

An integrated framework for treebanks and multilayer annotations

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Abstract

Treebank formats and associated software tools are proliferating rapidly, with little consideration for interoperability. We survey a wide variety of treebank structures and operations, and show how they can be mapped onto the annotation graph model, and leading to an integrated framework encompassing tree and non-tree annotations alike. This development opens up new possibilities for managing and exploiting multilayer annotations.

1. Introduction

There is a proliferation of treebanks, each with its own format and software tools. Examples include the Penn Treebank, the Prague Dependency Treebank, the Susanne Corpus, and treebanks of German, Spanish, Portuguese, French, Italian, Turkish, Polish, Bulgarian, Old English, and the recent development of Korean, Arabic and Chinese treebanks. Each treebank is associated with tools for annotation, search, and rendering. Despite the obvious benefits of interoperability, the tools associated with any given treebank rarely escape the confines of its own project. Moreover, treebanks both require and invite multilayer capabilities. Parsers depend on tokenizers, taggers, and morphological analyzers. Layers of annotation such as sense tagging and named entity tagging are built on top of treebanks. Disfluency tagging, as combined with treebanking in switchboard, adds another layer of indirection between parses and the surface string. In short, necessity dictates the integration of treebanks into a general multilayer annotation system, coupled with the development of a logical model and corresponding API which address the linguistic demands of treebanking.

Linguistically, the development of such a framework leads to some interesting challenges. Grammars and theories of syntax yield structures which stretch the simplistic notion of trees over surface strings (such as empty constituents, encoding of deep syntactic structure, pure dependency structures, etc). As advances in information extraction and language understanding bridge syntax and semantics, syntactic trees are growing various forms of semantic annotation. A case in point is the English Propbank, in which sentences are annotated with many fine grained semantic relations (or propositions) whose arguments in turn point to relevant syntactic substructures such as individual nodes or trace chains. The design and development of a system which aptly addresses these issues is certainly non-trivial.

In this paper we examine conventional phrase structure trees, dependency trees, and semantic trees. In each of these categories, we first survey the data formats and editing operations, outline an abstract API for the structural operations involved, and describe an implementation with annotation graphs.

A variety of treebank formats and models are covered by the survey. Sources of this variety are both linguistic and computational. On the linguistic side, languages may permit a greater or lesser degree of word-order freedom. In some cases, the conventional tree representation requires crossing branches. This happens to a limited extent in English, with phenomena such as adverbials and extraposition. However it is pervasive in languages having rich case-marking systems such as Czech. Treebanks for these languages typically use a dependency representation instead of the conventional tree representation. On the computational side, projects may have different prior commitments to file formats. The file format may simply be derived from the original Penn Treebank format, or be a novel plain text format, or be one of a variety of possible XML representations. To a considerable extent, these formats are inter-translatable. Another source of variation is the kind of information which is annotated, and the survey includes some recent work on semantic annotation and predicate-argument tagging.

After reviewing a diverse set of treebank projects, we consider the kinds of tree-manipulation operations they require, leading to an inventory of elementary tree operations. These operations may be composed with each other to perform complex tree manipulations. Next, we show how the operations can be implemented in the annotation graph model (Bird and Liberman, 2001). This mapping has an important consequence for multilayer annotations, for now treebanks can co-exist with a variety of other annotation types, such as prosodic and discourse level annotations. With all the annotations expressed in the same data model, it becomes a straightforward matter to investigate the relationships between the various linguistic levels. Modeling the interaction between linguistic levels is a central concern both for the study of human communicative interaction, and for the construction of naturalistic spoken language dialogue systems.

This inventory of elementary tree operations leads to a new application programming interface for treebanking, built on top of the existing annotation graph API which is implemented in the Annotation Graph Toolkit (?). This implementation work is ongoing, and will be released under an open source license with AGTK.

