Chapter 7

Representation and Processing Revisited: Meaning

7.1 Introduction

The discussion in previous chapters reinforces the point made in Chapter 3 about the value of syntactic, and ‘shallow’ semantic analysis, but it also shows why performing a syntactic analysis alone is not sufficient for translation. As the discussion in Chapter 6 indicates, there are many cases where problems seem to require deeper, more meaning oriented representations, and enrichment of the kind of knowledge systems are equipped with. In this chapter we will try to give a flavour of what is involved in this.

It is useful to think of this knowledge as being of three kinds: (i) linguistic knowledge which is independent of context, semantic knowledge; (ii) linguistic knowledge which relates to the context (e.g. of earlier utterances), sometimes called pragmatic knowledge; and (iii) common sense, general, non-linguistic knowledge about the real world, which we will call real world knowledge. It should be stressed that the distinction between these different kinds of knowledge is not always clear, and there are those who would dispute whether the distinction is real. However, it is at least a convenient subdivision of the field, and we will examine each sort of knowledge in turn, in Sections 7.2, 7.3, and 7.4. Discussing these different kinds of knowledge will also allow us to describe some more general translation problems.

Apart from giving an overview and flavour of what is involved, the point we would like to stress in this chapter is that though dealing with meaning in a general way poses many unsolved problems, and in general one should not expect to find much in the way of real world, pragmatic, or even semantic processing in current commercial MT systems, such processing it is not *totally* beyond the reach of current theory.

7.2 Semantics

Semantics is concerned with the meaning of words and how they combine to form sentence meanings. It is useful to distinguish **lexical** semantics, and **structural** semantics — the former is to do with the meanings of words, the latter to do with the meanings of phrases, including sentences. We will begin with the former.

There are many ways of thinking about and representing word meanings, but one that has proved useful in the field of machine translation involves associating words with **semantic features** which correspond to their sense components. For example, the words *man*, *woman*, *boy*, and *girl* might be represented as:

```
man = (+HUMAN, +MASCULINE and +ADULT)

woman = (+HUMAN, -MASCULINE and +ADULT)

boy = (+HUMAN, +MASCULINE and -ADULT)

girl = (+HUMAN, -MASCULINE and -ADULT)
```

Associating words with semantic features is useful because some words impose semantic constraints on what other kinds of words they can occur with. For example, the verb *eat* demands that its AGENT (the eater) is animate and that its PATIENT (that which is eaten) is edible, — concrete (rather than abstract, like sincerity, or beauty), and solid (rather than liquid, so one cannot 'eat' beer, coffee, etc.; soup is a borderline case). We can encode this constraint in our grammar by associating the features HUMAN and EDIBLE with appropriate nouns in our dictionary and describing our entry for *eat* as something like `cat=verb, AGENT=HUMAN, PATIENT=EDIBLE`. The grammar will now only accept objects of *eat* that have the feature EDIBLE. Thus these **selectional restrictions**, as they are called, act as a filter on our grammar to rule out unwanted analyses. Consider sentence (1):

(1) John ate the game.

The English word *game* is ambiguous - it can mean several things, including *a form of play or sport* or *a wild animal hunted or fished for food*. Using selectional restrictions of the sort described above we can eliminate the 'form of play or sport' meaning if the system is able to infer that 'food' is EDIBLE, but that forms of play are not.

Selectional restrictions have proved a very useful device and are found in most MT systems to a greater or lesser extent. Unfortunately, however, exceptions to selectional restrictions abound, especially in metaphorical speech. Thus we find sentences like *This car eats money*, used to mean that the car is expensive to maintain, so, rather than use selectional restrictions to eliminate interpretations, we should use them to state **preferences** between alternative interpretations.

Notice that stating selectional restrictions in terms of semantic relations is easier than trying to state them in terms of (surface) grammatical relations. Using grammatical relations we would have to say that *eat* prefers an animate SUBJECT in active sentences, and an animate NP in the *by* phrase in passive sentences (and an edible OBJECT in actives, and an edible SUBJECT in passives).

We will now look briefly at how semantic relations can help in one of the thorniest problems for machine translation, namely the translation of prepositions.

