ExFaKT: A Framework for Explaining Facts over Knowledge Graphs and Text

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1 INTRODUCTION

Motivation and Problem. Knowledge Graphs (KGs) are large collections of factual triples of the form \( \langle \text{subject} \, \text{predicate} \, \text{object} \rangle \) (SPO) about people, companies, places, etc. Projects like BabelNet [28], DBpedia [5], Wikidata [38] and YAGO [36] have constructed KGs with millions of entities and billions of facts. However, KGs also contain doubtful if not incorrect SPO triples, as they are partly built by automatic information extraction, crowd-sourcing, or methods for KG completion using rules [16] or embeddings [29, 31, 40]. This incurs the problem of validating if an SPO triple is correct or not, a task that is often referred to as fact-checking or truth discovery [24].

Traditionally, fact-checking has been performed manually by human reviewers but this is time-consuming. Therefore, with the increase of false facts on the Web, the automation of fact-checking is gaining more attention. Methods for automatic fact-checking (e.g., [18, 24, 26, 30, 32]) proceed in two steps. First, they perform fact-spotting by searching for occurrences of a fact candidate, such as \( \langle \text{Sadig Khan citizenOf Pakistan} \rangle \), and possible alternatives, such as \( \langle \text{Sadig Khan citizenOf UK} \rangle \), in the Web sources. This is done by expanding the predicate into paraphrases (e.g., "has nationality", "has passport") and searching for it jointly with the alias names of the S and O arguments. Then, the extracted evidence (or counter-evidence) is used to infer the truth value of the candidate fact.

Numerical scores produced by fully automated methods are not adequate whenever the final decision is made by KG curators. For humans, such scores are hard to understand or justify without explanations. Some approaches (e.g., [12, 18]) attempt to show the sources used in computing the scores as an explanation. Yet, the collected syntactic clues using fact-spotting are often not sufficient since textual sources are incomplete and biased in what is stated explicitly. For instance, the citizenship of London’s mayor Sadig Khan would rarely be mentioned. In addition, some predicates (e.g., influencedBy) are ambiguous, and their interpretation is domain-specific.

Proposed Approach. To better support KG curators in deciding the correctness of the candidate facts, we propose a novel framework for finding semantically related evidence in Web sources and the underlying KG, and for computing human-comprehensible explanations for facts. We refer to our framework, as ExFaKT (Explaining Facts over KGs and Text resources).
The key for detecting semantic evidence is intensional background knowledge in the form of rules, specifically, Horn rules of the form $H \leftarrow B_1, B_2, \ldots, B_n$. For example, 
\[ \text{citizenOf}(X, Y) \leftarrow \text{mayorOf}(X, Z), \text{locatedIn}(Z, Y) \]
intuitively states that mayors of cities are normally citizens of countries where these cities are located. Such rules can be specified by humans or automatically extracted from KGs using rule mining methods (e.g., [17, 39]). As the latter may fall short of covering all interesting situations, hand-crafted rules are a valuable asset. We performed a user study with university students who were novices to KGs, and obtained a good number of rules with low error rate in less than an hour (Section 4.6).

We utilize rules to decompose a fact-spotting query into more frequently stated and thus easier-to-spot related facts. This way, we counter the reporting sparseness and bias. Moreover, rules can encode domain-specific knowledge to better cope with ambiguous predicates. Finally, rules combine knowledge from both textual Web sources and the KG. For example, a rule could find the mayors of cities in news articles and look up the countries of cities in the KG.

Given a set of rules and a query for a fact candidate, ExFaKT rewrites the query into a set of subqueries. Whenever we find evidence in the KG or text that the body of the rule holds, the credibility of the head increases. This process creates semantic traces that explain, in a human-readable format, why a fact is likely to be true (or false).

A key difference between our setting and existing applications of query rewriting (e.g., [34]) is that the latter assume that the data is contained exclusively in an indexed KG. This is in contrast to our scenario of interest, where some information partially exists in the KG, while the remaining pieces of knowledge are to be extracted from large and noisy text sources on-the-fly. Accounting for this, our framework is particularly tailored towards reducing the cost and uncertainty of the retrieval procedures.

Contributions. Our contributions are summarized as follows:

- We introduce ExFaKT, a framework for computing semantic traces for facts in question from both KG and an implicit external source in the form of a text corpora by utilizing Horn rules.
- We develop optimization strategies, whose target is an automatic search for an effective rewriting plan based on our cost model.
- We evaluate ExFaKT over real-world KGs and rules from various sources to illustrate the effectiveness of our rewriting strategy. We also show the benefits of the computed explanations in supporting human fact-checkers, and the viability of exploiting explanations in automated fact-checking.

ExFaKT is available at https://www.mpi-inf.mpg.de/impact/exfakt.

2 \ PROBLEM STATEMENT

We start with providing background on KGs, rules, and fact-spotting. Then, we describe the problem of using them along with text in computing human-comprehensible explanations for query facts.

Knowledge Graphs. Let $E$ and $R$ be fixed sets of entities and relations respectively. A knowledge graph (KG) $\mathcal{G}$ is a repository of unary and binary facts (i.e., $p(s)$ and $p(s, o)$) encoding domain knowledge (e.g., `director`(`nolan`), `influencedBy`(`nolan`, `lucas`)), where $p \in R$ is a relation (predicate) and $s, o \in E$ are entities (constants).

Rules. To enable constructing explanations from KGs and other resources, we utilize sets of Horn rules, which we define below by borrowing the concepts from the Datalog language [1].