2. Conventional Syntax Trees

2.1. Survey

The Penn Treebank was the first syntactically annotated corpus, and consists of one million words of manually parsed text from the Wall Street Journal (Marcus et al., 1993). An example of the Treebank format is shown below.

```
((S (NP-SBJ-1
  (NP Yields)
  (PP on
    (NP money-market mutual funds)))
  (VP continued
    (S (NP-SBJ *-1)
      (VP to
        (VP slide))))
  (PP-LOC amid
    (NP signs
      (SBAR that
        (S (NP-SBJ portfolio managers)
          (VP expect
            (NP (NP further declines)
              (PP-LOC in
                (NP interest rates))))))))))
.))
```

The empty constituents, called *traces*, represent various forms of syntactic movement that serve to normalize the underlying grammar. In this example there is a trace *-1, immediately preceding the infinitive *to slide*. This node is an empty constituent and refers to the phrase *Yields on money-market mutual funds*, as is indicated by the fact that both nodes share the -1 label. The movement of this nominal phrase to the nominal position in the infinitival S clause normalizes this clause so that its constituents are NP followed by VP. In the Penn Treebank, traces are also used to indicate WH and other pronominal movement. Full details can be found in the annotation guidelines.

The data in the Penn Treebank were created with an Emacs mode called *parser-mode*. The tool parses files of bracketed text in various stages of the corpus development, starting with output from the automatic parser. Editing operations add function tags, relabel, coindex, insert, and delete constituents, and relocate subtrees from constituent to constituent. Each of these operations is associated with a handful of constraints, such as preservation of the surface string. Notably, this constraint on the tree editing operations leads to a set of tree editing functions for the user closed under the following structural manipulations: promotion of a leftmost or rightmost constituent, insertion of a constituent, insertion/deletion of empty constituents, and the movement of a constituent to its right (left, respectively) sibling's leftmost (rightmost, respectively) child position.

In the rest of this section we consider various extensions to the Penn Treebank format.

The Switchboard corpus of conversational speech (Godfrey et al., 1992) was later enriched with information about breath groups and disfluencies (Taylor, 1995). This new information is simple enough on its own, e.g.:

```
B.22: Yeah, / no one seems to be adopting it. /
Metric system, [ no one's very, + F uh, no one wants ]
it at all seems like. /
```

However, the disfluency information was also superimposed on the syntactic trees, resulting in extremely complex structures such as the following:

```
((S (NP-SBJ-1 no one)
  (VP seems
    (S (NP-SBJ *-1)
      (VP to (VP be (VP adopting (NP it)))))) .
    E_S))
((S (NP-TPC Metric system) ,
  (S-TPC-1 (EDITED (RM [
    (S (NP-SBJ no one)
      (VP 's (ADJP-PRD-UNF very))) ,
      (IP +)) (INTJ uh) ,
      (NP-SBJ no one)
      (VP wants (RS ]) (NP it) (ADVP at all)))
    (NP-SBJ *)
    (VP seems (SBAR like (S *T*-1))) . E_S))
```

This format demonstrates the acute problem that arises when we attempt to force one linguistic structure into a format that was designed for representing a completely different kind of structure.

A more conservative extension of the Penn Treebank format is the UAM Spanish Treebank (Moreno et al., 2000). In this format, the treebank node labels have a record structure:

```
(S
  (NP SUBJ ID-1 SG P3
    (ART "<El>" "e1" DEF MASC SG)
    (N "<Gobierno>" "Gobierno" SG P3))
  (VP TENSED PRES IND SG P3
    (V "<quiere>" "querer" TENSED PRES IND SG P3)
    (CL INFINITIVE OBJ1
      (NP * SUBJ REF-1)
      (VP UNTENSED INFINITE
        (V "<subir>" "subir" UNTENSED INFINITE)
        (NP OBJ1
          (ART "<los>" "e1" INDEF MASC PL)
          (N "<impuestos>" "impuesto" MASC PL))))))
```

Emacs is used for creating the structures, and a tree display tool is used for verification. Various other tools check for well formedness (e.g. of the node attributes and grammatical structures).

Other treebanks use the same conventional nested structure, but with a different syntax. For example, consider the following fragment from the Portuguese Treebank [<http://cgi.portugues.mct.pt/treebank/>].

```
<s>
SOURCE: CETEMPblico n=1 sec=clt sem=92b
C1-2 0 7 e Meio um ex-libris da noite algarvia.
A1
STA:fc1
SUBJ:np
=>N:art(M S) 0
=H:prop(M S) 7_e_Meio
P:v-fin(PR 3S IND)
SC:np
=>N:art(<arti> M S) um
=H:n(M P) ex-libris
=N:<pp
=H:prp(<sam->) de
==P:<np
===>N:art(<-sam> F S) a
===H:n(F S) noite
===N:<adj(F S) algarvia
.
</s>
```

Emacs macros are used to edit the data, with operations for insertion and deletion of nodes as well as increasing and decreasing the depth of the nodes in the tree. Some tree structural constraints are enforced: whenever a node's depth is increased, so are all of its constituents, and all nodes must have a label.