Take, for example, the translation of the English preposition *at* into Spanish, and, for the sake of exposition, make the simplifying assumption that it receives only two translations in Spanish, namely *a* and *en*, as in the following:

(2) a. at midday
    b. $\boxed{\text{a}}$ mediodía

(3) a. at school
    b. $\boxed{\text{en}}$ la escuela

The choice of Spanish preposition depends on the type of noun that follows it. Roughly, where the preposition is followed by a temporal noun, as in the first example, it translates as *a*, but where the preposition is followed by a locational noun, as in the second example, it translates as *en*.

We can pick out the correct translation of *at* by assigning it an appropriate Semantic Relation (SR) during analysis. For example, the feature `SR=TIME` might be assigned to indicate that *at* expresses a temporal relation, and the feature `SR=PLACE` might be used to mean that *at* expresses a location relation. We could then have translation rules of the following form:

```
at, SR=TIME ↔ a
at, SR=PLACE ↔ en
```

These semantic relations are assigned on the basis of the type of noun that follows the preposition. This means that the noun *midday* must be marked in the dictionary with some temporal feature (e.g. `semtype=time`), while nouns like *school* must be marked with some locational feature (e.g. `semtype=location`).

We are assuming that semantic relations attach to prepositions. More properly, a semantic relation describes the role which the whole prepositional phrase, not just the preposition, plays in relation to its head, but it is convenient to allow the preposition to carry this feature too, in order to formulate the above translation rules. A prepositional phrase marked with the semantic relation TIME, for example, might indicate the time at which the action indicated by the verb takes place, while a phrase marked with the semantic relation PLACE might indicate the location at which it took place.

Although these features would solve many problems in translating prepositions, the semantic relations expressed by PLACE and TIME are not always fine grained enough. We can, for example, distinguish two different types of usage for locational *at*: '(to be) at school' indicates a position, whereas '(to shoot) at the goal' indicates a movement towards a certain place. We could decompose the semantic relation into two separate relations, say PLACE_POSITION for the first phrase, and PLACE_PATH for the second phrase. Note that the calculation of these new semantic relations will depend not only on the semantic features of the nouns that follow them, but crucially on the type of verb.

Our brief example illustrates some of the problems we face when trying to assign semantic relations to prepositional phrases, or other categories. First, it is difficult to know what a canonical set of semantic relations might look like, since the refinement or granularity required (that is, the number of distinctions we want to make) depends to some extent on the type of translation problem encountered. Secondly, the finer the granularity, the more elaborate the feature system will have to be, in order to differentiate nouns, for example. Finally, the calculation of semantic relations depends on a number of factors, including as we have seen the type of verb and the type of the following noun.

We have described semantic features as more or less optional additions to representations — the addition of a semantic feature may serve to disambiguate a representation, by indicating which sense of a word is involved, but the representation is still conceived of as a structure consisting of lexical items (words). A more radical idea is to take the semantic features as exhausting the meaning of words, and to replace the lexical items by the appropriate set of features. Thus, one would have representations with `(+HUMAN, +MASCULINE, +ADULT, ...)` in place of the lexical item *man*. The idea is that the meanings of lexical items can be decomposed into sets of semantic primitives. Since such sets of semantic primitives might well be universal, one can in this way approach the goal of an interlingua. Here one cannot manage satisfactorily simply with sets of features, however. Instead, one needs to produce structures in which the predicates are semantic primitives. For example, the representation of *kill* might be along the following lines:

(4) CAUSE [BECOME [NOT [ALIVE]]

As we have already noted in Chapter 4 there are some doubts in general about the feasibility and advisability of this process of lexical decomposition. For example, there is a small but significant difference in meaning between *kill* and *cause to become not alive* — in particular, where a 'killing' is a single event, a 'causing to become not alive' involves at least two events (a 'causing', and a 'dying'), and if the causal chain that links a particular event to dying is long enough, one may admit that the event caused the dying, but not want to say there has been a 'killing'. Of course, these doubts depend on what one thinks the relation is between the semantic primitives like CAUSE, BECOME, etc., and English words like *cause*, *become*, etc., and also on the assumption that there is no semantic primitive KILL. Notice that, while a collection of semantic primitives that includes KILL is going to be quite large (perhaps in the order of a thousand primitives), this is still far less than the vocabulary one finds in normal use — so there may still be some value in semantic decomposition, even if the number of primitives that words decompose into is quite large.