A Horn rule is an expression of the form

\[ H \leftarrow B_1, \ldots, B_n \]  \hspace{1cm} (1)

where $H, B_1, \ldots, B_n$ are the atoms of the rule, i.e., expressions of the form $p(X)$ or $p(X, Y)$, where $p \in R$ and $X, Y$ are either entities or variables. We refer to $head(r) = H$ and $body(r) = \{B_1, \ldots, B_n\}$ respectively as the head and body of $r$.

Example 2.1. For $r$ from Section 1, $head(r) = \{\text{citizenOf}(X, Y)\}$, and $body(r) = \{\text{mayorOf}(X, Z), \text{locatedIn}(Z, Y)\}$.

Rules encode commonsense knowledge, e.g., capitals are located in countries or constraints, e.g., a person cannot be born in two places.

Given a rule $r$ of the aforementioned form (1) and a set $I$ of facts, we define the set of facts inferred by $r$ from $I$ as

\[ r(I) = \{H0 \mid B_1 \theta, \ldots, B_n \theta \in I\}, \]  \hspace{1cm} (2)

where $\theta$ is a postfix operator which substitutes variables with constants. We denote by $e$ empty substitutions, i.e., $qe = q$ for any $q$. Moreover, $\Pi(I) = \bigcup_{r \in R} r(I)$ is the extension to inferences produced by all rules in $\Pi$. The output of multiple rule executions is recursively defined by setting $\Pi^0(I) = I$ and $\Pi^{i+1}(I) = \Pi(\bigcup_{j \in \{0, \ldots, i\}} \Pi^j(I))$. The set $\Pi^\infty(I)$ (called closure) contains all possible inferences derived using $\Pi$ on $I$.

Fact Spotting. Let $textspot$ be a textual fact-spotting procedure, which gets as input an atom $q$ and a set $T$ of textual documents such as Wikipedia ($textspot(q, T)$), and outputs a set of tuples of the form $(\theta, s)$, where $\theta$ is a fact spotted in the text and $s$ is a textual string containing this fact.

Example 2.2. For the query $q = \text{directed}(`lucas`, `star_wars`)$ and the text $T = \{`G. Lucas, the director of Star Wars, signs..`, `Nolan got inspired by Star Wars`, `Star Wars 1977 directed by Lucas..`, `Nolan got inspired by Star Wars`, `Star Wars 1977 directed by Lucas..\}$, $textspot(q, T)$ returns $\{(\theta, s) = `G. Lucas, the director of Star Wars..`, (\theta, s) = `Star Wars 1977 directed by Lucas..\}$, where $\theta = e$.

We define the set of all facts involving entities from $E$ and relations from $R$ which can be extracted from the text $T$ using the syntactic fact-spotting procedure $textspot$ by $I_F = \{p(s, o) \mid s, o \in E, p \in R \land textspot(p(s, o), T) \neq \emptyset\}$.

Fact Explanations. Given a fact $q$, a KG $\mathcal{G}$, text corpus $T$ and a ruleset $\Pi$, a set $E \subseteq \mathcal{G} \cup I_F$ of facts is an explanation for $q$ w.r.t. $\Pi, \mathcal{G}, T$ if $q \in \Pi^\infty(E)$.

The presence of unstructured textual resources in the input makes the problem of computing explanations particularly challenging. Naturally, a given fact $q$ might have multiple explanations or a single trivial one, i.e., $q$ itself. Obviously, explanations as defined above may be subsumed by others. Among all explanations, ideally, we aim at computing non-trivial ones that are

- (D1) \textbf{concise}, i.e., contain a small number of atoms;
- (D2) \textbf{close to the query}, i.e., obtained by using few rules;
- (D3) \textbf{reliable}, i.e., contain as many facts from the KG as possible, since KGs are usually more reliable than text.
3 EXFAKT FRAMEWORK

ExFaKT utilizes rules to compute explanations over the content of KGs and textual resources. We first start with an overview of how these explanations are computed. Then, we illustrate the technical details underlying our framework.

3.1 Computing Explanations

Computing the entire KG closure is not feasible as it requires the extraction of all possible facts from \( T \). Thus, we proceed backwards, i.e., we start from the input fact, and check whether any of the rules can potentially produce such derivation. If so, then we move to the body of the rule, and search for possible instantiations for each body atom. This triggers a recursive process, where the new input is constituted by the body atoms. The recursion stops in case no rules can be found or all atoms are instantiated either by facts in the KG or by text. In this last case, the rules produce new derivations which are returned to earlier recursive calls.

We illustrate the overview of computing explanations using the following example:

**Example 3.1.** Consider the following input

- a query \( q = \text{influencedBy}(\text{nolan}, \text{lucas}) \)
- a text corpus \( T \) composed of Wikipedia articles
- a KG \( G = \{ \text{directed}(\text{lucas}, \text{star\_wars}), \text{isDirector}(\text{nolan}), \text{directed}(\text{lucas}, \text{amer\_graffiti}) \} \)
- a ruleset \( \Pi = \{ r_1, r_2 \} \), where
  - \( r_1 : \text{inspiredBy}(X, Y) \rightarrow \text{isDirector}(X), \text{directed}(Y, Z), \text{inspiredBy}(X, Z) \),
  - \( r_2 : \text{inspiredBy}(X, Y) \rightarrow \text{liked}(X, Y), \text{isArtist}(X) \).

