Annotation Graphs as a Framework for Multidimensional Linguistic Data Analysis

Steven Bird and Mark Liberman
Linguistic Data Consortium, University of Pennsylvania
3615 Market St, Philadelphia, PA 19104-2608, USA
{sb,myl}@ldc.upenn.edu

Abstract
In recent work we have presented a formal framework for linguistic annotation based on labeled acyclic digraphs. These ‘annotation graphs’ offer a simple yet powerful method for representing complex annotation structures incorporating hierarchy and overlap. Here, we motivate and illustrate our approach using discourse-level annotations of text and speech data drawn from the CALLHOME, COCONUT, MUC-7, DAMSL and TRAINS annotation schemes. With the help of domain specialists, we have constructed a hybrid multi-level annotation for a fragment of the Boston University Radio Speech Corpus which includes the following levels: segment, word, breath, ToBI, Tilt, Treebank, coreference and named entity. We show how annotation graphs can represent hybrid multi-level structures which derive from a diverse set of file formats. We also show how the approach facilitates substantive comparison of multiple annotations of a single signal based on different theoretical models. The discussion shows how annotation graphs open the door to wide-ranging integration of tools, formats and corpora.

1 Annotation Graphs
When we examine the kinds of speech transcription and annotation found in many existing ‘communities of practice’, we see commonality of abstract form along with diversity of concrete format. Our survey of annotation practice (Bird and Liberman, 1999) attests to this commonality amidst diversity. (See [www.ldc.upenn.edu/annotation] for pointers to online material.) We observed that all annotations of recorded linguistic signals require one unavoidable basic action: to associate a label, or an ordered sequence of labels, with a stretch of time in the recording(s). Such annotations also typically distinguish labels of different types, such as spoken words vs. non-speech noises. Different types of annotation often span different-sized stretches of recorded time, without necessarily forming a strict hierarchy: thus a conversation contains (perhaps overlapping) conversational turns, turns contain (perhaps interrupted) words, and words contain (perhaps shared) phonetic segments. Some types of annotation are systematically incommensurable with others: thus disfluency structures (Taylor, 1995) and focus structures (Jackendoff, 1972) often cut across conversational turns and syntactic constituents.

A minimal formalization of this basic set of practices is a directed graph with fielded records on the arcs and optional time references on the nodes. We have argued that this minimal formalization in fact has sufficient expressive capacity to encode, in a reasonably intuitive way, all of the kinds of linguistic annotations in use today. We have also argued that this minimal formalization has good properties with respect to creation, maintenance and searching of annotations. We believe that these advantages are especially strong in the case of discourse annotations, because of the prevalence of cross-cutting structures and the need to compare multiple annotations representing different purposes and perspectives.

Translation into annotation graphs does not magically create compatibility among systems whose semantics are different. For instance, there are many different approaches to transcribing filled pauses in English – each will translate easily into an annotation graph framework, but their semantic incompatibility is not thereby erased. However, it does enable us to focus on the substantive differences without having to be concerned with diverse formats, and without being forced to recode annotations in an agreed, common format. Therefore, we focus on the structure of annotations, independently of domain-specific concerns about permissible tags, attributes, and values.

As reference corpora are published for a wider range of spoken language genres, annotation work is increasingly reusing the same primary data. For instance, the Switchboard corpus [www.ldc.upenn.edu/Catalog/LDC93S7.html] has been marked up for disfluency (Taylor, 1995). See [www.cis.upenn.edu/~treebank/samples.html] for an example, which also includes a
separate part-of-speech annotation and a Treebank-style annotation. Hirschman and Chinchor (1997) give an example of MUC-7 coreference annotation applied to an existing TRAINS dialog annotation marking speaker turns and overlap. We shall encounter a number of such cases here.

The Formalism

As we said above, we take an annotation label to be a fielded record. A minimal but sufficient set of fields would be:

- **type** this represents a level of an annotation, such as the segment, word and discourse levels;
- **label** this is a contentful property, such as a particular word, a speaker’s name, or a discourse function;
- **class** this is an optional field which permits the arcs of an annotation graph to be co-indexed as members of an equivalence class.

