.

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6The task also has applications to semi-automatic annotation of sentences with our scheme, if we could generate questions with high enough recall and only require annotators to provide all the answers. We leave this important direction to future work.

| \( w \in \{ \text{Who, What} \} \land \text{voice} = \text{active} \) |
| --- |
| **WH** \( \rightarrow \) **R0** | **WH** \( \rightarrow \) **R1** | **WH** \( \rightarrow \) **R2[^p]** |
| **SBJ** \( = \phi \) | **SBJ** \( \rightarrow \) **R0** | **SBJ** \( \rightarrow \) **R0** |
| **OBJ1** \( \rightarrow \) **R1** | **OBJ1** \( = \phi \) | **OBJ1** \( \rightarrow \) **R1** |
| **OBJ2** \( \rightarrow \) **R2[^p]** | **OBJ2** \( \rightarrow \) **R2[^p]** | **OBJ2** \( = \phi \) |

| \( w, h \in \{ \text{When}, \text{Where}, \text{Why}, \text{How}, \text{HowMuch} \} \land \text{voice} = \text{active} \) |
| --- |
| **WH** \( \rightarrow \) **R[^h]**[p] | **WH** \( \rightarrow \) **w[h]** |
| **SBJ** \( \rightarrow \) **R0** | **SBJ** \( \rightarrow \) **R0** |
| **OBJ1** \( \rightarrow \) **R1** | **OBJ1** \( \rightarrow \) **R1** |
| **OBJ2** \( \rightarrow \) **R2[^p]** | **OBJ2** \( \rightarrow \) **R2[^p]** |

| \( w, h \in \{ \text{When}, \text{Where}, \text{Why}, \text{How}, \text{HowMuch} \} \land \text{voice} = \text{passive} \) |
| --- |
| **WH** \( \rightarrow \) **w[^h]**[p] | **WH** \( \rightarrow \) **w/h** |
| **SBJ** \( \rightarrow \) **R1** | **SBJ** \( \rightarrow \) **R1** |
| **OBJ1** \( \rightarrow \) **R2** | **OBJ1** \( \rightarrow \) **R2** |
| **OBJ2** \( \rightarrow \) **R2[^p]** | **OBJ2** \( \rightarrow \) **R2[^p]** |

Table 7: Mapping question fields to roles in \( \mathcal{R} \). The mapping is based on whether certain question fields are empty and the voice of the verb in the question (active or passive). \( \phi \) indicates that a field is either an empty string or equals “do/doing”. If a question is in passive voice and contains the preposition “by”, then **OBJ2** is tagged with R0 instead, as in *What is built by someone?*
For each sentence $s$ and verb $v$, the set of positive training samples corresponds to the set of labels in the annotated questions, and the negative samples are all the other labels in $L_{train}$, the subset of labels appeared in training data.\footnote{We pruned the negative samples that contain prepositions that are not in the sentence or in the set of frequently-used prepositions (by, to, for, with, about).} We train a binary classifier for every label in $L_{train}$ using L2-regularized logistic regression by Liblinear (Fan et al., 2008), with hyper-parameter $C = 0.1$. Features of the binary classifiers are listed in Table 10. For each sentence $s$ and verb $v$ in the test data, we take the $k$ highest-scoring labels, and generate questions from these.

**Question Generation** After predicting the set of labels for a verb, we generate a question to query each role. First, we define the concept of an abstract question, which provides a template that specifies the role to be queried, other roles to include in the question, and the voice of the verb. Abstract questions can be read directly from our training data.

We can map an abstract question to a surface realization by substituting the slots with the pronoun values of the predicted labels. Table 8 shows the abstract questions we could use to query roles R0 and R1; and the generated questions, based on the set of predicted labels $\{\text{R0:someone, R1:something}\}$.

Therefore, to generate a question to query a role $r \in R$, we simply return the most frequent abstract question that occurred in training data that matches the role being queried, and the set of other predicted labels.

**Experiments** Native English speakers manually evaluated 500 automatically generated questions (5 questions per verb). Annotators judged whether the questions were grammatical\footnote{Some automatically generated questions are ungrammatical because of label prediction errors, such as *Who sneezed someone?*, where the label R1:someone shouldn’t be predicted.} and answerable from the sentence.