As \( q \notin G \), and assuming that \( \text{textspot}(q, T) = \emptyset \), ExFaKT utilizes those rules in \( \Pi \), such that \( \text{Head}(r) = \text{influencedBy} \) to explore the potential explanations resulting in the set:

\[
P = \{ \text{isDirector}(\text{nolan}), \text{directed}(\text{lucas}, \text{Z}), \text{inspiredBy}(\text{nolan}, \text{Z}) \}\.
\]

For this candidate, it holds that \( \text{isDirector}(\text{nolan}) \notin G \), hence, we move to the second atom \( \text{directed}(\text{lucas}, \text{Z}) \). Grounding this atom from the KG results in the updated set of candidate explanations

\[
P = \{ \text{isDirector}(\text{nolan}), \text{directed}(\text{lucas}, \text{star\_wars}), \text{inspiredBy}(\text{nolan}, \text{amer\_graffiti}), \text{inspiredBy}(\text{nolan}, \text{amer\_graffiti}) \}.
\]

We start processing the first explanation, and since the first two atoms are in \( G \), they are marked as found, and we move to the third atom \( \text{inspiredBy}(\text{nolan}, \text{star\_wars}) \). As this third atom is spotted in the text, we get \( E_1 = \{ \text{isDirector}(\text{nolan}), \text{directed}(\text{lucas}, \text{star\_wars}), \text{inspiredBy}(\text{nolan}, \text{star\_wars}) \} \). Since all atoms in \( E_1 \) were found, it is added to the output set.

However, since the last atom in \( E_1 \) was found in text which is a noisy resource, we would still rewrite it, seeking for more reliable evidences. In this case, \( r_2 \) is used for rewriting leading to \( E_2 = \{ \text{isDirector}(\text{nolan}), \text{directed}(\text{lucas}, \text{star\_wars}), \text{isArtist}(\text{nolan}), \text{liked}(\text{nolan}, \text{star\_wars}) \} \). Assuming that the last two atoms of \( E_2 \) are spotted in \( T \), we get \( E_2 \) to be in the output set.

Analogously, we process the second explanation candidate in \( P \), i.e., \{isDirector(nolan), directed(lucas, amer_graffiti), . . .\}. ExFaKT explanations are human-interpretable; allowing KG curators to judge the validity of the fact. They can also be used as input features to automatically assess the candidate fact truthfulness.

3.2 Prerequisites

Besides the KG, ExFaKT requires two key resources, rules and fact-spotting engine over textual sources, which are obtained as follows:

**Ruleset Acquisition.** In general, rules can be either automatically extracted using tools such as [17, 37, 39], or manually specified by domain experts as in the context of ontology engineering [4]. We performed experiments to evaluate the effectiveness of using rule-sets from both sources. We have also conducted a pilot experiment to ensure the feasibility of manual rule construction where we asked non-experienced participants to create useful rules. From these experiments, we observed that adequate rules can be produced not only by KG curators (which are our target group), but also by non-experts (more details in Section 4).

**Fact-spotting Realization.** ExFaKT utilizes the syntactic fact-spotting subroutine \( \text{textspot} \), defined above. In practice, similar to [26, 32], it is implemented relying on a textual-search-based method, in which the SPO query \( q \) is converted to textual representation (i.e., verbalization) using paraphrasing dictionaries for relations such as PATTY [27] and entity-mentions dictionaries for entity name aliases. Then, \( q \) with its paraphrasing is issued to get the documents containing it. Finally, a named entity recognizer, e.g., [14], is utilized to collect entities from the documents and compute the substitution \( \theta \). This versatile approach is easily scalable without extensive training, but any other fact-spotting method can easily be plugged in ExFaKT.

3.3 ExFaKT Algorithm

We identify two main operations in ExFaKT’s recursive process, namely, bind and rewrite. The first retrieves answers for a given query from the underlying data sources, while the second rewrites a query into subqueries. We formally specify them below.

**Bind.** Prior to defining bind, we introduce some formal notations. Let \( g \) be an atom, \( G \) a KG, and \( T \) a text corpus. We define \( \Sigma_G(g) = \{ \sigma \mid \sigma \in G \} \) and \( \Sigma_T(g) = \{ \sigma \mid \text{textspot}(\sigma, T) \neq \emptyset \} \) as the sets of substitutions that result in answers to the query \( g \) from the KG and text respectively. Every substitution \( \sigma \in \Sigma_G(g) \) is annotated with the metadata \( \text{source}[\sigma] = \text{KG} \), while every \( \sigma' \in \Sigma_T(g) \) is annotated with \( \text{source}[\sigma'] = \text{TEXT} \); moreover, each \( \sigma' \) is annotated with another metadata \( \text{text}([\sigma']) \) which contains the string that mentions \( g \) in \( T \) (as returned by \( \text{textspot} \)).

Metadata of substitutions is passed to atoms they substitute, e.g., if \( \text{text}([\sigma]) = \text{X} \) then \( \text{text}([\sigma]) = \text{X} \). In our procedures, we use another two types of metadata, \( \text{status}[] \), to mark atoms which are already processed, and \( \text{depth}[] \), to record the number of rewritings that led to the atom at hand. Finally, metadata is not considered for the equality of substitutions and atoms, i.e. two atoms can be equivalent even if they are annotated with different metadata.