One might add further fields for holding comments, annotator id, update history, and so on.

Let $T$ be a set of types, $L$ be a set of labels, and $C$ be a set of classes. Let $R = \{(t, l, c) \mid t \in T, l \in L, c \in C\}$, the set of records over $T$, $L$, $C$. Let $N$ be a set of nodes. Annotation graphs (AGs) are now defined as follows:

**Definition 1** An annotation graph $G$ over $R, N$ is a set of triples having the form $\langle n_1, r, n_2 \rangle$, $r \in R$, $n_1, n_2 \in N$, which satisfies the following conditions:

1. $\langle N, \{\langle n_1, n_2 \rangle \mid \langle n_1, r, n_2 \rangle \in A\}\rangle$ is a labelled acyclic digraph.
2. $\tau : N \rightarrow R$ is an order-preserving map assigning times to (some of) the nodes.

XML is a natural ‘surface representation’ for annotation graphs and could provide the primary exchange format. A particularly simple XML encoding of the above structure is shown below; one might choose to use a richer XML encoding in practice.

```
<annotation>
  <arc>
    <begin id=1 time=52.46>
      <label type="W" name="oh">
        <end id=2>
      </label>
    </begin>
  </arc>

  <arc>
    <begin id=2 time=53.14>
      <label type="W" name="okay">
        <end id=3>
      </label>
    </begin>
  </arc>

  <arc>
    <begin id=1 time=52.46>
      <label type="D" name="IOS:Commit">
        <end id=3 time=53.14>
      </label>
    </begin>
  </arc>
</annotation>
```

2 AGs and Discourse Markup

2.1 LDC Telephone Speech Transcripts

The LDC-published CALLHOME corpora include digital audio, transcripts and lexicons for telephone conversations in several languages, and are designed to support research on speech recognition [www.ldc.upenn.edu/Catalog/LDC96S46.html]. The transcripts exhibit abundant overlap between speaker turns. What follows is a typical fragment of an annotation. Each stretch of speech consists of a begin time, an end time, a speaker designation, and the transcription for the cited stretch of time. We have augmented the annotation with + and * to indicate partial and total overlap (respectively) with the previous speaker turn.

```
<annotation>
  <arc>
    <begin id=1 time=52.46>
      <label type="W" name="oh">
        <end id=2>
      </label>
    </begin>
  </arc>

  <arc>
    <begin id=2>
      <label type="W" name="okay">
        <end id=3 time=53.14>
      </label>
    </begin>
  </arc>

  <arc>
    <begin id=1 time=52.46>
      <label type="D" name="IOS:Commit">
        <end id=3 time=53.14>
      </label>
    </begin>
  </arc>
</annotation>
```
15 16 W/and 31 994.19 32 994.46 speaker/B 994.65 W/%um 33 996.51 19 20 996.59 W/%um 34 W/whatever’s 35 997.61 speaker/B 998.21 998.56 A: He was changing projects every couple of weeks, and he said he couldn’t keep on top of it. He couldn’t learn the whole new area.

968.71 969.00 B: %um.

970.35 971.94 A: that fast each time.

971.23 971.42 B: %um.

972.46 979.57 A: %um, and he says he went in and had some tests, and he was diagnosed as having attention deficit disorder. Which

980.18 989.56 A: you know, given how he’s how far he’s gotten, you know, he got his degree at %Tufts and all, I found that surprising that for the first time as an adult they’re diagnosing this. %um

989.42 991.86 B: %um. I wonder about it. But anyway.

991.75 994.65 A: yeah, but that’s what he said. And %um

994.19 999.46 B: yeah.

995.21 996.59 A: He %um

996.51 997.61 B: Whatever’s helpful.

997.40 1002.55 A: Right. So he found this new job as a financial consultant and seems to be happy with that.