Finally, XML is now being used to represent treebanks. The simplest and most direct way to do this is to use element nesting to represent hierarchy. An example of this

use of XML is provided by the French Treebank (Abeille et al., 2000), and we show a translation below. [http://treebank.linguist.jussieu.fr/].

```
<S>
  <NP>The proportion:NC
    <PP>of:P students:NC</PP>
  </NP>
  <PP>compared to:P
    <NP>the population:NC
      <PP>of:P
        <NP>our:D country:NC</NP>
      </PP>
    </NP>
  </PP>
  <PONCT>,:PONCT</PONCT>
[rest of sentence elided]
</S>
```

It is notable that the part of speech labels are structured by convention in the embedded text rather than by using XML markup.

2.2. API

Many conventional tree operations, such as adding, moving or deleting a subtree, also modify the sequence of terminals (or leaves). In syntactic annotation, this sequence is usually fixed, since it is an external artefact which is not subject to editing. Therefore, we need to provide a complete inventory of tree operations which preserve the terminal string.

Many treebanking projects incorporate a preprocessing phase, which may create some low-level constituents (such as noun phrase chunking) or may create an entire parse of the sentence. Therefore, the inventory of tree operations must be capable of reorganizing the structure of an existing tree, not just building a tree from scratch.

In this section we define an inventory of elementary tree operations which preserve the terminal string and which is sufficiently expressive to permit any well-formed phrase-structure tree to be built over the terminal string, beginning either from an unparsed string or from a previously parsed string. The inventory is inspired by the various operations that are provided by existing tree annotation tools. We consider only those operations which modify the structure of a tree (as opposed to the operations for modifying node labels).

Each operation requires a tree t along with a selected node n . We write t_n for the tree t oriented at node n .

move down $m_{\downarrow}(t_n)$ This creates a new node \bar{n} in the position formerly occupied by n , and makes n the sole child of \bar{n} . The new node \bar{n} is an unlabeled non-terminal symbol. For example, under this operation, the tree on the left becomes the tree on the right:



move up $m_{\uparrow}(t_n)$ This applies only if n has no siblings, deleting \bar{n} , the parent of n . Node n now occupies the former position of \bar{n} .



promote right $m_{\nearrow}(t_n)$ This applies only if n has at least one sibling, but no siblings to its right. Node n is moved up to the position immediately to the right of its parent \bar{n} .



promote left $m_{\nwarrow}(t_n)$ mirror image operation of $m_{\nearrow}(t_n)$.

demote right $m_{\searrow}(t_n)$ This applies only if n has a sibling to the right \bar{n} , and \bar{n} is a non-terminal. Node n becomes the leftmost child of \bar{n} .



demote left $m_{\swarrow}(t_n)$ mirror image operation of $m_{\searrow}(t_n)$

All operations preserve the orientation of the tree; the selected node remains selected after the operation. Observe that all operations have inverses: $m_{\uparrow\uparrow}(t_n) = t_n$; $m_{\nearrow\swarrow}(t_n) = t_n$; $m_{\nwarrow\searrow}(t_n) = t_n$. All of these operations preserve the order of the terminal string, and all are elementary as none can be expressed as a combination of any others.

More complex operations can be built from these elementary operations. For instance, in a particular user interface, it may be possible for a user to select a set of contiguous terminals and non-terminals, and group them under a new non-terminal:



This can be done with a sequence of operations: $m_{\downarrow}(t_C), m_{\swarrow}(t_D)$. This is a generalized **move down** operation, for which there is an corresponding generalized **move up**.

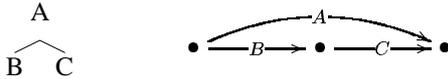
Note that there is another pair of elementary operations not discussed above, that could be called trace-insertion and trace-deletion. These involve the creation/deletion of a zero width element in the terminal sequence (or equivalently, of a “non-terminal” which dominates no terminal).

