Annotation Graphs as a Framework for Multidimensional Linguistic Data Analysis

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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 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 (Jachendorff, 1972) often cut across conversational turns and syntactic constituents.

A minimal formalization of this basic set of practices is a directed graph with labeled 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 pronunciation 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.htm] has been marked up for disfluency (Taylor, 1995). See [www.cis.upenn.edu/~treebank/speech/sample.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 related. A minimal but sufficient set of 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 which permits the arcs of an annotation graph to be co-indexed as members of an equivalence class.¹

One might add further for indexing 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.

For detailed discussion of these structures, see (Bird and Liberman, 1999). Here we present a fragment (taken from Figure 8 below) to illustrate the definition. For convenience the components of the reddited which decorate the arcs are separated using the slash symbol. The example contains two word arcs, and a discourse tag encoding ‘influence on speaker’. No class are used. Not all nodes have a time reference.

![Diagram of an annotation graph](image)

The minimal annotation graph for this structure is as follows:

\[
T = \{w,d\} \\
L = \{oh,okay,IOS:Commit\} \\
C = \emptyset \\
N = \{1,2,3\} \\
\tau = \{(1,52.46),(3,53.14)\} \\
A = \{\langle 1,w/oh/2\rangle, \langle 2,w/okay/3\rangle, \langle 1,d/IOS:Commit/3\rangle\}
\]