The turns are attributed to speakers using the speaker/ type. All of the words, punctuation and disfluencies are given the W/ type, though we could easily opt for a more refined version in which these are assigned different types. The class field is not used here. Observe that each speaker turn is a disjoint piece of graph structure, and that hierarchical organisation uses the ‘chart construction’ (Gazdar and Mellish, 1989, 179ff). Thus, we make a logical distinction between the situation where the endpoints of two pieces of annotation necessarily coincide (by sharing the same node) from the situation where endpoints happen to coincide (by having distinct nodes which contain the same time reference). The former possibility is required for hierarchical structure, and the latter possibility is required for overlapping speaker turns where words spoken by different speakers may happen to sharing the same boundary.

2.2 Dialogue Annotation in COCONUT

The COCONUT corpus is a set of dialogues in which the two conversants collaborate on a task of deciding what furniture to buy for a house (Di Eugenio et al., 1998). The coding scheme augments the DAMSL scheme (Allen and Core, 1997) by having some new top-level tags and by further specifying some existing tags. An example is given in Figure 3.

The example shows five utterance pieces, identified (a-e), four produced by speaker S1 and one produced by speaker S2. The discourse annotations can be glossed as follows: Accept - the speaker is agreeing to a possible action or a claim; Commit - the speaker potentially commits to intend to perform a future specific action, and the commitment is not contingent upon the assent of the addressee; Offer - the speaker potentially commits to intend to perform a future specific action, and the commitment is contingent upon the assent of the addressee; Open-Option - the speaker provides an option for the addressee’s future action; Action-Directive - the utterance is designed to cause the addressee to undertake a specific action.

In utterance (e) of Figure 3, speaker S1 simultaneously accepts to the meta-action in (d) of not
Accept, Commit  
S1:  (a) Let’s take the blue rug for 250,  
(b) my rug wouldn’t match  

Open-Option  
S2:  (c) which is yellow for 150.  

Action-Directive  
S2:  (d) we don’t have to match...  

Accept(d), Offer, Commit  
S1:  (e) well then let’s use mine for 150

To make the referent of the Accept tag clear, we make use of the class field. Recall that the third component of the fielded records, the class field, permits arcs to refer to each other. Both the referring and the referenced arcs are assigned to equivalence class d.

### 2.3 Coreference Annotation in MUC-7

The MUC-7 Message Understanding Conference specified tasks for information extraction, named entity and coreference. Coreferring expressions are to be linked using SGML markup with ID and REF tags [Hirschman and Chinchor 1997]. Figure 3 is a sample of text from the Boston University Radio Speech Corpus [www.ldc.upenn.edu/Catalog/LDC96S36.html], marked up with coreference tags. (We are grateful to Lynette Hirschman for providing us with this annotation.)

Noun phrases participating in coreference are wrapped with <coref>...</coref> tags, which can bear the attributes ID, REF, TYPE and MIN. Each such phrase is given a unique identifier, which may be referenced by a REF attribute somewhere else. Our example contains the following references: 3 → 2, 4 → 2, 6 → 5, 7 → 5, 8 → 5, 12 → 11, 15 → 13. The TYPE attribute encodes the relationship between the anaphor and the antecedent. Currently, only the identity relation is marked, and so coreferences form an equivalence class. Accordingly, our example contains the following equivalence classes: {2, 3, 4}, {5, 6, 7, 8}, {11, 12}, {13, 15}.

In our AG representation we choose the first number from each of these sets as the identifier for the equivalence class. MUC-7 also contains a specification for named entity annotation. Figure 5 gives an example, to be discussed in §3.2. This uses empty
This woman receives three hundred dollars a month under General Relief, plus four hundred dollars a month in A.F.D.C. benefits for her son, who is a U.S. citizen. She’s among an estimated five hundred illegal aliens on General Relief for the state’s total illegal immigrant population of one hundred thousand.

General Relief is for needy families and unemployable adults who don’t qualify for other public assistance. Welfare Department spokeswoman Michael Reganburg says the state will save about one million dollars a year if illegal aliens are denied General Relief.