2.3. Implementation

Bird and Liberman have developed a model for expressing the logical structure of linguistic annotations, and have demonstrated that it can encode a great variety of existing

annotation types (Bird and Liberman, 2001). An annotation graph is a directed acyclic graph where edges are labeled with fielded records, and nodes are (optionally) labeled with time offsets. The model is implemented in the Annotation Graph Toolkit and used as the basis for several annotation tools, including one for editing conventional syntax trees (?; Bird et al., 2002).

Annotation graphs can most easily be used to represent trees using the so-called “chart construction,” in which each tree node is mapped to an annotation graph arc. An example tree and its corresponding annotation graph are shown below:

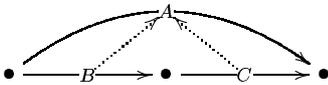


This approach has two shortcomings. First, in the situation where a non-terminal has a single child, the annotation graph is ambiguous. Thus, the following two simple trees have the same annotation graph representation:



The second shortcoming is that the annotation graph representation cannot express discontinuous constituency (i.e. trees that contain crossing lines).

Both problems can be addressed by using equivalence classes or cross references (Bird and Liberman, 2001). We depict the relation between a child arc and its parent using a dotted arrow, as shown below. While this is partly redundant, it involves minimal overhead.

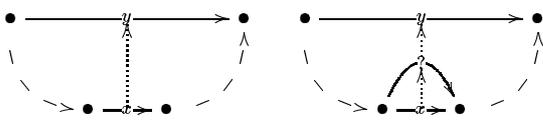


The elementary tree operations that we discussed above can now be implemented directly in terms of the annotation graph model. We begin with some definitions. Let $x.start$ (resp. $x.end$) be the start (resp. end) anchor of annotation x . Let \bar{x} be x 's parent (undefined if x has no parent). Define x 's right sibling as follows:

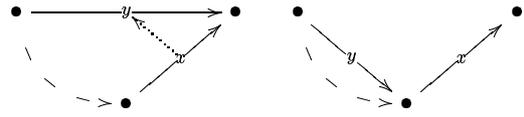
$$\vec{x} = \begin{cases} y & \text{if } y.start = x.end, \bar{x} = \bar{y} \\ \text{undefined} & \text{otherwise} \end{cases}$$

Annotation graph arcs are typed, and our implementation requires two types, namely “word” for word arcs (the orthographic string), and “phrasal” for the phrasal arcs. Now we can define the above tree operations in terms of annotation graphs.

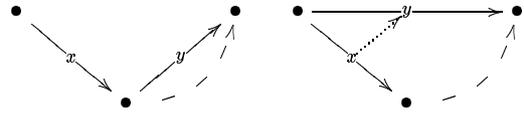
move down Given the arc x , insert a new coterminous arc which becomes the parent of x .



promote right Move a rightmost child to the right, out of the subtree; x 's parent (y) becomes x 's left sibling. Note that y must be a phrasal arc.



demote right Move a subtree right, to become the leftmost daughter; x 's right sibling y becomes x 's parent. Note that y must be a phrasal arc.



Observe that none of these operations alter the content or arrangement of the word arcs.

3. Dependency Treebanks

Dependency grammar is an approach to syntactic representation in which words are organized into a hierarchy using a binary “dependency” relation. Dependency trees pose a different set of challenges for representation and manipulation, as discussed in this section.

3.1. Survey

The Turin University Treebank (Bosco et al., 2000) provides an example of a pure dependency structure, showing a binary relation between the words. The treebank consists of 500 sentences, available from [http://www.di.unito.it/~tutreeb/]. A sample follows

```
1 E' (ESSERE VERB MAIN IND PRES INTRANS 3 SING) [0;TOP-VERB]
2 italiano (ITALIANO ADJ QUALIF M SING) [1;PREDCOMPL-SUBJ]
3 , (# PUNCT) [1;OPEN-PARENTHETICAL]
4 come (COME CONJ SUBORD MOD+TEMPO) [1;PREPMOD]
5 progetto (PROGETTO NOUN COMMON M SING) [4;PREPARG]
6 e (E CONJ COORD) [5;COORD]
7 realizzazione (REALIZZAZIONE NOUN COMMON F SING REALIZZARE TRANS) [6;COORD-2ND]
8 , (# PUNCT) [1;CLOSE-PARENTHETICAL]
9 il (IL ART DEF M SING) [1;SUBJ]
10 primo (PRIMO ADJ ORDIN M SING) [11;ADJCMOD-ORDIN]
11 porto (PORTO NOUN COMMON M SING) [9;NBAR]
12 turistico (TURISTICO ADJ QUALIF M SING) [11;ADJCMOD-QUALIF]
13 dell' (DI PREP MONO) [11;PREPMOD-LOC-SPEC]
13.1 dell' (LA ART DEF F SING) [13;PREPARG]
14 Albania (|Albania| NOUN PROPER) [13.1;NBAR]
```

This format consists of: the index of the word in the sentence; the word; parentheses containing the lemma and its morphosyntactic features; brackets containing a reference to the parent of this dependent and the name of the grammatical relation.