**Definition 3.2.** The function \( \text{bind}(g, G, T) \) receives as input an atom \( g \), a KG \( G \), and a text corpus \( T \). It returns in output the set

\[
\Sigma = \{ \Sigma_G(g) \cup \{ \Sigma_T(g) \setminus \Sigma_G(g) \} \}.
\]
**Algorithm 1:** Algorithm for computing explanations.

```plaintext
Input: fact q, KG G, text corpus T, ruleset Π, nonnegative parameter max_depth for ensuring termination
Output: set of explanations O
1 function explain(q, G, T, Π)
2    depth[q] ← 0; status[q] ← T000; P ← \{q\}; O ← {} 
3    while P ≠ ∅ do
4        Pick explanation E from P (i.e., E ∈ P)
5        P ← P \ {E}
6        if status[q] = FOUND for all g ∈ E then
7            O ← O ∪ {E} 
8            We found a valid explanation.
9        else
10           Pick an atom g from E s.t. status[g] = T000
11           NT ← process_goal(g, E \ {g}, G, T, Π)
12           P ← P ∪ NT
13           return O
14 function process_goal(q, E, G, T, Π)
15    O ← ∅
16    Σ ← bind(g, G, T)
17    TR ← \{g\}
18    for σ ∈ Σ do
19        a ← σ[a]
20        depth[a] ← depth[g], status[a] ← FOUND
21        if source[σ] = KG then TR ← TR \ \{a\}
22        for gr ∈ TR s.t. depth[g] < max_depth do
23            O ← O ∪ rewrite(gr, E, Π)
24    return O
```

Example 3.3. Let us assume that q = directed(lucas, Z), G = \{directed(lucas, star_wars)\} and T = “Along with Star Wars, Lucas has directed short documentaries Herbie, ...”. Then, \(\Sigma_G = \{\sigma_1\}\), \(\Sigma_T = \{\sigma_2\}\), where \(\sigma_1 = \{Z \rightarrow \text{star_wars}\}\), \(\sigma_2 = \{Z \rightarrow \text{herbie}\}\). Also, \(\text{source}[\sigma_1] = \text{KG}, \text{source}[\sigma_2] = \text{TEXT}, \text{and text}[\sigma_2]\). store string coordinates of films in T.

**Rewrite.** The function rewrite moves the search space of the answers for a given query from the rule’s head to its body by rewriting an input query into a respective set of subqueries.

**Definition 3.4.** The function rewrite \((g, E, Π)\) receives as input an atom g, a set of atoms in a program and a program Π. It computes the set \(B_g = \{\text{body}(r)σ_r \in E \cap \text{head}(r)σ_r = g\}\) where \(σ_r\) is a substitution that unifies the rule head with g and propagates the substituted terms to the rule body, while \(σ_r\) renames among the rest of the body variables those that appear in E into fresh ones. Moreover, for each atom a in \(B_g\) the function sets status[\(σ_r[a] = \text{T000}, depth[a] = depth[g] + 1\) and returns the set \(\{E \cup a \mid a \in B_g\}\).

Example 3.5. For the input predicate \(g = \text{inspiredBy(nolan, Z)}\), the intermediate explanation \(E = \{\text{isDirector(nolan)}, \text{directed}(Y, Z)\}\) and the ruleset Π=\{\(r_2\): inspiredBy(X, Y) ← liked(X, Y), isArtist(X)\}, the function rewrite \((g, E, Π)\) first computes \(B_g = \text{body}(r_2)σ_r \in Π\), where \(σ_r = \{X \rightarrow \text{nolan}, Y \rightarrow Z\}\) and \(E_F = \varepsilon\), since \(σ_r\) already handled all variables appearing in body \(r_2\). Finally, in the output we obtain \(E = \{\text{isDirector(nolan)}, \text{directed}(Y, Z), \text{liked}(nolan, Z), \text{isArtist(nolan)}\}\), where for every atom a in \(B_g\), the status is assigned as status[\(a = \text{T000}\), and the depth as depth[a] = depth[g] + 1.

**Main Procedure.** Algorithm 1 shows the main procedure underlying ExFaKT. Our procedure takes as input a query q, a KG G, a text corpus T, a ruleset Π and a global parameter max_depth specifying a maximum number of allowed rewritings to ensure termination, and as output provides a set O of explanations for q. Initially, the status of the input query is set to T000, and the set P of potential explanations is initialized with \{q\}. In (3) the algorithm iterates over the set P of potential explanations. Explanations \(E ∈ P\), all of whose atoms have status FOUND, are moved to the output set O in (7). For other candidate explanations, atoms with the status T000 are processed by the procedure process_goal.

Procedure process_goal takes as input an atom g and first retrieves all substitutions of variables to constants that result in answers to g in the KG and text using bind function and copies g into the set TR (to be rewritten). Then, it iterates over the retrieved substitutions and sets the depth of every obtained answer (a) to the one of g and the status to FOUND in line (19). After that, the answer is added to the existing atom in the current explanation (E), which is included in O (line 21).

Lastly, process_goal rewrites the input query using the rules in the program by invoking the function rewrite. Notice that TR might be empty: This occurs if \(g\) is a fact, which was verified in the KG. In this case, we do not need to rewrite it, since the fact is already explicitly stated; thus we remove it from TR in line (20).

Note that since no restriction is put on the form of allowed rules, Algorithm 1 might not terminate. To avoid this, we bound the number of rewritings using the max_depth parameter, so that the algorithm always terminates. As output, Algorithm 1 returns explanations for the input candidate, which is a property formally stated in the following theorem:

**Theorem 3.6.** Let \(G\) be a KG, T a text corpus, Π a program, q an input fact, and O = explain \((q, G, T, Π)\). If \(E ∈ O\) then \(E\) is an explanation of \(q\) w.r.t. Π, G, T.

**Optimizations.** Often, we do not need to calculate all explanations; few relevant ones are sufficient for establishing the truth value of a fact in question. To improve the performance, we introduce anytime behavior and incrementally collect new explanations as they are added to the output set (line 7 of Algorithm 1). In this new setting, we can stop the algorithm whenever it has returned satisfactory explanations, but it is crucial that the most relevant explanations based on the criteria (D1)-(D3) from Section 2 are computed first.