So far we have concentrated our discussion of semantics on the meaning of words, but semantics is also concerned with linguistic 'systems' such as tense and aspect and determination, all of which are of considerable importance in translation. Consider the problem of how to translate the present tense in French into English, where there are at least three possibilities, exemplified in the following:

(5) a. Elle vit à Londres.
    b. She lives in London.

(6) a. Elle vit à Londres depuis le mois dernier.
    b. She has lived in London since last month.

(7) a. Elle mange son dîner.
    b. She is eating her dinner.

Of course, one could try to formulate rules which describe the conditions under which French present tense is realized as English present, English present perfect, or present progressive, but such rules would be very complex. A more attractive possibility is to try to find some more abstract representation which directly describes the temporal and aspectual relations that these sentences involve. Here we will outline one type of approach.

The English tense system is used to convey two different types of information. One is the time of the event — both the present simple *I sing* and the present progressive *I am singing* describe an event in the present. The other is the nature of the event — e.g. the progressive stresses that the event is 'in progress'. Henceforth we shall reserve the word **tense** to mean the time of an event and use the word **aspect** to refer to the way the event is viewed (as an on-going or completed process, a state, or a simple event, etc.). We will use the term **time reference** to cover both tense and aspect.

We can think of tense as expressing a relation between the time of the event and the time of speech. Thus, with the present (*I sing*), the time of the event (which we could call E) overlaps with the time of speech (which we could call S). Contrast the future (*I shall sing*) where the time of the event follows the time of speech (E follows S), or the past, where E precedes S. However, this is not sufficient to distinguish all the different temporal forms of the English verb. There is a problem with the past, where our definition of tense does not allow us to differentiate between the simple past (*I sang*) and the pluperfect (or past-perfect — *I had sung*), since in both cases the time of the event is prior to the time of speech. One solution is to define an additional point of time, called the **reference time** (R). Consider, for example, the sentence:

(8) At two o'clock Sam had already eaten.

At two o'clock specifies a moment in time which precedes the time of speech, but which is not the time of event. Two o'clock is not the time at which John ate, but the time by which he had already eaten. The temporal relations of this sentence can be expressed as follows, where $<$ means 'precedes':

$$\mathtt{E} < \mathtt{R},\ \mathtt{R} < \mathtt{S}$$

This indicates that the time of the event (E) precedes the reference time (R), and R precedes the time of speech (S).

We can now distinguish the pluperfect from the simple past by stipulating that in both cases the time of the event precedes the time of speech ($\mathtt{E} < \mathtt{S}$), but while in the pluperfect the time of the event precedes the reference time ($\mathtt{E} < \mathtt{R}$), in the simple past the time of event and the reference time coincide ($\mathtt{E} = \mathtt{R}$).

We can do something similar to distinguish the present perfect (9) from the other tenses. Here too the event described precedes the speech time, but there is a sense in which sentences in the present perfect are 'about' the present (for example, (9) would be appropriate only if Sam's previous eating habits are still of current relevance). We can capture this by making reference time and speech time coincide (R=S).

(9) Sam has eaten snails.

This gives the following picture:

	Sam had eaten.	pluperfect	$\mathtt{R}<\mathtt{S},\mathtt{E}<\mathtt{R}$
(10)	Sam ate.	simple past	$\mathtt{R}<\mathtt{S},\mathtt{E}=\mathtt{R}$
	Sam has eaten.	present perfect	$\mathtt{R}=\mathtt{S},\mathtt{E}<\mathtt{R}$

We now have the apparatus to represent the difference in tense and aspect between the examples above. Of course, having a way of representing tense and aspect values as above is one thing, calculating the representations for particular inputs is another. This is no trivial task, since the tense and aspect values of the verb will in general depend on many factors, including the form of the verb, and whether it is modified by any time adverbials such as *yesterday* and *tomorrow*.

