Computational Linguistics (Spring 2010) — Exercise 3b

High-Level Goals

- Perform list concatenation using open-ended lists and unification.
- Finally, add semantics to lexical entries and grammar rules.
- Use the LKB generator to identify overgeneration in the grammar.

1 Obtaining the Starting Grammar (0 Points)

(a) Connect to the IFI Linux environment and launch the LKB. For this week, please obtain a fresh starting grammar, by executing the following command from the shell prompt.

```
exercise3b
```

The resulting grammar (in the new sub-directory '`exercise3b/`'), essentially is the model solution to the previous exercise, but we have made a small number of changes to allow concatenation of `ORTH` values on phrases. Specifically, the attribute `ORTH` has moved from *lex-item* to *expression* and changed its value from **string** to **dlist** (for difference list). In the lexicon, we converted all values of the feature `ORTH` to one-element difference lists (e.g. `ORTH <! "dog" !>` instead of `ORTH "dog"`. Accordingly, we applied a similar change to the type *prep-lxm*, i.e. to make sure that what is equated with the `PFORM` feature is the first element of the `ORTH` value.

Finally, we activated the LKB facility for printing parse trees with more conventional (and more compact) node labels, like 'S', 'NP', et al. The rules and feature structures corresponding to each node are unchanged, but the file '`labels.tdl`' provides a set of templates that determine how to abbreviate feature structures for display purposes. Take a quick look at the contents of '`labels.tdl`' to refresh your understanding of how specific feature structure configurations correspond to traditional category labels.

2 Open-Ended Lists and Concatenation by Unification (20 Points)

- The typed feature structure formalism that is implemented in the LKB (and similar systems) excludes relational constraints (like `append()` or `reverse()` of lists). However, the *difference list* encoding in feature structures allows us to achieve list concatenation using pure unification. A difference list is an open-ended list that is embedded into a container structure providing a 'pointer' to the end of the list, e.g.

A: *dlist* [LIST 1 *ne-list* [FIRST *"foo"* , REST 2 *list*] , LAST 2]

B: *dlist* [LIST 3 *ne-list* [FIRST *"bar"* , REST 4 *list*] , LAST 4]

Now, using the `LAST` pointer of difference list A we can append A and B by (i) unifying the front of B (i.e. the value of its `LIST` feature) into the tail of A (its `LAST` value) and (ii) using the tail of difference list B as the new tail for the result of the concatenation (see Copestake, 2002, for a more elaborate discussion).

The goal of this exercise is to pass up the `ORTH` values from words to phrases and use list concatenation to determine the value of `ORTH` at each phrase. The top ('S') node in a complete analysis of a sentence should have as its `ORTH` value a difference list that contains all words of the sentence, preferably in the right order.

(a) Each rule will be required to concatenate the `ORTH` values of all daughters to the rule and make the resulting list the `ORTH` value on the mother. To avoid duplication of the append operation in the '`rules.tdl`' file, introduce types *unary-rule* and *binary-rule* that inherit from *phrase* and perform the concatenation of `ORTH` values.

(b) In order to have one specific type for each actual rule in the rules file and to allow unification of various *phrase* subtypes to succeed, we need to cross-multiply the two types accounting for arity (number of daughters) with the existing dimension we already have for phrases, namely the position of the head daughter (*head-initial* vs. *head-final*). Use multiple inheritance to create the following types combining the arity dimension with the dimension of head position: *unary-head-initial*, *binary-head-initial*, and *binary-head-final*.

(c) We also need to account for the effect on orthography of inflectional rules, which are subtypes of *word*. Since inflectional rules can change the `ORTH` value, we cannot simply identify the `ORTH` of a word with the `ORTH` of its `ARGS.FIRST` (the lexeme being inflected). But we still have to ensure that the `ORTH` difference list is terminated. So add a constraint to the type *word* making its `ORTH` value be a one-element difference list, which we can define as '`<! [] !>`'.

(d) Rework the file '`rules.tdl`' to use the new, more specific rule types, as appropriate. Reload the grammar and check correctness by parsing a few sentences interactively and verifying that the `ORTH` value on 'S' nodes contains all the words that contribute to the sentence.

(e) Run the 'Batch parse' machinery on the '`all.items`' file and validate the results.