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.

```xml
<annotation>
  <arc id="1" time="52.46">
    <label type="W" name="oh">
      <end id="2"/>
    </label>
  </arc>
  <arc id="2">
    <label type="W" name="okay">
      <end id="3" time="53.14"/>
    </label>
  </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.

¹We have avoided using explicit pointers since we prefer not to associate formal identifiers to the arcs. Equivalence classes will be exemplified later.
Long turns (e.g. the period from 972.46 to 989.56 seconds) were broken up into shorter stretches for the convenience of the annotators and to provide additional time references. A section of this annotation which includes an example of total overlap is represented in annotation graph form in Figure 1, with the accompanying visualization shown in Figure 2. (We have no commitment to this particular visualization; the graph structures can be visualized in many ways and the perspicuity of a visualization format will be somewhat domain-specific.)

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 `/opt` is 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 the utterance pieces, identified as the 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 utterance 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  
(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

Figure 3: Dialogue with COCONUT Coding Scheme

![Diagram showing dialogue structure with COCONUT coding scheme]

having matching colors, and to the regular action of using S1’s yellow rug. The latter acceptance is not explicitly represented in the original notation, so we shall only consider the former.

In representing this dialogue structure using annotation graphs, we will be concerned to achieve the following: (i) to treat multiple annotations of the same utterance fragment as an unordered set, rather than a list, to simplify indexing and query; (ii) to explicitly link speaker S1 to utterances (a–c); (iii) to formalize the relationship between Accept(d) and utterance (d); and (iv) formalize the rest of the annotation structure which is implicit in the textual representation.

We adopt the types Sp (speaker), Ut (utterance) and D (discourse). A more refined type system could include other levels of representation, it could distinguish forward versus backward communicative function, and so on. For the names we employ: speaker identifiers S1, S2; discourse tags Offer, Commit, Accept, Open-Option, Action-Directive; and orthographic strings representing the utterances. For the classes (the third, optional) we employ the utterance identifiers a, b, c, d, e.

An annotation graph representation of the COCONUT example can now be represented as in Figure 4. The arcs are structured into three layers, one for each type, where the types are written on the left. If the optional class is specified, this information follows the name separated by a slash. The Accept/d arc refers to the S2 utterance simply by virtue of the fact that both share the same class.

Observe that the Commit and Accept tags for (a) are unordered, unlike the original annotation, and that speaker S1 is associated with all utterances a–c, rather than being explicitly linked to (a) and implicitly linked to (b) and (c) as in Figure 3.

To make the referent of the Accept tag clear, we make use of the class Relink that the third component of the redarc, the class pink, nits 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 5 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 instance from each of these sets as the identifier for the equivalence class. MUC-7 also contains a specification for named entity annotation. Figure 7 gives an example, to be discussed in §3.2. This uses empty
This woman receives three hundred dollars a month under General Relief.

She's among an estimated five hundred illegal aliens on General Relief, plus four hundred dollars a month in A.F.D.C. benefits for her son, who is a U.S. citizen.

Utterances can be transcribed using different formats for different levels. Two examples of hybrid annotation will be discussed here: a TRAINS+DAMSL annotation, and an eight-level annotation of the Boston University Radio Speech Corpus.

3.1 DAMSL annotation of TRAINS

The TRAINS corpus (Heeman and Allen, 1993) is a collection of about 100 dialogues containing a total of 5,900 speaker turns [www.ldc.upenn.edu/Catalog/LDC95S25.html]. Part of a transcript is shown below, where s and u designate the two speakers, <sil> denotes silent periods, and + denotes boundaries of speaker overlaps.
This woman receives
\texttt{<numex TYPE=\"MONEY\>}
three hundred dollars
\texttt{<numex>}
a month under General Relief, plus
\texttt{<numex TYPE=\"MONEY\>}
four hundred dollars
\texttt{<numex>}
a month in F.D.C. benefits for her son, who is a
\texttt{<numex TYPE=\"LOCATION\>}
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.
\texttt{<numex TYPE=\"ORGANIZATION\>}
Welfare Department
\texttt{<numex>}
spokeswoman
\texttt{<numex TYPE=\"PERSON\>}
Michael Regensburg
\texttt{<numex>}
says the state will save about
\texttt{<numex TYPE=\"MONEY\>}
one million dollars
\texttt{<numex>}
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 speci-
timed Silence is marked explicitly (again using
\texttt{<sil>}) so we can infer that the \texttt{wordshello}' 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.

<table>
<thead>
<tr>
<th>Time</th>
<th>Label</th>
<th>Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.110000</td>
<td>&lt;sil&gt;</td>
<td>0.100000 122 &lt;sil&gt;</td>
</tr>
<tr>
<td>0.488555</td>
<td>hello</td>
<td>0.220000 122 hh</td>
</tr>
<tr>
<td>0.534001</td>
<td>&lt;sil&gt;</td>
<td>0.260000 122 eh : *</td>
</tr>
<tr>
<td>0.640000</td>
<td>can</td>
<td>0.320000 122 l</td>
</tr>
<tr>
<td>0.690000</td>
<td>I</td>
<td>0.460000 122 ow !</td>
</tr>
<tr>
<td>0.930000</td>
<td>help</td>
<td>0.580000 122 k</td>
</tr>
<tr>
<td>1.068003</td>
<td>you</td>
<td>0.780000 122 ih</td>
</tr>
<tr>
<td>1.467000</td>
<td>&lt;sil&gt;</td>
<td>0.640000 122 n</td>
</tr>
<tr>
<td>1.920000</td>
<td>oh</td>
<td>0.680000 122 ay</td>
</tr>
<tr>
<td>15.419292</td>
<td>right</td>
<td>0.760000 122 hh</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Time</th>
<th>Label</th>
<th>Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.130000</td>
<td>&lt;sil&gt;</td>
<td>0.122 &lt;sil&gt;</td>
</tr>
<tr>
<td>0.260000</td>
<td>so</td>
<td>0.122 so</td>
</tr>
<tr>
<td>0.330000</td>
<td>we</td>
<td>0.122 we</td>
</tr>
<tr>
<td>0.480000</td>
<td>need</td>
<td>0.122 need</td>
</tr>
<tr>
<td>0.540000</td>
<td>to</td>
<td>0.122 to</td>
</tr>
<tr>
<td>0.651746</td>
<td>get</td>
<td>0.5104197 122 &lt;sil&gt;</td>
</tr>
<tr>
<td>51.360000</td>
<td>oranges</td>
<td>51.360000 122 or</td>
</tr>
<tr>
<td>51.470000</td>
<td>&lt;sil&gt;</td>
<td>51.410000 122 we</td>
</tr>
<tr>
<td>51.540000</td>
<td>to</td>
<td>51.580000 122 need</td>
</tr>
<tr>
<td>51.975728</td>
<td>Elmira</td>
<td>51.600000 122 to</td>
</tr>
<tr>
<td>52.080767</td>
<td>&lt;sil&gt;</td>
<td>51.860000 122 pick</td>
</tr>
<tr>
<td>52.807672</td>
<td>76 &lt;sil&gt;</td>
<td>52.020000 122 up</td>
</tr>
<tr>
<td>53.047996</td>
<td>76 yeah</td>
<td>52.470000 122 oranges</td>
</tr>
<tr>
<td>53.305091</td>
<td></td>
<td>52.66781 122 ch</td>
</tr>
</tbody>
</table>

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.

Now, independently of this annotation there is also a dialogue annotation in DAMSL, as shown in Figure 8. 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 8 have the form of \texttt{<rel>birds} 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 it inconvenient 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. 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
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.saiic.com/proceedings/muc_7_toc.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 bewildering
variety of 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 “breakindices” (which are ToBI’s characterizations
of the nature of interword disjuncture) are
mediated only by identity in the
overlapping
time values assigned to word boundaries and to break
indices in separate strings. 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. 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 merely 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
attributes, 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-

}
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 without having to wait until 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 formats, it would be a major programming chore to ask even a simple question.

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References