However, let us assume that we have calculated the tense and aspect values of the following sentence, and see how this helps translation.

(11) Elle vit à Londres depuis le mois dernier.

This sentence might receive a semantic representation along the lines of Figure 7.1. The feature `time-ref` encodes the information about tense and aspect, in particular, the fact that the reference time coincides with the time of speech, and the event time precedes the reference time (and hence also the time of speech).

Since the information encoded by the `time-ref` feature is presumed to be preserved in translation, this feature can treated as an interlingual feature, and thus can be mapped unchanged onto the target language (in this case English), giving the representation in

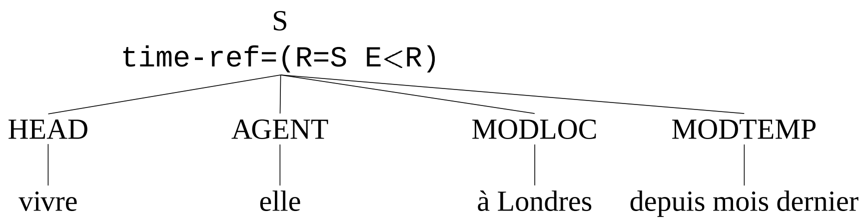

Figure 7.1 Representation Indicating Time Values after French Analysis

Figure 7.2.

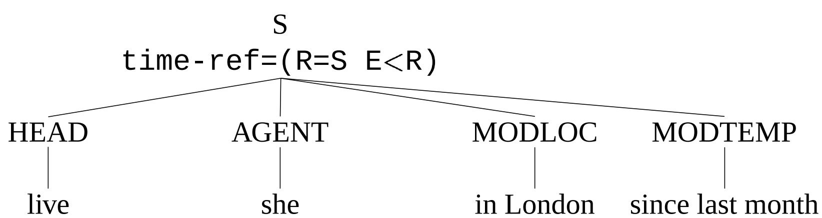

Figure 7.2 Representation after Transfer but before English Synthesis

The verb form *has lived* can then be generated from this representation by English synthesis, giving the translation (12). Other `time-ref` values would be realized differently — in principle, the correct translations of the examples above can be obtained.

(12) She has lived in London since last month.

This treatment of tense and aspect involves a lot of complicated machinery, and is not entirely unproblematic. Nevertheless it gives some indication of how one might attempt to handle the difficult problem of tense and aspect in MT.

7.3 Pragmatics

Recall that we made a distinction between semantics, or context-independent meaning, and pragmatics, or context-dependent meaning. The term 'context' is used ambiguously, to refer to the rest of the text in which a sentence occurs (sometimes referred to as the discourse), and to circumstances external to the text itself, such as who the author of the text is, and the social setting in which it occurs, which also contribute to its interpretation.

To see why the discourse is important, let us consider the translation of **anaphoric pronouns**. Anaphoric pronouns are those which refer back to some **antecedent** earlier in the text, as the pronoun *it* in (13) refers back to its antecedent *the cake*.

(13) Sam took the cake from the table. Then he ate it.

Take the translation of (13) from English into French. We know that *it* must refer back to some singular noun in the previous text or discourse. It has been shown that it is very often the case that the antecedent of a pronoun is in the same sentence or in the immediately preceding sentence. Assuming that these are the first sentences in our text, then *it* can potentially refer back to one of three NPs, namely *Sam*, *the cake* or *the table*. The syntactic facts of English constrain the pronoun to agree in number and gender with its antecedent, so *it* being a neuter pronoun cannot possibly refer to *Sam*, which is either masculine or feminine. That leaves us with the choice of either *cake* or *table*. One might wonder at this stage whether we need to decide between the two at all, or whether we can preserve the ambiguity of *it* in translation. It turns out that French, like English, requires a pronoun to agree in number and gender with its antecedent. However, since *cake* translates as the masculine noun *gâteau* in French and *table* as the feminine noun *table*, this means that we do have to decide which noun the pronoun *it* refers back to, in order to translate *it* either as *le* (where it would be interpreted as referring to *le gâteau* — cake) or as *la* (where it would refer back to *la table* in the translation of the first sentence). In the above example we can use selectional restrictions on the type of object that *eat* can have (namely 'edible' objects) to exclude, or at least 'disprefer', *table* as an antecedent for *it*. This leaves *cake* as the best candidate. Providing rules which allow this sort of process to be performed automatically is not too difficult, but unfortunately resolving pronoun reference is not generally that simple.