The Prague Dependency Treebank (PDT) (Hajičová, 2000) is a corpus with three distinct layers of annotation – morphological, analytic (syntactic), and tectogrammatical. We won't address the morphological annotation in order to focus on more tree and treelike structures. Both analytic and tectogrammatical structures are represented as hybrid dependency trees, mixing a pure dependency relation over the words with a minimum of constituents. This representation is indicative of the underlying grammatical theory, functional generative grammar. As the corpus uses an extensive tagset and views annotations via a special tool, we refer the reader to the url above for data

samples. PDT has an online tree viewer available (see [http://shadow.ms.mff.cuni.cz/pdt/]).

The editor for the analytic level restricts the user to operations that maintain a well formed dependency tree with constituent nodes mixed in. In accordance with the relatively free word order in Czech, the tool allows movement of subtrees to arbitrary nodes, along with the creation and deletion of constituents.

Further discussion of the tectogrammatical annotation is deferred to section §4.

The TIGER Project uses a model intermediate between conventional trees and dependency trees, represented in XML (Mengel and Lezius, 2000). The dependency structure is represented as a collection of nodes (n elements) and words (w elements) connected using edges.¹ A simplified version is shown below:

```
<n id="n1_500" cat="S">
  <edge href="#id(w1)"/>
  <edge href="#id(w2)"/>
</n>

<w id="w1" word="the"/>
<w id="w2" word="boy"/>
```

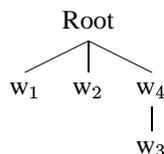
This format can represent arbitrary digraphs. The linear ordering of the children of any given node is represented by the file order of the corresponding elements (or by the internal structure of node identifiers).

An important property of this format is its extensibility. For instance, edges can be typed (with an attribute `type`, and coreference is marked using edges having `type="semantic"`. Edges can also be labeled with the grammatical role of their dependent (e.g. `label="HD"` for the head daughter).

3.2. API

An API for the structural editing of pure dependency trees is remarkably simple. We start with an arbitrary root node, and make all the words dependent upon this node. From this point, we can create any dependency relation by iterative application of a single **move subtree** operation, which takes a source node other than the root and a target node and makes one dependent upon the other. Thus, after an annotator identifies a single dependency, we may see a tree as follows.

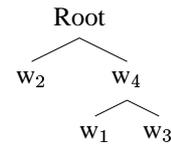
Tree 1



Since the word order is free, it may be that w_1 is dependant on w_4 . To accomodate for this, we can either let the branches of the tree cross and retain the terminal order, or we can rearrange the terminal order so that the branches don't cross. After **move subtree** is applied to source w_1 and target w_4 , we would attain the following tree

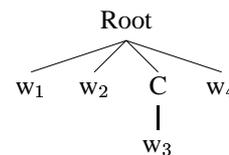
¹A more abstract version of the same idea is described by Ide and Romary (2000).

Tree 2



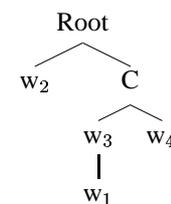
But some systems may use an underlying grammar which mixes pure dependency structure and a constituent based approach, as is found in the PDT. Such an approach allows the insertion of constituent nodes, equivalent to the **move down** operation described for basic trees in §2.2.

Tree 3



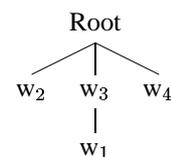
Such a constituent may then interact with the others just like the pure dependency nodes associated with a single word. For example, after two **move subtree** operations, we may end up with the following.

Tree 4



A user interface may facilitate a **delete** command which takes all the children of a proper constituent node and moves them to the parent of the deleted node, deleting the resulting empty constituent.

