Syntactic tree queries in Prolog

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Abstract
In this paper, we argue for and demonstrate the use of Prolog as a tool to query annotated corpora. We present a case study based on the German TüBa-D/Z Treebank to show that flexible and efficient corpus querying can be started with a minimal amount of effort. We end this paper with a brief discussion of performance, that suggests that the approach is both fast enough and scalable.

1 Introduction
Corpus investigations that go beyond formulating queries and studying (graphical renderings of) the retrieved annotation very quickly begin to require a general purpose programming language to do things like manipulating and transforming annotation, categorizing results, performing non-trivial counting and even statistical analysis, as query tools only offer a fixed, restricted set of operations. The use of a general purpose programming language has drawbacks, too, however: one has to deal with interfacing with a database, non-deterministic search, definition of linguistically relevant relations and properties in terms of the lower level database relations, etcetera.

As a solution for this dilemma of trading flexibility and power against the ease with which one can query corpora, we propose to use Prolog. Prolog is well suited to query databases (Nilsson and Maluszynski, 1998). Unlike in other general purpose languages, the programmer is relieved of the burden of writing functions to non-deterministically search through the corpus or database.

In comparison to dedicated query languages and their processors, the fact that one can always extend the Prolog predicates that constitute the query language lifts many restrictions on the kinds of queries one can pose. A more specific point is that we can have fine grained control over the scope of negation and quantification in queries in Prolog, something that is sometimes lacking from dedicated languages (for discussion, see Lai and Bird (2004); for a prominent example, König et al. (2003); for an exception, Kepser (2003))

Lai and Bird (2004) formulated a number of queries to compare query languages for syntactically annotated corpora. In this paper, we demonstrate the ease with which a flexible and fast query environment can be constructed by implementing these queries and using them as a rudimentary benchmark for performance.

2 Representing the TüBa-D/Z corpus
The TüBa-D/Z treebank of German newspaper articles (Telljohann et al., 2006, v5) comprises about 800k tokens in 45k sentences. We store the corpus as collection of directed acyclic graphs, with edges directed towards the roots of the syntactic trees (Brants, 1997).

% node/7 SentId NodeId MotherId Form Edge Cat Other
node(153, 4, 503, die, -, art, [morph=asf]).
node(153, 503, 508, '$phrase', hd, nx, []).

By using the sentence number as the first argument of node/7 facts, we leverage first argument indexing to gain fast access to any node in the treebank. Provided we know the sentence number, we never need to consider more nodes than the largest tree in the corpus. Since all nodes that stand in a syntactic relation are within the same sentence, querying syntactic structure is generally fast. An example tree and its full representation is given in Figure 1. Note that in this paper, we only consider the primary nodes and edges, even though we are in no fundamental way restricted to querying only this annotation level.

A set of interface relations provide a first level of abstraction over this representation. Direct dom-
“This has effects on the willingness to accept therapy.”

Figure 1: A tree from Tüba-D/Z and its Prolog representation.
TIGERSearch implements an alternative definition of linear precedence, where two left-corners are compared (König et al., 2003). It would be straightforward to implement this alternative.

3 Application & Comparison

Lai and Bird (2004) compare the expressiveness of query languages by formulating queries that test different aspects of a query language, such as the ability to constrain linear order and dominance, to use negation and/or universal quantification, and to separate context from the returned subgraphs. The queries have thus been designed to highlight strengths and weaknesses of different query languages in querying linguistic structure. Six of these queries – with categories changed to match the Tüba-D/Z corpus – are given in Table 1 and expressed in TIGERSearch query syntax in Table 2. Since TIGERSearch does not allow for negation to outscope existential quantification of nodes, queries Q2 and Q5 are not expressible (also see Marek et al. (2008) for more discussion). In addition, Q7 has two interpretations, depending on whether one wants to return NPs once for each PP in the context or just once altogether. TIGERSearch does not allow us to differentiate between these two interpretations.

Q1 & Q2 The implementation of domination, has_ancestor/2, performs database lookup. We therefore call it last in q1/1. To ensure the correct scope of the negation, lookup of A in q2/1 is explicit and outside the scope of negation-as-Prolog-failure \(+/-1\), whereas B is looked up inside its scope.

Q1 Find sentences that include the word sah.
Q2 Find sentences that do not include sah.
Q3 Find NPs whose rightmost child is sah.
Q4 Find NPs that contain an AdjP immediately followed by a noun that is immediately followed by a prepositional phrase.
Q5 Find the first common ancestor of sequences of an NP followed by a PP.
Q7 Find an NP dominated by a PP. Return the subtree dominated by that NP only.