First of all, let us consider cases where the pronoun antecedent is not in the current or preceding sentence. An example might be the following dialogue between two speakers A and B, which appeared in Chapter 6.

(14) a. A: Now insert the cartridge at the back.
b. B: Okay.
c. A: By the way, did you order more toner today?
d. B: Yes, I got some when I picked up the new paper.
e. A: OK, how far have you got?
f. A: Did you get $\boxed{\text{it}}$ fixed?

It in the last sentence of (14) refers to the cartridge, although the cartridge was last mentioned in the first sentence. Looking for the pronoun's antecedent in the present or preceding sentence this time will not get us the right result. To find the antecedent, we need to think of the previous discourse not as an unstructured whole, or a simple sequence of sentences, but rather as a series of 'segments', where a segment is a stretch of discourse in which the (not necessarily adjacent) sentences address the same topic. Cue phrases such as *by the way*, and *next* provide clues to where one segment ends and another one begins. We then constrain the referent of an anaphor to belong to the same discourse segment as the anaphor.

In the example (14), there are three obvious referents for *it*: the cartridge (14a), toner (14c), and paper (14d). However, sentences (14c) and (14d) which form a digression, that is, a discourse segment with a topic (namely toner) distinct from the main discourse (and whose purpose is not directly related to the purpose of the main discourse — in this case the purpose of reassembling the printer). The start of the new segment is signalled by *by the way* and the resumption of the old segment is signalled by *OK*. It is for this reason that the expressions *toner* and *new paper* cannot provide referents for *it*. In fact, once discourse structure is taken into account, it can be seen that *the cartridge* is the only possible antecedent, because it is the only possible antecedent which is in the same discourse segment as the anaphor.[1]

Top Level Discourse Segment

A: Now insert **the cartridge** at the back.

B: Okay.

Embedded Discourse Segment

A: By the way, did you order some more toner?

B: Yes, I got some when I picked up the new paper.

A: Okay, how far have you got?

Did you get **it** fixed?

Figure 7.3 Discourse Structure

Faced with two competing candidates for pronominal reference in a segment, there is another fact about discourse that we can exploit to get at their resolution, and this is the notion of **focus**. At any time in a discourse segment there is an object which is the prime candidate for pronominal reference, and this element is called the focus. Different suggestions have been made as to how to identify the focus. Often, there are syntactic signals. For example, in the following example, the focus is much more likely to be *Kim*, than *Sam*, and *Kim* is more likely to be the antecedent of a pronoun in the following sentence.

(15) It was Kim who Sam telephoned. $\boxed{\text{She}}$ was in the bath.

The focus of a sentence is also often the NP that has the THEME role in the previous sentence (the THEME role includes what we have been calling the PATIENT role, but is slightly more general). This is the case with *Kim* in (15), which reinforces the structural cue. But even in the following sequence, where there are no clear structural clues, *key* is the THEME and hence most likely to be the focus of the first sentence (and therefore *key*

[1]This is a simplification, of course. For one thing, *it* could be used to refer to something outside the discourse, to some entity which is not mentioned, but pointed at, for example. For another thing, there are some other potential antencedents, such as *the back* in (14a), and it could be that Speaker A is returning to the digression in sentence (14f). Though the discourse structure can helps to resolve pronoun-antecedent relations, discovering the discourse structure poses serious problems.

is preferred to *doormat* as the referent of *it* in the second sentence).

(16) She put the key under the doormat.
When she came home, she found that $\boxed{\text{it}}$ had been stolen.

Thus, information about discourse structure is of some help in the resolution of pronoun-antecedent relations. However, employing knowledge of discourse alone will not enable us to resolve the reference of all pronouns, as we shall see below.