3 Adding Semantics (40 Points)

- Our approach to adding semantics to the grammar builds on list concatenation as the basic operation of composition. Semantic relations are introduced by lexical entries and successively combined as words are combined with other words (or phrases) to form larger phrases. We will use a type *relation* to capture the basic units of semantics that are associated with words, and we'll use subtypes *arg1-relation*, *arg12-relation*, and *arg123-relation* for predicates of corresponding arity:

$$\textit{relation}\begin{bmatrix}\texttt{PRED}\ \textit{*string*}\\ \texttt{ARG0}\ \textit{index}\end{bmatrix},\quad \textit{arg1-relation}\begin{bmatrix}\texttt{PRED}\ \textit{*string*}\\ \texttt{ARG0}\ \textit{index}\\ \texttt{ARG1}\ \textit{index}\end{bmatrix},\quad \cdots\quad \textit{arg123-relation}\begin{bmatrix}\texttt{PRED}\ \textit{*string*}\\ \texttt{ARG0}\ \textit{index}\\ \texttt{ARG1}\ \textit{index}\\ \texttt{ARG2}\ \textit{index}\\ \texttt{ARG3}\ \textit{index}\end{bmatrix}$$

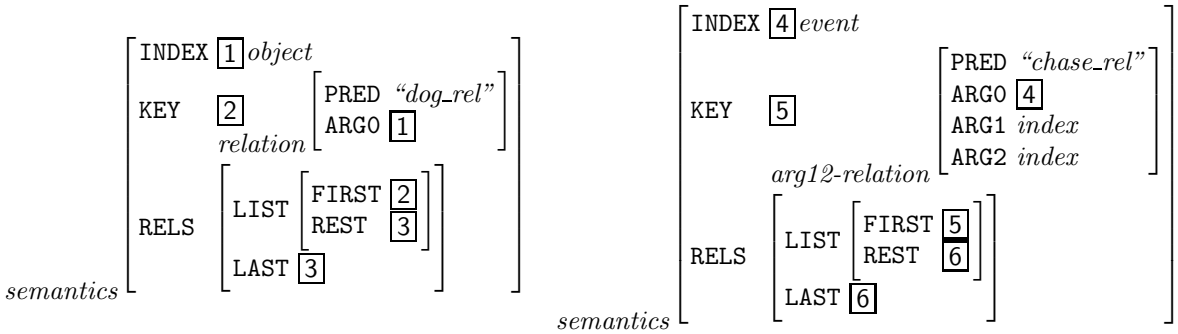
(a) Add an atomic type *index* with subtypes *object* and *event*, which we will use to represent variables in role assignment within relations.

(b) Add the types *relation* through *arg123-relation* (as shown above) below *feat-struc*.

- To associate semantics with words and phrases, we need another type that will serve as the value of a new `SEM` attribute in *expression*:

$$\textit{semantics}\begin{bmatrix}\texttt{INDEX}\ \textit{index}\\ \texttt{KEY}\ \ \textit{relation}\\ \texttt{RELS}\ \ \textit{*dlist*}\end{bmatrix}$$

Roughly speaking, the `INDEX` attribute corresponds to the external variable that is available for binding, the `KEY` attribute points to the distinguished relation that is used for semantic selection (typically contributed by the semantic head; see the MRS paper on the course web site, if you strongly want to learn more about our specific approach to semantics), and the `RELS` attribute holds a list of relations (see below). For the lexical entries 'dog' and 'chase', respectively, we want the following semantics (as the value of their `SEM` feature):



(c) Introduce the type *semantics*, add the feature SEM to *expression*, and constrain its value to *semantics*.

(d) Enrich the *lexeme* type to reflect that (i) lexical items have a singleton RELS list, (ii) the KEY relation corresponds to the first (and only) element in RELS, and (iii) the INDEX is the ARG0 of the KEY.

(e) Enrich the types *det-lxm*, *noun-lxm*, and *verb-lxm* (or their equivalents) to constrain the semantic INDEX to be of type *object* (for determiners and nouns) and *event* (for verbs), respectively.

(f) Add a unique semantic predicate name, as the value of SEM.KEY.PRED, to each entry in the lexicon. Reload the grammar and use the 'View – Lex Entry' menu command to inspect the lexical entries for 'dog' and 'chase', making sure they look as specified above (ignoring for now the linking of ARG1 et al. values to syntactic arguments, of course, which will also affect the specificity of relation types you will see for now).

- Roughly similar to ORTH, each phrase will accumulate the semantic contributions from each of its daughters and use list concatenation in building up the RELS value; while technically we use a list for this purpose, the order of elements in RELS is actually irrelevant: we are using a list to represent a bag (or multi-set) of objects. Add the principles of semantic composition.

(g) While unary rules simply pass up the entire SEM value from the daughter to the mother, binary rules apply difference list concatenation to the SEM.RELS values.

(h) In each phrase, the INDEX and KEY values are contributed by the semantic head, which can in principle be distinct from the syntactic head daughter. For this exercise, however, we'll always take the syntactic head to be the semantic head. Add appropriate co-indexation of INDEX and KEY to the *head-initial* and *head-final* types to express this generalization.