Table 1: Query descriptions

| Query | Description |
|-------|-------------|
| Q1    | {cat="SIMPX"} ++ {word="sah"} |
| Q2    | (not expressible) |
| Q3    | #n1:[{cat="NX"}] > #n2:[{pos="NN"}] & #n1 >@r #n2 |
| Q4    | #nx:[{cat="NX"}] ++ #ax:[{cat="ADJX"}] & #nx ++ #n:[{pos="NN"}] & #nx >@l #px:[{cat="PX"}] & #px >@l #pxl & #ax >@r #axr & #axr . #n & #n . #pxl |

Table 2: TIGERSearch queries

Q3, Q4 The implementation of spans/3 relies on given nodes, which means that database lookup is performed before checking linear order constraints, explicitly in q3/1 and implicitly in q4_a/1. In addition, these constraints are expensive to check, so we make sure we postpone their evaluation as much as possible.

q3(A):-  
  has_cat(A,nx),  
  has_pos(B,nn),  
  is_under(B,A),  
  A, B, are_right_aligned(A,B).

q4_a(A):-  
  has_cat(A,nx),  
  has_cat(B,adjx),  
  has_pos(C,nn),  
  has_cat(D,px),  
  has_ancestor(B,A),  
  has_ancestor(C,A),  
  has_ancestor(D,A),  
  directly_precedes(B,C),  
  directly_precedes(C,D).

If we precalculate spans/3, the alternative order of checking dominance and linear precedence constraints becomes viable, as in q4_b/1.

q4_b(A):-  
  has_cat(A,nx,A_s),  
  has_cat(B,adjx,A_s),  
  has_pos(C,nn,A_s),  
  has_cat(D,px,A_s),  
  B,C,D, % (cont. on next page)
directly_precedes(B,C),
directly_precedes(C,D),
has_ancestor(B,A),
has_ancestor(C,A),
has_ancestor(D,A).

The procedural sides of Prolog make that these two alternatives are processed with considerable speed differences.

**Q5** The lowest common ancestor part of Q5 can be implemented by constraining the paths between two nodes and their common ancestor:

\[
q_5(A) : - \\
\text{has_cat}(B, nx, A_s), \\
\text{has_cat}(C, px, A_s), \\
B, C, \\
\text{precedes}(B, C), \\
\text{has_ancestor}(B, A, BA\_path), \\
\text{has_ancestor}(C, A, CA\_path), \\
\text{\+ (} \text{last}(BA\_path, D), \text{last}(CA\_path, D) \text{)}.
\]

**Q7** Precise control over the quantification of the two nodes in Q7 is achieved by using the built-in `once/1` predicate (~existential quantification) and by choosing different moments of database lookup for the two nodes.

\[
q_7\_a(A) : - \% \text{once for each np-pp pair} \\
\text{has_cat}(A, nx), \\
\text{has_cat}(B, px), \\
\text{has_ancestor}(A, B).
\]

\[
q_7\_b(A) : - \% \text{just once per np} \\
\text{has_cat}(A, nx), \\
\text{has_cat}(B, px), \\
A, \text{once(has_ancestor}(A, B)).
\]

### 4 Performance

In Table 3, we list wall-clock times for execution of each of the queries. These serve to demonstrate the fact that our straightforward use of Prolog results in a system that is not only flexible and with short development times, but that is also fast enough to be usable. We have also included TIGERSearch execution times for the same queries to give an idea of the speed of querying with Prolog.¹

Table 3 shows Prolog execution times fall well within usable ranges, provided we precalculate span/3 facts for queries that rely heavily on linear order. The non-declarative side of Prolog is most clearly seen in the difference between Q4-a and Q4-b – the latter constraint ordering is more than twice as fast. Even with precalculated span/3 facts, the whole corpus and query code uses less than 0.5Gbytes of RAM to run.

| Proto | # hits | T.Search | Precalc. spans |
|-------|--------|----------|----------------|
| Loading from source | 30 | 50 | |
| Loading precompiled | 3 | 4 | |
| Precalculating `span/3` | 90 | | |
| Q1 | 73 | 3 | 1 |
| Q2 | 65727 | | 1 |
| Q3 | 152669 | 33 | 10 | 4 |
| Q4-a | 8185 | 200 | 60 | 50 |
| Q4-b | | | 21 | |
| Q5 | 312753 | 196 | 70 | |
| Q7-a | 145737 | 6 | 8 |
| Q7-b | 119649 | 6 | |

Table 3: Rounded up wall-clock times in seconds.

To give an impression of scalability, we can report Prolog queries on a 40M tokens, dependency parsed corpus (Bouma et al., 2010). The setup requires about 13Gbyte of RAM on a 64-bit machine. Loading a corpus takes under a minute when pre-compiled. Due to first-argument indexing, time per answer does not increase much. Handling of larger corpora remains a topic for future work.

### 5 Conclusions

On the basis of six queries designed to highlight strengths and weaknesses of query languages, we have demonstrated that querying syntactically annotated corpora using Prolog is straightforward, flexible and efficient. Due to space constraints, the example queries have been rather simple, and many of the more interesting aspects of using a general purpose programming language like Prolog for corpus querying have not been dealt with, such as querying structures between and above the sentence, result categorization, on-the-fly annotation transformation, and the combination of annotation layers. For examples of these and other use cases, we refer the reader to Witt (2005), Bouma (2008), Bouma et al. (2010), and Bouma (Ms). This paper’s Prolog code and further conversion scripts will be available from the author’s website.

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