Let us first look briefly at the other side of pragmatics we mentioned, the context of use. It is obvious that the identity of the speaker/writer and the addressee will affect the translation of indexical expressions such as *I* and *you* since some languages make a distinction, for instance between *you* (singular) and *you* (plural). Similarly, in languages where an adjective agrees in gender with its noun (as in French, for example), it will be necessary to know not only the number of the speakers and the addressees, but also their gender in translating an example like *Are you happy?*. In addition, knowing the relationship between the addresser and addressee can be important for translation. The degree of formality between them will affect, for example, the choice of either *vous* (formal) or *tu* (informal) as the translation of *you* when translating from English into French. In many languages, including Japanese, the social relation of speaker and hearer can determine the form of verb, and even the choice of verb. There are, for example, different verbs for giving as from a superior to an inferior, and for giving as an inferior to a superior.[2]

We have said that a sentence has to be interpreted relative to both the previous discourse and to the situation in which it is uttered. In addition, it seems that the meaning of a message is shaped by its producer's intentions and beliefs. For example, how we interpret (17) depends on whether the speaker intended it as a command (to close the front cover), or as an statement (describing the state the cover is likely to be in).

(17) The front cover should be closed.

Of course, the interpretation also depends on the hearer inferring correctly what the speaker's intentions are. Whether the above sentence is interpreted as a command or statement will affect its translation in some languages.

7.4 Real World Knowledge

The above discussion may lead one to suspect that all the knowledge we need to extract the meaning from texts and translate them can be got from the texts or their contexts. This is, however, clearly not the case, as the following classic examples show:

(18) a. Little Johnny was very upset. He had lost his toy train. Then he found it. It

[2] Politeness dictates that giving by the hearer to the speaker is normally giving 'downwards' (*kureru*), so this is the verb used to describe requests, and giving by the speaker to the hearer is normally giving 'upwards' (*ageru*), so this is the verb used to describe offers, etc.

was in his $\boxed{\text{pen}}$.

b. I saw the soldiers aim at the women, and I saw several of $\boxed{\text{them}}$ fall.

c. The council refused the women a permit because $\boxed{\text{they}}$ advocated violence.

d. Sue went to put the key under the doormat. When she lifted $\boxed{\text{it}}$ up, a cockroach quickly scampered across the path.

In the first example, the problem is the interpretation of *pen* — it must be playpen, not writing pen, because (roughly) for A to be *in* B, A must be smaller than B, and toy trains are smaller than playpens, but not writing pens. In the second example, the question is who fell over — soldiers or women? In general, we reason that 'aiming at' is often followed by firing at, and that firing at is usually followed by those aimed at falling over, and only rarely followed by those who do the aiming falling over. In the third case, most people understand that it is the women who advocate violence — this seems a normal enough ground for refusing a permit (of course, it could be that the council advocated violence, and refused the women a permit so as to enrage them, and incite them to violence). In the case of (18d), we exploit the fact that cockroaches are more likely to hide under doormats than under keys to work out the most likely interpretation of *it*.

In order to translate these examples one will often have to decide what the pronounsrefer to, because many languages use different forms, depending on properties of the antecedent. For example, translating (18d) into German involves deciding what *it* refers to, since the possible candidates are the key or the doormat, which have different genders in German, which the pronoun reflects. Similar issues are involved in translating (18b,c). The knowledge that is deployed here appears to be non-linguistic knowledge, and the reasoning is more or less 'common sense', perhaps with some small amount of specialist knowledge of the subject matter. This is perhaps less obvious in the first case, where one may think that the meaning of *in* is central, but it is surely clear for the others — it is nothing to do with the *meaning* of *aim at* that it is often followed by those aimed at falling over. However, even in the playpen – writing pen case, we can surely imagine a bizarre situation where little Johnny's playpen is in fact tiny, and he has just been given a large fountain pen as a present. In such a situation, the interpretation would be changed, but not because the meaning of the words had changed.

The real world knowledge that is involved here includes common sense reasoning, as well as general knowledge, and facts about certain more specialized domains. Representing and manipulating such knowledge automatically is one of the outstanding research questions of our time, and the raison d' être of an entire discipline (Artificial Intelligence, AI). The problems of representing and manipulating linguistic knowledge pale into insignificance compared to the problems posed by real world knowledge.