(i) Inflectional rules are subtypes of *word* but behave much like unary rules; add the passing up of the SEM value from the daughter to that of the mother on the type *word*. Also modify the derivational rule for dative-shift (a lexeme-to-lexeme rule) to preserve the semantics from daughter to mother. Note that, in general, derivational rules would be expected to alter the semantics, like the agentive rule which we have excluded for this exercise.

(j) Reload the grammar, eliminate remaining errors (if any), and make sure that (i) coverage remains unchanged and (ii) the RELS value on 'S' nodes contains the relations of all words in the input sentence. Since each word contributes exactly one relation in our grammar, the number of elements in the RELS list should always be the same as the number of words in the sentence.

- What remains to be achieved is the linking of syntactic arguments to semantic roles. We will use the INDEX value of arguments (often called the *index*) to make this linking explicit. This requires enriching the types for all lexemes that take arguments (i.e. have non-empty SPR or COMPS lists, and likewise for non-empty MOD values on modifiers) to identify the INDEX value of each argument with exactly one role in the relation of the functor (the semantic head).

(k) Nouns identify the INDEX of their specifier with their own INDEX (also their ARG0).

(l) All verbs identify the INDEX of their specifier with their ARG1 role; in addition, transitive verbs identify the INDEX of their complement with their ARG2; analogously, ditransitive verbs map their complements to ARG2 and ARG3 (note, however, that for the dative alternation we expect identical meanings).

(m) Prepositions are special: they identify the `INDEX` of the *expression* selected for by `MOD` with their own `INDEX`, and map the `INDEX` of their complement to `ARG1`. Adjectives are similar to prepositions, but have no `ARG1` role.

(n) Reload the grammar, confirm everything works, and admire the beauty of semantic composition. Make sure to verify that in sentences like 'the dog barks', 'the cat gave that dog those aardvarks', or 'the cat barked near those dogs' the following well-formedness conditions hold in the semantics: (i) all `INDEX` values are specialized to either *event* or *object*, (ii) determiner and noun in each noun phrase share the same `ARG0` variable, (iii) each role in a verbal relation is bound to the index of the corresponding argument, (iv) the `ARG0` of a prepositional phrase *modifier* is bound to the `ARG0` of the noun or verb being modified, and (v) the `ARG0` of adjectives is bound to the `ARG0` of the noun it modifies.

(o) The LKB provides facilities to read out a semantic formula from a feature structure, print it in various formats, perform (limited) semantic inference, and generate from it. Because our semantics is (currently) very shallow, however, only a subset of this functionality can be used meaningfully.

From the tree summary display (the window showing tiny trees after parsing), execute the menu commands 'MRS' and 'Indexed MRS' to see a readable form of the semantics produced by your grammar.

4 Generation: The Inverse of Parsing (5 Points)

- The LKB comprises a chart-based generator that, given a suitable semantic formula, can generate all sentences (i.e. well-formed strings) that correspond to this semantics. For the generator to work, we need to make a final small extension to our grammar:

(a) For generator-internal purposes, the generator requires `INDEX` values to have one appropriate magic feature, `SKOLEM`, whose value is of type **string**. Enrich the type definition for *index* appropriately. Reload the grammar.

(b) To get full access to the LKB generation component, execute the 'Options – Expand Menu' command. Then, to make the lexicon accessible to the generator, execute 'Generator – Index'; if there are warnings or errors at this stage, revisit your grammar. In order for the indexing to happen at load time, edit the file 'script' in your grammar directory which is the load file for the grammar. Towards the end of the file, uncomment the line `(index-for-generator)` by removing all semicolons.

- Once indexing is complete, from the tree summary display explore the output of the 'Generate' command for various sentences; this is a short-cut command for extracting the indexed semantics from a feature structure and using that as the input for the generator.

5 Eliminate More Overgeneration (15 Points)

- At this point, generating from the semantics of *the aardvark barks* should return four sentences. Investigate the reasons for this overgeneration, identify the missing bits of information, and speculate about changes to the grammar that would be needed to eliminate this ambiguity. Submit a few paragraphs of text summarizing your findings.

- Use the LKB to (re-)generate from the semantics of *that cat gave those dogs the aardvark* and *that cat gave the aardark to those dogs*. Inspect the associated semantics and determine why the two sentences are *not* considered semantically equivalent yet. In one paragraph (or two) of text, sketch a modification to the grammar that will make both usages of ditransitive verbs like *give* result in equivalent semantics. What is the main challenge here?

6 Submitting Your Results

To provide your results to us, please pack up the entire contents of your '`exercise3b/`' directory when you are done—for example as one '`.tgz`' or '`.zip` file. Email the archive file to both Arne and Stephan before the final deadline, Monday, May 24. For the IFI Linux environment, we provide a command-line tool for you to automate the process of submitting results to us.