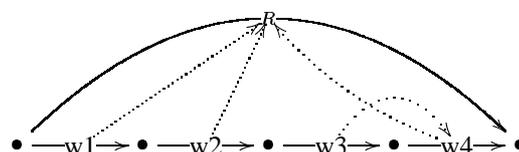
Tree 5



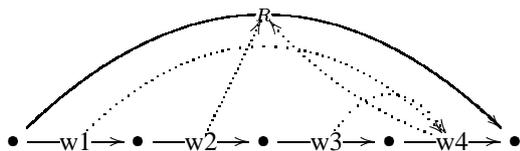
3.3. AG Implementation

To implement editable dependency trees with annotation graphs, we begin by defining a root node as an arc which spans the length of the sentence. As with basic trees, each node in this tree has a parent pointer which by default points to the root. The primary editing operation is **move subtree**, which takes a tree and two distinguished nodes (w_1 and w_2), setting the parent of w_1 to w_2 . This operation is sufficiently expressive to define any structural editing operation on a pure dependency tree.

Below we show a simple AG implementation of the editing operation **move subtree** with source w_1 and target w_4 .



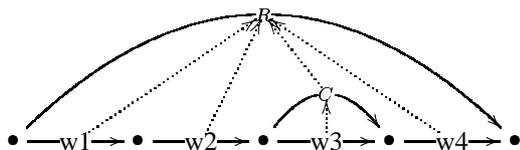
Tree 1



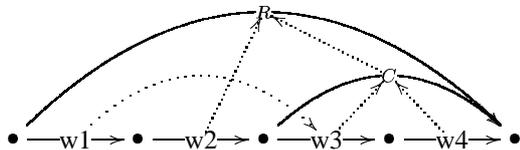
Tree 2

For hybrid systems which allow constituents, we want to constrain the length of the constituent arcs as much as possible. In spite of the fact that setting the length of these arcs to a constant would reduce overhead, we take this approach in anticipation that the quasi-ordering over annotations will provide a more substantial basis for layered annotation than following pointers.

We proceed by superimposing the implementation of **move up** and **move down** directly on top of this and extend the definition of **move subtree** so that it works on arbitrary constituents and maintains a well formed hybrid structure. We have developed an algorithm for this which requires the ability to distinguish between words and proper constituents as well as between proper constituents and the root node. We accomplish this simply by checking the type of the arcs involved. We illustrate these extensions showing annotation graph representations of trees 3 and 4 below.



Tree 3



Tree 4

4. Treebanks and Semantic Trees

4.1. Survey

While many semantic relations are described in treebanks, predicate argument structure remains the most commonly and systematically explored. Each treebank formulates some schema to represent the argument structure of clausal verbs, and indeed this information is to some extent explicit in the parse itself. To complete the picture, the nodes of the parse tree are often decorated with labels denoting more abstract relations. In some cases, an entire extra level of annotation is supplied separately in a parallel corpus, as in the Prague Dependency Treebank (PDT). In this section we catalog a variety of predicate argument schemas, observing commonalities, and exploring requirements inherent in capturing predicate argument structures with treebanks.

The Susanne Corpus, developed as a by-product of a parsing schema for unambiguous syntactic annotation, provides perspicuous coverage of predicate argument structure of clausal verbs. It decorates nodes with a variety of function tags, though it restricts their usage to immediate constituents of clauses.

```
[Nns:s John] expected [Nns:O999 Mary] [Ti:o [s999 GHOST]
to admit [Ni:o it]]
```

The example above is similar to the Penn Treebank example in that it requires coindexed nodes, but unlike the English Propbank, it does not use references to syntactic nodes. The complexity of predicate argument well-formedness constraints together with a close coupling of syntactic and argument relations are noteworthy by-products of embedding these relations in the syntactic schema.

We examine the tectogrammatical level of annotation in the PDT, as it represents a more abstract linguistic structure closely related to predicate argument structure. These trees are of the hybrid dependency variety described in §3. The tectogrammatical dependency trees are roughly parallel to the analytic ones and their structure is derived by deleting and adding nodes to the analytic trees. Spurious elements of the surface string are removed and dropped arguments are added. While these operations produce the structure of the tree, edge labels such as *actor*, *patient*, *addressee*, *location* denote semantic roles and modifiers.