One of the problems it raises is that (unlike most linguistic knowledge, in particular, most knowledge of syntax and semantics) such knowledge is generally 'defeasible', that is, subject to revision, and not guaranteed correct[3] – humans have little trouble assuming one

[3] As noted above, knowledge about selectional restrictions is unusual in being defeasible in just this way: the restriction that the AGENT of *eat* is ANIMATE is only a preference, or default, and can be overridden.

thing most of the time, but managing with a contradictory assumption on occasions (as in the small playpen example above). This is extremely difficult to automate. A second problem is the huge amount of such knowledge we seem to have (knowledge about the relative sizes of almost everything, for example). However, there are some methods of representation that are useful for some kinds of knowledge.

One particularly useful representation is the so called **Semantic Net** which can be used for representing 'is a' relations (such as 'a dog is a mammal'). Figure 7.4 gives a small part of such a network.

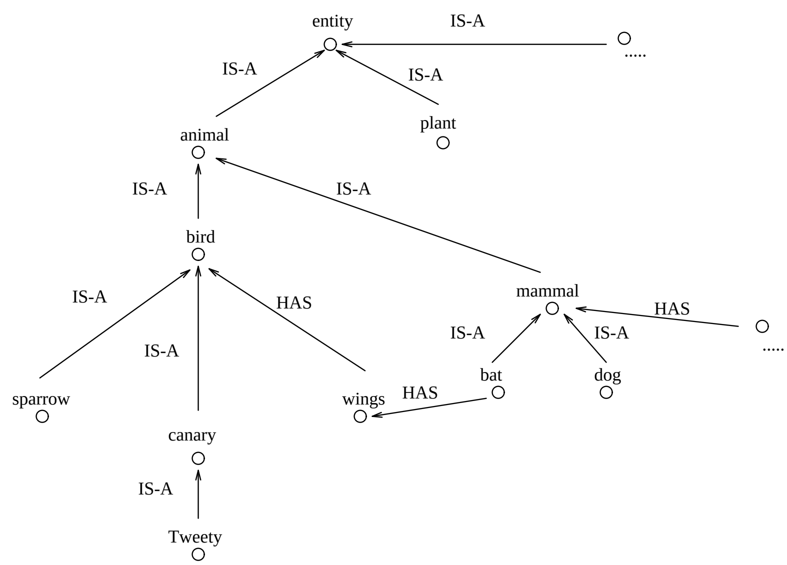

Figure 7.4 A Fragment of a Semantic Net

Intuitively, the nodes in such a network stand for things, and the links between them are relations. This means that it can easily be generalized for other sorts of relations. For example, adding other objects, and using a 'part of' relation, one could represent the fact that (say) a printer is made up of various components, and the fact that these are in turn made up of subcomponents, etc. Such information might be important in understanding sentences like the following:

(19) Put the toner in the cartridge in the reservoir.

Knowing that the reservoir does not have a cartridge as a part would allow one to work out that this is an instruction to put the toner *which is* in the cartridge in the reservoir, rather than an instruction to put the toner in a particular cartridge (i.e. the one that is in the reservoir).

This leads some to think that it is not strictly speaking linguistic knowledge at all. In general, the distinction between linguistic and real world knowledge is not always very clear.

An alternative approach to general knowledge representation is to attempt to formulate it as collections of ‘facts’ and ‘rules’. Examples of facts might be the following, which indicate individuals’ departments:

```
dept(jones,sales).
dept(brown,sales).
dept(smith,personnel).
...
```

The following rule might be used to indicate that two individuals are colleagues, if they work for the same department (‘A and B are colleagues if A works in department D, and B works in department D’):

```
colleagues(A,B) <- dept(A,D), dept(B,D).
```

One problem with both the semantic net, and the ‘facts and rules’ representations are that they are both rather ‘small’, or loosely organized collections of knowledge. This is not how at least some kinds of human knowledge seem to be. For example, what the reader knows about her own home is probably not spread around as sets of unconnected facts. In some way, it seems to be organized into a coherent, structured whole. (One way of seeing this is by describing your home to someone – what you will probably do is take them on a sort of mental tour, which closely mirrors the physical organization of your home). Similarly, for many practical purposes, such as eating in restaurants, one does not seem to have a collection of facts and rules, but a structured ‘script’ of things that typically happen. A great deal of effort has been devoted to the issue of just what the right kinds of structure are for knowledge representation. The generic name for such larger knowledge structures is *frames*. We will give an example of such a representation in Chapter 10, but we will not pursue the idea here, because to a great extent these larger knowledge structures can be built out of smaller ones, such as the ones we have described.