Accompanying this transcription are a number of xwaves label files containing time-aligned word-level and segment-level transcriptions. Below, the start of file speaker0.words is shown on the left, and the start of file speaker0.phones is shown on the right. The first number gives the file offset (in seconds), and the middle number gives the label color. The final part...
This woman receives three hundred dollars a month under General Relief, plus four hundred dollars a month in A.F.D.C. benefits for her son, who is a U.S. citizen. She’s among an estimated five hundred illegal aliens on General Relief out of the state’s total illegal immigrant population of one hundred thousand. General Relief is for needy families and unemployable adults who don’t qualify for other public assistance.

Welfare Department spokeswoman Michael Reganburg says the state will save about one million dollars a year if illegal aliens are denied General Relief.

Figure 7: Named Entity Annotation for BU Example

is a label for the interval which ends at the specified time. Silence is marked explicitly (again using \(<\text{sil}>\)) so we can infer that the first word ‘hello’ occupies the interval [0.110000, 0.488555]. Evidently the segment-level annotation was done independently of the word-level annotation, and so the times do not line up exactly.

The TRAINS annotations show the presence of backchannel cues and overlap. An example of overlap is shown below:

| Time     | 122 <sil> | 0.100000 122 <sil> | 0.534001 122 <sil> | 0.640000 122 can | 0.690000 122 I | 0.930000 122 help | 1.068003 122 right |
|----------|-----------|---------------------|---------------------|------------------|-----------------|-----------------|-------------------|
| 0.110000 | 122       | 0.200000 122 hh     | 0.250000 122 eh ;*  | 0.330000 122 l   | 0.460000 122 ov*1| 0.530000 122 k   | 0.640000 122 n |
| 0.260000 | 122       |                      |                     |                  | 0.570000 122 ih  |                 | 0.690000 122 ay |
| 0.330000 | 122 we    |                      |                     |                  |                 | 0.760000 122 hh  |                   |
| 0.480000 | 122 need  |                      |                     |                  |                 |                  |                   |
| 0.540000 | 122 to    |                      |                     |                  |                 |                  |                   |
| 0.651716 | 122 get   | 0.094197 122 <sil>  | 0.306658 122 oh     | 0.410000 122 we  | 0.560000 122 need| 0.620000 122 to  | 0.850000 122 pick|
| 0.186292 | 122 right | 0.470000 122 <sil>  | 0.540000 122 to     | 0.975728 122 Elmira| 0.020000 122 up  | 52.470000 122 oranges| 52.666781 122 oh |
| 0.287837 | 76 <sil>  | 0.940000 122 okay   | 52.940000 122 okay  | 53.535600 122 <sil> | 53.785600 122 alright| 54.303529 122 so |
| 0.347996 | 76 yeah   | 53.535600 122 <sil> | 53.785600 122 alright| 54.303529 122 so |

As seen in Figure 2 and explained more fully in (Bird and Liberman, 1999), overlap carries no implications for the internal structure of speaker turns or for the position of turn-boundaries.

Figure 8: Corpus Annotation with Segmented Dialogue

Now, independently of this annotation there is also a dialogue annotation in DAMSL, as shown in Figure 3. Here, a dialog is broken down into turns and thence into utterances, where the tags contain discourse-level annotation.

In representing this hybrid annotation as an AG we are motivated by the following concerns. First, we want to preserve the distinction between the TRAINS and DAMSL components, so that they can remain in their native formats (and be manipulated by their native tools) and be converted independently to AGs then combined using AG union, and so that they can be projected back out if necessary. Second, we want to identify those boundaries that necessarily have the same time reference (such as the end of utterance 17 and the end of the word ‘Elmira’), and represent them using a single graph node. Contributions from different speakers will remain disconnected in the graph structure. Finally, we want to use the equivalence class names to allow cross-references between utterances. A fragment of the proposed annotation graph is depicted using our visualization format in Figure 9. Observe that, for brevity, some discourse tags are not represented, and the phonetic segment level is omitted.