Example 3.7. If \(\text{influencedBy(nolan, lucas)}\) from Ex. 3.1 was found in text, then \(E_0 = \{\text{influencedBy(nolan, lucas)}\}\) would be the most concise explanation, since it contains only a single atom. Moreover, for \(E_1\) and \(E_2\) from the same example we have that \(E_1\) is closer to the query than \(E_2\), since less rules were used to produce \(E_1\). If there is another explanation \(E_3\) which equals to \(E_2\) but with star_wars substituted by Herbie and directed(lucas, herbie) is found in text, it holds that \(E_2\) is more reliable than \(E_3\), since \(E_2\) contains fewer atoms from text sources.

Our optimizations along these lines affect two operations: the explanation selection and the atom selection criteria.

**Explanation Selection Criterion.** In line 4, Algorithm 1 selects one explanation to be processed from those in P. To prioritize the processing of promising explanations we change the order in which they are picked based on the following criteria: (i) we favor shorter explanations, i.e., explanations with the lowest number of atoms (D1); (ii) we favor explanations produced with fewer rewritings by picking the query with the smallest depth value (D2).
4 EVALUATION

We start in Section 4.2 with evaluating the effectiveness of ExFaKT with respect to the increase in the coverage of the collected pieces of evidence while preserving their precision (as shown later in Section 4.3). Additionally, we present a user-study which targets assessing the quality of the explanations and their readability and usefulness for human-reviewers in Section 4.3. Later in Section 4.4, we demonstrate the effectiveness of ExFaKT using automatically mined rules as input. Moreover, a showcase for integrating ExFaKT into the pipeline of a fully automated fact-checking system is given in Section 4.5. Finally, Section 4.6 reports the results of our study on the feasibility of manual rule construction.

4.1 Experimental Setup

Datasets. We conducted our experiments on two datasets:

- YAGO-based benchmark, which consists of 300 true candidate facts, uniformly distributed over six relations (listed in Table 1). The instances of the first three relations were randomly selected from YAGO [36]. The other three relations do not appear in the KG; hence, their instances were semi-automatically curated using simple logical rules. Then, 50% of the facts used during their creation were removed at random; thus, intentionally introducing incompleteness in the KG and hence the need for textual sources.

- DBpedia-based benchmark is a subset of the dataset proposed by [35] containing facts over the predicates, for which AMIE, a state-of-the-art rule mining system [16], managed to learn at least 5 rules having them in the head. This benchmark contains four predicates with a total of 1763 correct facts.

Rules. We constructed a ruleset for each benchmark as follows: For the YAGO-based benchmark, we selected rules from the top-ranked ones mined by AMIE from YAGO, and added further rules with new predicates that do not exist in the KG. We refer to these new predicates as text-based, as they need to be verified from the text. This way we obtained 20 rules on average for each head predicate. For the DBpedia-based benchmark, we used the rules mined by AMIE from DBpedia without altering them. Each head predicate in the dataset obtained a set of 100 related rules on average. This setup is designed to study the case of fully relying on automatically learned rules.

Knowledge Graph. We used YAGO3 [36] as KG in all experiments. YAGO3 contains around 5.5M facts and 35 relations. This KG is geared towards precision rather than recall, allowing us to treat it as a trusted resource.

Text Corpora. As for text, we experimented with two different sources: (i) Wiki which contains 5.5M Wikipedia articles, whose textual parts were split into sentences and indexed as separate documents using Elasticsearch [19] and (ii) Web constructed relying on the Bing API for searching in Web pages.

4.2 Explanations Coverage

Experimental Details. In this experiment, we show the effectiveness of ExFaKT in retrieving more explanations for candidate facts. We used the YAGO-based dataset and compared all five configurations of our method against the baselines. We computed the recall of each configuration as the ratio of the queries for which at least one explanation was retrieved.

Results. Table 1 reports the recall for each predicate in the dataset and the recall of the whole dataset as the total. These results show that ExFaKT configured with KG+Wiki or KG+Web almost doubled the recall of the baselines B-Wiki and B-Web respectively, whereas rules on the KG alone (KG) have the worst recall. Similarly, configurations over text corpora alone, namely Wiki or Web could not compensate the absence of the KG.

Observe that since mayorOf is prominent enough to be easily spotted in the text, there is no increase in the recall for this predicate. In contrast, our method is particularly successful for countryWon, since the baselines fail to spot facts over this newly created predicate. Overall, the results demonstrate that while neither the KG nor textual sources alone are sufficient to collect strong evidence, their combination doubles the recall, and is doubtlessly the best configuration. Moreover, comparing KG+Wiki with KG+Web shows that increasing the size of the textual corpus enhances the results.

| Table 1: Recall of baselines vs. ExFaKT configurations |
|----------------|--------|--------|--------|--------|--------|--------|--------|--------|
|                | B-Wiki | B-Web | KG     | Wiki   | Web    | KG+Wiki| KG+Web |
| influences     | 0.30   | 0.24  | 0.00   | 0.38   | 0.88   | 0.42   | 0.92   |
| isPolitOf      | 0.02   | 0.16  | 0.26   | 0.18   | 0.88   | 0.42   | 0.92   |
| wroteMusic     | 0.08   | 0.28  | 0.00   | 0.10   | 0.72   | 0.24   | 0.78   |
| mayorOf        | 0.56   | 0.9   | 0.00   | 0.66   | 0.90   | 0.66   | 0.90   |
| actedWith      | 0.26   | 0.52  | 0.18   | 0.26   | 0.60   | 0.54   | 0.94   |
| countryWon     | 0.18   | 0.38  | 0.00   | 0.18   | 0.38   | 0.70   | 0.92   |
| Total          | 0.25   | 0.41  | 0.07   | 0.29   | 0.73   | 0.50   | 0.90   |

Baselines. We compared against three baselines:

- B-Wiki: a method that syntactically spots candidate facts and their paraphrases in the Wiki corpus.
- B-Web: a method that retrieves fact occurrences in the Web using the Bing search API and post-filters the results to obtain the relevant text snippets (this baseline was extracted from [32]).
- B-Search: a simulation for a user issuing verbalized versions of candidate facts to commercial search engine and retrieving the top-5 results.