We evaluated the top $k$ questions produced by our baseline technique. The results in Table 9 show that our system is able to produce questions which are both grammatical and answerable. The average number of QA pairs per verb collected by human annotator is roughly 2.5, demonstrating significant room for improving these results.

### 5 Answer Identification

The goal of the answer identification task is to predict an answer $a$ given sentence $s$, target verb $v$ and a question $q$. Our annotated answers can be a series of spans, so the space of all possible answers is $2^{|s|}$. To simplify the problem, we transform our span-based answer annotation to answer head words, thus reducing the answer space to $|s|$. We model whether a word is the head of an answer as a binary classification problem.

Each training sample is a tuple $(s, v, q, a, \pm 1)$. The answer head $a$ is extracted from the k-best dependency parses and the annotated answer span. Given a dependency tree, if any word in the annotated answer span has a parent coming from outside the span, then it is considered an answer head. Therefore, a gold question-answer pair can be transformed into multiple positive training samples. The negative samples come from all the words in the sentence that are not an answer head. For learning, we train a binary classifier for every word in the sentence (except for the verb $v$).

**Experiments** We use L2-regularized logistic regression by Liblinear (Fan et al., 2008) for binary classification. Features are listed in Table 10.

The performance of our answer identification approach is measured by accuracy. For evaluation, given each test sentence $s$, verb $v$ and question $q$, we output the word with highest predicted score using the binary classifier. If the predicted word is contained inside the annotated answer span, it is considered a correct prediction. We also use the

| Question | Abstract Question |
|----------|-------------------|
| Who finished something? | R0: / active R1: / |
| What did someone finish? | R1: R0: active / / |

Table 8: Example surface realization templates from abstract questions.

| Question | Abstract Question |
|----------|-------------------|
| Newswire | Wikipedia |
| Ans. | Gram. | Ans. | Gram. |
| **prec@1** | 66.0 | 84.0 | 72.0 | 90.0 |
| **prec@3** | 51.3 | 78.7 | 53.3 | 86.0 |
| **prec@5** | 38.4 | 77.2 | 40.0 | 82.0 |

Table 9: Manual evaluation results for question generation in two domains, including the averaged number of distinct questions that are answerable given the sentence (Ans.) and the averaged number of questions that are grammatical (Gram.).
Table 10: Indicator features that are included in our role classifiers for question generation (Section 4) and the answer identification classifier (Section 5). Many come from previous work in SRL (Johansson and Nugues, 2008; Xue and Palmer, 2004). To mitigate syntactic errors, we used 10-best dependency parses from the Stanford parser (Klein and Manning, 2003).

| Feature Class                  | Question Generation                                                                 | Answer Identification                |
|-------------------------------|-------------------------------------------------------------------------------------|--------------------------------------|
| Predicate                     | Token, Predicted POS-tag, Lemma extracted from Wiktionary                           | Dependency parent and edge label, dependency children and edge label |
| Question                      |                                                                                     | Question role label, Wh-word, Preposition |
| Answer Word                   | /                                                                                    | Syntactic parent and edge label, Left/Right-most syntactic children, |
| Predicate-Answer              | /                                                                                    | Relative position (left or right), Syntactic relation, Syntactic path |

Table 11: Answer identification accuracy on newswire and Wikipedia text.

|          | Newswire | Wikipedia |
|----------|----------|-----------|
| Classifier | 78.7     | 82.3      |
| Random    | 26.3     | 26.9      |

The biggest challenge in annotating sentences with our scheme is choosing the questions. We introduced a method for generating candidate questions automatically, which has the potential to enable very large-scale annotation by only asking the annotators to provide answers. This will only be possible if performance can be improved to the point where we achieve high recall question with acceptable levels of precision.

Finally, future work will also explore applications of our annotation. Most obviously, the annotation can be used for training question-answering systems, as it directly encodes question-answer pairs. More ambitiously, the annotation has the potential to be used for training parsers. A joint syntactic and semantic parser, such as that of Lewis et al. (2015), could be trained directly on the annotations to improve both the syntactic and semantic models, for example in domain transfer settings. Alternatively, the annotation could be used for active learning: we envisage a scheme where parsers, when faced with ambiguous attachment decisions, can generate a human-readable question whose answer will resolve the attachment.

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