Note that the tags in Figure 3 have the form of fielded records and so, according to the AG definition, all the attributes of a tag could be put into a single label. We have chosen to maximally split such records into multiple arc labels, so that search predicates do not need to take account of internal structure, and to limit the consequences of an erroneous code. A relevant analogy here is that of pre-composed versus compound characters in Unicode. The presence of both forms of a character in a text raises problems for searching and collating. This problem is avoided through normalization, and this is typically done by maximally decomposing the characters.

3.2 Multiple annotations of the BU corpus

Linguistic analysis is always multivocal, in two senses. First, there are many types of entities and
relations, on many scales, from acoustic features spanning a hundredth of a second to narrative structures spanning tens of minutes. Second, there are many alternative representations or construals of a given kind of linguistic information.

Sometimes these alternatives are simply more or less convenient for a certain purpose. Thus a researcher who thinks theoretically of phonological features organized into moras, syllables and feet, will often find it convenient to use a phonemic string as a representational approximation. In other cases, however, different sorts of transcription or annotation reflect different theories about the ontology of linguistic structure or the functional categories of communication.

The AG representation offers a way to deal productively with both kinds of multivocality. It provides a framework for relating different categories of linguistic analysis, and at the same time to compare different approaches to a given type of analysis.

As an example, Figure 10 shows an AG-based visualization of eight different sorts of annotation of a phrase from the BU Radio Corpus, produced by Mari Ostendorf and others at Boston University, and published by the LDC [www.ldc.upenn.edu/Catalog/LDC96S36.html]. The basic material is from a recording of a local public radio news broadcast. The BU annotations include four types of information: orthographic transcripts, broad phonetic transcripts (including main word stress), and two kinds
of prosodic annotation, all time-aligned to the
digital audio files. The two kinds of prosodic
annotation implement the system known as ToBI
[www.ling.ohio-state.edu/phonetics/E/ToBI/].
ToBI is an acronym for “Tones and Break
Indices”, and correspondingly provides two types of
information: Tones, which are taken from a fixed
vocabulary of categories of (stress-linked) “pitch
accents” and (juncture-linked) “boundary tones”; and
Break Indices, which are integers characterizing
the strength and nature of interword disjunctures.

We have added four additional annotations:
coreference annotation and named
entity annotation in the style of MUC-7
[www.muc.saic.com/proceedings/muc_7hoc.html]
provided by Lynette Hirschman; syntactic structures
in the style of the Penn TreeBank [Marcus et al.,
1993] provided by Ann Taylor; and an alternative
annotation for the F0 aspects of prosody, known as
Tilt [Taylor, 1998] and provided by its inventor,
Paul Taylor. Taylor has done Tilt annotations for
much of the BU corpus, and will soon be publishing
them as a point of comparison with the ToBI tonal
annotation. Tilt differs from ToBI in providing a
quantitative rather than qualitative characterization
of F0 obtrusions: where ToBI might say “this is a
L+H* pitch accent,” Tilt would say “This is an F0
obtrusion that starts at time t0, lasts for duration d
seconds, involves a Hz total F0 change, and ends l
Hz different in F0 from where it started.”

As usual, the various annotations come in a bewil-
dering variety of file formats. These are not entirely
trivial to put into registration, because (for instance)
the TreeBank terminal string contains both more
(e.g. traces) and fewer (e.g. breaths) tokens than the
orthographic transcription does. One other slightly
tricky point: the connection between the word string
and the “break indices” (which are ToBI’s character-
izations of the nature of interword disjunctures) are
mediated only by identity in the floating-point time
values assigned to word boundaries and to break
indices in separate files. Since these time values are
expressed as ASCII strings, it is easy to lose the
identity relationship without meaning to, simply by
reading in and writing out the values to programs
that may make different choices of internal variable
type (e.g. float vs. double), or number of decimal
digits to print out, etc.

Problems of this type are normal whenever multi-
ple annotations need to be compared. Solving them
is not rocket science, but does take careful work.
When annotations with separate histories involve
mutually inconsistent corrections, silent omissions of
problematic material, or other typical developments,
the problems are multiplied. In noting such difficul-
ties, we are not criticizing the authors of the annota-
tions, but rather observing the value of being able to
put multiple annotations into a common framework.