Configurations. To analyze the influence of the various sources, we ran ExFaKT with the following:

- KG: Rules are used over the KG facts only.
- Wiki: Rules are used only with syntactic fact-spotting over the Wiki corpus, i.e., no KG facts are exploited.
- Web: Rules are used only with fact-spotting over the Web, i.e., no KG facts are used.
- KG+Wiki: Rules used together with both Wiki corpus and KG.
- KG+Web: Both Web corpus and KG are used with the rules.

In all of the experiments, we set the parameter max_depth to 5 unless otherwise stated.
Examples. As anecdotal evidence, Table 2 shows two examples of candidate facts for which our approach managed to compute supporting explanations even though fact-spotting failed to find direct mentions for them. The first fact to be spotted is about the country Guatemala and the predicate country has won prize. Our method was able to find positive evidence for Guatemala winning the Nobel prize by spotting the Nobel laureate Miguel Asturias, and combining this information with the fact that he is a citizen of Guatemala.

In the second example, we were able to extract an evidence about the influence of a writer on another one by spotting the fact that the latter read books written by the former. Note that here the relation read is not present in the KG but mentioned in the Wikipedia text.

### 4.3 Explanations Quality and Usefulness

In this experiment, we evaluate the quality of the retrieved explanations by estimating the precision of the results and their readability based on human judgment.

**Experimental Details.** We designed a Mechanical Turk [6] task to collect human judgments on the quality of the computed explanations. To facilitate readability, we translated our task into a natural language question. The participants were shown a candidate fact and some extracted explanation (i.e., in a human readable format), and their task was to judge the correctness of the fact relying only on the provided information.

Since it may be hard for non-experts to give a solid judgment, the participants were asked to choose one out of five answers: (i) "For sure, yes", (ii) "Probably, yes", (iii) "Probably, no", (iv) "For sure, no", or (v) "Can not judge". As a confirmation, they were also asked for their explicit feedback on the usefulness of the provided information. Participants were provided with a set of instructions and clarification examples covering all possible cases. Each record was assigned to 5 different participants.

We evaluated the top-5 explanations produced by ExFaKT’s configurations KG+Wiki and KG+Web on the YAGO-based dataset as reported in Section 4.2. We compared them to the results of the baselines B-Wiki and B-Web respectively. Additionally, we included the results of the third baseline B-Search for annotations.

**Evaluation Metrics.** The target of this experiment is to assess the relevance of the extracted traces for the query by relying on whether participants were able to make a correct judgment. To this end, we used the annotations given by the participants to perform majority voting on three categories: correct judgment (i.e., yes case), incorrect judgment (i.e., no case), and unable to judge. Tie cases are randomly broken. Explanations with a majority of the correct judgment are counted as relevant.

We calculated Precision@K, which is defined as the ratio of candidate facts for which our method returned one or more relevant explanations to those that have at least one (relevant or irrelevant) explanation. Finally, we computed the $f_1$ score and the mean average precision at top-5 (MAP@5).

**Results.** Table 3 reports the sizes of each dataset and the distribution of the majority voting over the classes. The second column shows the number of candidate facts involved in the evaluation, while the third column indicates the total number of explanations produced for all of the candidates. The annotations demonstrate a fair Fleiss Kappa [20] agreement of 0.35 for the Wiki-based configurations and a slight agreement of 0.03 for Web-based configurations, reflecting the difficulty and subjectivity of the task in the presence of noisy results. Deeper analysis showed that the lower the ratio of atoms binded from text, the easier it is to judge the explanation correctly. While reducing the number of rules has a similar effect, increasing the the number of atoms in the explanation increases human-comprehensibility of explanations.

Observe that the average time required for the annotator to judge the truthfulness of a fact candidate based on explanations retrieved by our method (27 seconds) was almost half the time required to judge it based on standard Web search results (51 seconds), yet the quality of the judgments in the former case is higher. This illustrates the benefits of using our method for increasing the productivity and accuracy of human fact-checkers.

![Figure 1: Precision@k computed using human annotations](image)

Figure 1 shows the results for Prec@k for $k = 1, 2, 3$. First, we observe that the Prec@1 of ExFaKT’s configurations KG+Wiki and KG+Web are 6% and 2% lower than for the respective baselines B-Wiki and B-Web which both have precision of 0.85, yet all configurations have significantly higher precision compared to the case when a traditional commercial search engine was exploited as for

### Table 2: Examples of explanations produced by ExFaKT

<table>
<thead>
<tr>
<th>Fact candidates</th>
<th>Explanations</th>
</tr>
</thead>
<tbody>
<tr>
<td>countryWon(guatemala, nobel)</td>
<td>isCitizenOf(miguel_asturias, guatemala), source = TEXT, text=&quot;Asturias is a Nobel Prize-winning Guatemalan poet...&quot;</td>
</tr>
<tr>
<td>influences(s_fitzgerald, r_yates)</td>
<td>wrote(s_fitzgerald, the_great_gatsby), source = KG read(r_yates, the_great_gatsby), source = TEXT, text=&quot;Yates, called &quot;The Great Gatsby&quot; the most nourishing novel he read:&quot;</td>
</tr>
</tbody>
</table>