The Penn Treebank uses attributes of phrase labels in conjunction with grammatical relations to describe predicate argument structure. In the example below, the last nominal phrase is decorated with a LGS tag denoting logical subject. The syntactic environment indicates the remaining parts of the argument structure, with the head verb taking the role of the predicate and the preceding noun phrase taking on the role of direct object.

```
(S
(NP-SBJ (PRP they) )
(VP (VBP attribute)
(NP (-NONE- *T*-1) )
(ADVP-MNR (RB directly) )
(PP-CLR (TO to)
(NP
(NP (NNS forces) )
(VP (VBN controlled)
(NP (-NONE- * ) )
(PP (IN by)
(NP-LGS (NNP PLO) (NNP Chairman)
(NNP Yasser) (NNP Arafat)))))))
```

Algorithms for extracting predicate argument structure, even from such rich syntactic data, are faced with numerous complexities and ambiguities. For example, ghost constituents without explicit referents should be resolved, disjoint constituents may form arguments, prepositional phrases may or may not constitute arguments, and this information tends to be lexicalized over the predicates (Palmer and Rosenzweig, 2001).

As a next step, the English Propbank is under development, using the predicate argument tagger mentioned above and hand-correcting the output. The example of this data below shows that the entire argument relation is explicitly marked. Note that the argument label ARG1 implicitly refers to specific syntactic nodes rather than the surface string, in this case resolving the passive trace.

```
... they attribute directly to forces controlled by PLO Chairman Yasser Arafat .
```

```
rel: controlled
ARG1: *trace* -> forces
ARG0-by: PLO Chairman Yasser Arafat
```

Additionally, the constituents of a particular argument may be disjoint as the utterance argument of a sentence like

"I'm going home", John said, "so I can get some sleep".

```
rel:      said
ARG0:     John
ARG1:     [I'm going home] [so I can get some sleep]
```

Phrasal predicates, such as *give up*, are almost never dominated by a single node, and so are treated similarly.

Another source of variation occurs with conjunctions over more than one argument. For example, the sentence below yields two propositions.

John drove Mary to the store and Mike home

```
rel:      drove
ARG0:     John
ARG1:     Mary
ARG2-to:  the store
```

```
rel:      drove
ARG0:     John
ARG1:     Mike
ARG2:     home
```

In the English propbank, we witness argument structure using *references to syntactic annotation*, a one to many relation from arguments to constituents (also vice versa), and the marking of sentence-local equivalences to resolve grammatical motion.

In conclusion, capturing predicate argument structure is of definite interest in the development of treebanks. In all the cases examined, an extra level of indirection from the syntactic structure is required. The English Propbank makes use of explicit references to syntactic constituents, the Susanne Corpus employs highly structured decoration of nodes, inducing relations between the nodes, and the PDT utilizes *differences* against the syntactic structure, replacing analytic with semantic functions and recovering dropped arguments as necessary.

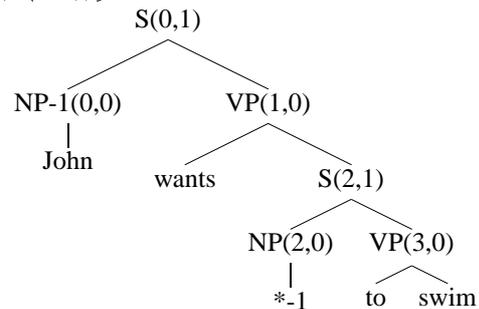
4.2. API

As predicate argument structure has quite varied treatment, we'll look at both argument structure as treated with the Penn Treebank and argument structure as in the Prague Dependency Treebank. However, we will restrict ourselves to working with predicate argument data as derived from syntactic data rather than as derived from scratch in order to best address the extant tagging efforts in this domain.

In the case of the English Propbank, the operations are not editing operations on trees *per se*, but operations on relations between constituents in a given tree. For each instance of a predicate in some parsed text, we can characterize a proposition as a 4-tuple consisting of the predicate, its arguments predicate, its modifiers, and an equivalence relation over the nodes in the parse tree. Each of the arguments or modifiers consists of a label and a non empty set of constituents, denoting its surface string content. While this set of constituents is often singleton, any non-singleton set of constituents represents a surface string which is not dominated by a single node (this occurs with phrasal verbs and often with the utterance argument in verbs of saying). The equivalence relation over the nodes of the parse serve to recover dropped arguments (as occurs with empty constituents) and sentence-local antecedents of pronouns. The case of conjunctions whose conjuncts are not dominated by a single syntactic node is handled by associating multiple

propositions with the instance of the predicate (or lemma) at hand.