Once this common framework is established, via
translation of all eight “strands” into AG graph
terms, we have the basis for posing queries that
cut across the different types of annotation. For
instance, we might look at the distribution of Tilt
parameters as a function of ToBI accent type; or
the distribution of Tilt and ToBI values for initial
vs. non-initial members of coreference sets; or the
relative size of Tilt F0-change measures for nouns
vs. verbs.

We do not have the space in this paper to dis-
cuss the design of an AG-based query formalism at
length – and indeed, many details of practical AG
query systems remain to be decided – but a short
discussion will indicate the direction we propose to
take. Of course the crux is simply to be able to put
all the different annotations into the same frame of
reference, but beyond this, there are some aspects
of the annotation graph formalism that have nice
properties for defining a query system. For example,
if an annotation graph is defined as a set of “arcs”
like those given in the XML encoding in (4), then
every member of the power set of this arc set is
also a well-formed annotation graph. The power set
construction provides the basis for a useful query
algebra, since it defines the complete set of possible
values for queries over the AG in question, and is
obviously closed under intersection, union and rela-
tive complement. As another example, various time-
based indexes are definable on an adequately time-
anchored annotation graph, with the result that
many sorts of precedence, inclusion and overlap rela-
tions are easy to calculate for arbitrary subgraphs.
See [Bird and Liberman, 1999] §5) for discussion.

In this section, we have indicated some of the ways
in which the AG framework can facilitate the anal-
ysis of complex combinations linguistic annotations.
These annotation sets are typically multivocal, both
in the sense of covering multiple types of linguistic
information, and also in the sense of providing multi-
ple versions of particular types of analysis. Discourse
studies are especially multivocal in both senses, and
so we feel that this approach will be especially help-
ful to discourse researchers.

4 Conclusion

This proliferation of formats and approaches can be
viewed as a sign of intellectual ferment. The fact
that so many people have devoted so much energy to
fielding new entries into this bazaar of data formats
indicates how important the computational study of
communicative interaction has become. However,
for many researchers, this multiplicity of approaches
has produced headaches and confusion, rather than productive scientific advances. We need a way to integrate these approaches without imposing some form of premature closure that would crush experimentation and innovation.

Both here, and in associated work [Bird and Liberman, 1999], we have endeavored to show how all current annotation formats involve the basic actions of associating labels with stretches of recorded signal data, and attributing logical sequence, hierarchy and coindexing to such labels. We have grounded this assertion by defining annotation graphs and by showing how a disparate range of annotation formats can be mapped into AGs. This work provides a central piece of the algebraic foundation for inter-translatable formats and inter-operating tools. The intention is not to replace the formats and tools that have been accepted by any existing community of practice, but rather to make the descriptive and analytical practices, the formats, data and tools universally accessible. This means that annotation content for diverse domains and theoretical models can be created and maintained using tools that are the most suitable or familiar to the community in question. It also means that we can get started on integrating annotations, corpora and research findings right away, without having to wait until final agreement on all possible tags and attributes has been achieved.

There are many existing approaches to discourse annotation, and many options for future approaches. Our explorations presuppose a particular set of goals: (i) generality, specificity, simplicity; (ii) searchability and browsability; and (iii) maintainability and durability. These are discussed in full in [Bird and Liberman, 1999, §6]. By identifying a common conceptual core to all annotation structures, we hope to provide a foundation for a wide-ranging integration of tools, formats and corpora. One might, by analogy to translation systems, describe AGs as an interlingua which permits free exchange of annotation data between n systems once n interfaces have been written, rather than n² interfaces.

Although we have been primarily concerned with the structure rather than the content of annotations, the approach opens the way to meaningful evaluation of content and comparison of contentful differences between annotations, since it is possible to do all manner of quasi-correlational analyses of parallel annotations. A tool for converting a given format into the AG framework only needs to be written once. Once this has been done, it becomes a straightforward task to pose complex queries over multiple corpora. Whereas if one were to start with annotations in several distinct file formats, it would be a major programming chore to ask even a simple question.

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