### Table 3: Mechanical Turk task statistics

<table>
<thead>
<tr>
<th>Config</th>
<th>Candid.</th>
<th>Explan.</th>
<th>Question 1</th>
<th>Question 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-Wiki</td>
<td>75</td>
<td>75</td>
<td>0.87</td>
<td>0.04</td>
</tr>
<tr>
<td>B-Web</td>
<td>122</td>
<td>122</td>
<td>0.85</td>
<td>0.01</td>
</tr>
<tr>
<td>KG-Wiki</td>
<td>159</td>
<td>311</td>
<td>0.64</td>
<td>0.35</td>
</tr>
<tr>
<td>KG+Web</td>
<td>267</td>
<td>1021</td>
<td>0.82</td>
<td>0.01</td>
</tr>
</tbody>
</table>
B-Search. From the figure we can observe that KG+Web exceeds the baselines starting from top-2 with Prec@2 = 0.95 and KG+Wiki overcomes the baselines for the top-3 explanations. The results also indicate that the precision for the both configurations KG+Wiki and KG+Web consistently increase till they achieve Prec@5 of 0.87 and 0.97 respectively. Furthermore, MAP@5 for KG+Web is 0.84, which exceeds MAP@5 = 0.77 of KG+Wiki.

Since our method doubles the recall (Table 1), it also significantly enhances the F1 score achieving 0.64 and 0.93 with KG+Wiki and KG+Web compared to 0.4 and 0.55 for the corresponding baselines.

### 4.4 Extracting Explanations using Mined Rules

So far we have considered manually refined rules. We now evaluate ExFaKT using automatically learned, hence noisier rules.

**Experimental Details.** We used the DBpedia-based dataset with the ruleset automatically mined by AMIE from DBpedia. These rules contain many predicates that are not in YAGO; thus, textual sources are vital. We compare the recall of KG+Wiki against the configurations B-Wiki, KG, and Wiki. For this experiment, we set the rewriting depth max depth to 2 to reduce propagation of noisy rule rewritings. We computed Prec@5, MAP@5 and f1@5 scores in the same way as in Section 4.3.

**Results.** Table 4 reports the recall for the fact candidates over four different predicates. We observe that our method improves the recall for all predicates, with the best result obtained for graduatedfrom, where the recall has even doubled. Based on human annotations, we obtained Prec@5 = 0.84, MAP@5 = 0.84 for B-Wiki and Prec@5 = 0.64, MAP@5 = 0.56 for KG+Wiki. Despite that, KG+Wiki configuration achieved a better f1 with f1@5 = 0.45 compared to a lower value f1@5 = 0.32 obtained by B-Wiki. These results demonstrate the effectiveness of ExFaKT also when automatically mined rules are used as input.

### 4.5 Rule-based Automatic Fact-checking

In this experiment, we focus on the viability of exploiting extracted explanations in automated fact-checking. To this end, we implemented a simple automated fact-checker that uses the explanations to determine whether a given fact should be supported or rejected.

For the sake of computing numerical scores over explanations, we define the notion of explanation confidence as

$$
\text{confidence}(E) = \frac{1}{|E|} \sum_{a \in E} \frac{\text{trust(source}[a])]^{\text{depth}[a]}
$$

where $E$ is an explanation, trust(·) is 1 if source[·] is KG, or 0 otherwise, representing the trust in the source, and depth[·] is number of rewritings performed to obtain the atom as in Section 3. Then, for each fact candidate $f = p(a, b)$, we exploit two rules sets $\Pi^+$ for supporting it and $\Pi^-$ for refuting it. Then, we compute the supporting explanations set $O_+ = \text{explain}(p(a, b), G, T, \Pi^+_\text{to})$, and another set of refutation evidence $O_- = \text{explain(not}_p(a, b), G, T, \Pi^-_\text{to})$ where not $p$ is newly introduced predicate representing the negation of $p$.

Then, we compute the truthfulness score for $f$ as:

$$
\text{truth. score}(f) = \text{quality}(O_+) - \text{quality}(O_-)
$$

where quality(·) is the average confidence of explanations belonging to this set. The truth score acts as a threshold value which determines whether the fact should be accepted or rejected.

**Dataset.** We applied the automated fact-checking on two datasets containing both correct and erroneous candidate facts.

- **Politics benchmark** [26] with 275 candidates, which contains for each true fact a set of its alternatives. For fairness, we removed the existing candidates from the KG which would trivially support the input facts. For this dataset, we used a ruleset of both manually specified and automatically mined rules by AMIE.

- The previously used DBpedia-based dataset enriched by adding a set of erroneous alternative instances from [35] for each true fact. In this case, we used the set of automatically learned rules from Section 4.4 extended with rules for not $p$ for each predicate $p$ in the given dataset.

**Experimental Details.** The explanations were computed using the KG+Wiki configuration. We compare the results of our simple ExFaKT-based fact checker to two state-of-the-art approaches:

- **TruthFinder** [41] which uses a voting approach over the retrieved documents weighted based on their sources.

- **Language-Stance-Credibility (LSC)** [32] which decides the truthfulness of a claim based on language, stance, and reliability of the evidence sources.

We considered the first 5 explanations retrieved by the KG+Wiki configuration per supporting $O_+$ and refuting $O_-$ sets respectively. Note that LSC collects clues from the whole Web, while TruthFinder and ExFaKT rely only on the Wikipedia text corpus.