The editing operations for the annotation process consist of associating argument labels (e.g. *arg0 ... argN*) with constituents and identifying equivalent nodes of the parse. For example, annotating the argument structure of the predicate *swim* on the parse tree below (with nodes identified in terms of their leftmost terminal number and height) would yield a single proposition whose predicate is $\{(3, 0)\}$, whose arguments consist of $\{(Arg0, \{(2, 0)\})\}$, whose modifiers are \emptyset , and whose equivalences are $\{((2, 0), (0, 0))\}$.



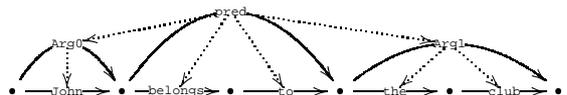
In the PDT tectogrammatical annotation, the operations are structurally similar to those of the analytic annotation, except that dropped arguments are added to the structure and words can be deleted. We defer addressing these issues for future work.

4.3. Semantic Implementation

We describe an implementation of propbank annotation with annotation graphs. Given an annotation graph parse of a basic tree as described in §2.3., we first define the predicating lemma over a set of constituents as an arc whose start point is the minimum of the start points of the associated constituents and whose end point is the maximum of the end points of the associated constituents. For example, if the sentence is

α_1 John α_2 belongs α_3 to α_4 the α_5 club α_6 and α_n is an annotation graph anchor, and our predicating lemma is *belongs to*, then the arc defining our predicate will start at α_2 and end at α_4 . Just as pointers were added for basic tree constituents, we add sets of pointers to this arc to the constituents containing *belong* and *to*. This arc gets a label indicating that it is the predicating label, say *pred*.

The arguments and modifiers of the lemma are denoted similarly, with an appropriate label for the item in question. The end-product is diagrammed below:



Finally, we specify the constituent equivalences by noting all the non singleton equivalence classes whose members are among those associated with a label.

5. Discussion and Further Work

Treebank formats and associated software tools are proliferating rapidly, with little consideration for interoperability. We have surveyed a wide variety of treebank structures

and operations, and shown how they can be mapped onto the annotation graph model. This has two important ramifications, distinguishing our work from previous work. First, the false dichotomy between conventional trees and dependency trees goes away; both types along with hybrid structures can be represented in a uniform framework. Second, a single comprehensive framework is used for both tree and non-tree annotations, an integration that greatly facilitates multilayer queries.

Several aspects of the survey and the analysis are incomplete, and we list just three areas here. First, there is another class of treebanks used for grammar development, usually consisting of hand-crafted sentences illustrating a particular linguistic phenomenon. Each sentence is associated with the correct analysis, expressed in a particular syntactic formalism such as HPSG (Pollard and Sag, 1994). An example of this kind of corpus is the HPSG Treebank for Polish (Marciniak et al., 2000). Representing such treebanks using annotation graphs would require a more expressive model of arc labels than is currently permitted (namely attribute-value matrices).

A second open question is in the area of bidirectionality. Texts may involve a mixture of directionality, such as an Arabic text containing stretches of English. In such texts, there is no longer a transparent relationship between the sequence of orthographic words and their sequence in a spoken utterance; the linguistic representation needs to encompass both orderings somehow, even though annotation graphs force us to choose one of the orderings as primary.

A third area for further investigation is query. Now that the annotations are all expressed in the same framework, how do we want to express queries over the annotations? A range of tree query languages have been proposed, as discussed by (?). It is highly unlikely that a single tree query language will ever meet the requirements of all research projects. Instead, we plan to investigate a number of tree query languages and their mapping to a low-level annotation graph query language, such as the one proposed by Bird et al. (2000).

In this article we have surveyed treebanks, examining their data formats and editing operations. We have found that the existing treebank models do not accommodate overlaid annotation very well. We have developed abstract APIs for treebanking operations which encompass the requirements of conventional trees, dependency trees, and even predicate argument structure. We have described how these APIs may be directly implemented using annotation graphs. This facilitates multi-layered annotations and leverages the array of annotation types that are already supported by the annotation graph model.

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