**Evaluation Metric.** In order to compare the performance of the various approaches, we grouped the true facts with their alternatives and ranked the elements of the group using the scoring function of each method. For instance, let $f_j$ be a true fact and $f_{j_1}, \ldots, f_{j_n}$ be alternative false facts. In this setting, each method assigns a score value to every fact thus producing a ranking. After the ranked list is computed, we compute the recall as the number of groups where the method at hand was capable of returning some truthfulness scores for the true fact. Then, for each given group $G_i = \{f_i, f_{j_1}, \ldots, f_{j_n}\}$ we compute the accuracy as

$$
\text{Accuracy}(G_i) = \frac{1}{|G_i|} \sum_{f_j \in G} \text{score}(f_i) \geq \text{score}(f_j)
$$

where $|\cdot|$ is the Iverson bracket and score(f) is the truthfulness score computed by each method. This accuracy estimates the probability that the true fact $f_j$ has the highest rank among its alternative facts as in [26].

**Results.** Table 5 shows the results of the average accuracy (Accu.) for all groups of facts and recall of our method compared to the
competitors. According to the first two rows, we can observe that our method is on par with the accuracy of TruthFinder, despite the simplicity of our ranking function. Moreover, our method is advantageous, as it offers clear explanations of the results, and has a better recall compared to TruthFinder, especially for the politicians dataset. Moreover, importantly while LSC is utilizing the benefits of scraping the whole Web, our system still achieves significantly higher accuracy. We analyzed the cases where our method failed, and observed that some of the relations in the test set require more complex rules to be properly supported or refuted. For instance, this dataset contains facts over such predicates as isMarriedTo or holdsPosition, which are better explained using temporal rules, as they change over time (e.g., one person can be married to multiple persons, but not at the same time). Extending our approach to support also rules of this kind is a promising future direction.

4.6 Rule Specification
In addition to automatically mined rules, our approach benefits from hand-crafted rules. In this experiment, we examine the feasibility and cost of this kind of rule specification.

Experimental Details. We asked 10 students from different fields to create rules. Most of these had no prior exposure to logical rules or KGs; so we gave them 20 minutes of explanation on KGs and Horn rules. Each participant picked 5 predicates from a list of KG predicates, and was asked to write at least one supporting rule and at least one refuting rule. The participants were given 30 minutes to create the rules.

Evaluation Metric. We classified the resulting rules into three categories: (i) strong rules that represent causality and generalize (e.g., politicianOf(X, Y) ← electedIn(X, Z), in(Z, Y)); (ii) valid rules that capture typical correlations but may be tied to specific cases (e.g., citizenOf(X, Y) ← grewupIn(X, Y)); (iii) invalid rules that are logically flawed or do not properly reflect typical situations (e.g., not_memberOf(X, Y) ← leader(X, Y)). We consider strong and valid rules as suitable.

Results. Within 30 minutes, the 10 participants created 96 rules for 23 different head predicates (i.e., with average of 3 minutes per rule). Table 6 shows their distribution over the three categories. More than half of the rules were strong, and more than 80% were strong or valid. The remaining incorrect rules could be filtered out by having the same participants judge the validity of each others’ rules, using a voting scheme. This study clearly demonstrates that manual construction of rules is not a bottleneck, and can be accomplished by informed crowdsourcing at fairly low cost.

5 RELATED WORK
Fact-checking. Starting with TruthFinder [41] and T-Verifier [23], text-based fact-checking has become an established research field [24]. The majority of the state-of-the-art methods (e.g., [11, 18, 22, 25, 26, 32]) perform joint estimation of the fact’s truth value based on the credibility of the fact candidates syntactically spotted in text and the trustworthiness of the underlying sources. These approaches, unlike ours, are purely syntactic, i.e., they ignore domain background knowledge often vital for inferring the fact in question.

A query language to assess the validity of claims in multiple contexts over structured information sources has been proposed in [21]. Other works (e.g., [2, 9, 33, 35]) estimate the support for factual statements by mining and ranking connectivity patterns in KGs. In contrast to ours, all of these approaches ignore textual sources. The inclusion of textual sources makes the execution of bottom-up procedures (like the well-known chase in [21]) problematic, as they require the execution of fact-spotting for any possible fact, which is unfeasible due to the high cost of this procedure. This problem has been circumvented by our top-down approach. The same holds for less related works that explain semantic connections among given KG entities (e.g., [3, 15]).

Checking facts jointly over KGs and textual resources has been explored in the context of natural language question answering in, e.g., [10], where given a relation and an entity (i.e., subject or object), the task of retrieving a set of other entities that form a true triple is solved using neural networks. Our work differs from [10] in several aspects. First, instead of retrieving entities we are given a fact to be checked. Second, we do not merely estimate the truthfulness of the fact, but also output human-readable semantic traces that support or refute it, while the output of [10] cannot be explained to humans.

Inductive and Deductive Reasoning over KGs. Mining rules for KG completion (e.g., [8, 16, 37]) is orthogonal to our work. Indeed, instead of inducing rules from KGs, we are rather interested in exploiting them effectively for fact-checking over both structured and unstructured (textual) resources.

Logical query rewriting is well-studied in databases, e.g., for the Datalog language. This line of research (see [7] for an overview) is focused on structured databases, though. In contrast, we consider also external sources in text form, which introduces additional challenges and requires optimizations. Deductive reasoning over multiple external sources has been explored, e.g., in [13]. However, joint query rewriting over structured and textual sources has not been studied in this context.

6 CONCLUSION
Prior methods for automatic fact-checking focused on producing final truthfulness scores, which are hard to interpret for humans. Moreover, existing approaches spot solely explicit occurrences of facts in text. In this paper, we moved forward towards deriving more human understandable evidence based on background knowledge in the form of rules. ExFaKT utilizes these rules to collect pieces of evidence from both KGs and textual sources. The conducted experiments demonstrate the usefulness of our method for supporting human curators in making accurate decisions about the truthfulness of facts as well as the potential of our explanations for improving automated fact-checking systems.

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