We now have a way of representing at least some real world knowledge. The question is, how can it be manipulated? This is a complex and not particularly well-understood matter, and we will give only the barest outline. However, two points should be emphasised: (a) that as a whole, the general problem of manipulating knowledge of the world in anything like the way humans do is unsolved, and may even prove to be insoluble (this is something of a philosophical question); but (b) under some restricted circumstances, something useful can be done. The kind of restricted circumstances we have in mind are where there are relatively few things to think about, and the ways they are related and can be organized and interact are very limited. An example of this sort might be the internal workings of a printer – it is possible to list all the ‘things’ (the printer parts), their relations, and relevant properties (cf. again Chapter 10).

One thing that manipulating this knowledge means is using it to answer questions, and draw inferences. For example, given that one knows that Smith works in the Finance Department, and Jones works in the Finance Department, how can one work out that Smith and Jones are colleagues? Given that Tweety is a bird, and that birds have wings, how can one work out that Tweety has wings? Of course, given the representations above, these questions are not so hard to answer. In the first case we have provided a rule, the only problem is to find the rule, and follow it. In the other case, we have exemplified a datastructure (a semantic net), the only problem is to define a procedure that allows one to use it.

In the first case, one could proceed as follows. In order to answer the question of whether Brown and Jones are colleagues, one should look for appropriate facts and rules. Assuming there are no appropriate facts, we have only the rule given above. This tells us that A and B are colleagues if A works in department D, and B works in department D. We can treat these two conditions as fresh questions, and answer them in the same way, except that now we have relevant facts, which will tell us that Brown works in sales, and Jones works in sales. We have now answered all the subsidiary questions in the affirmative. It follows that we have also answered the initial question.

In the case of the semantic nets, we might define a procedure that answers questions in the following way: to answer the question of whether an object has a property, first look to see if the property is linked to the object by a HAS link. If it does, answer ‘yes’. If it does not, inspect each of the IS-A links that end at the object, asking the same question at each one. Thus, though it is not indicated that Tweety HAS wings, because Tweety IS-A bird, and bird HAS wings, we can infer that Tweety HAS wings, and answer questions about whether Tweety has wings.

This is a somewhat vague description. However, one may be able to see that some things are possible, but also that this approach to representing and manipulating real world knowledge is insufficient. These are some of the things that are lacking.

1 We have not provided a way of handling defeasible rules, or dealing with vague or ‘fuzzy’ predicates such as *tall*, *hot*, etc. For example, penguins are birds, but cannot fly. Working on the principles just described, one would expect a system to assume that they could fly. The rules we have given are interpreted as general or universal — in fact, they should only be interpreted as indicating defaults. Though there are some partial techniques for dealing with this, how best to automate default reasoning remains an open research question. Similarly, the categories we have mentioned in the discussion are generally rather clear, in the sense that whether something is a bird, or a mammal seems to be a question that can have a clear, yes or no answer. This is not the case with vague predicates like *hot*, or *tall*. In these cases, not only is there usually some idea of a standard of comparison (“Hot compared to what?”), which must be inferred from the context, in some way, but the question of whether something is hot is one that often lacks a clear answer — rather than yes, or no, one may be inclined to answer a question like *Is it hot?*, with a reply like ‘a little’, or ‘somewhat’. Again, though there are some interesting theories, it is mainly an

open research question how to model the sort of reasoning with fuzzy categories that humans can perform.

2 We have suggested how one can answer questions, once they are posed — but not how one can reason ‘forwards’ independent of particular questions. For example, if someone says *The printer is broken*, hearers may typically draw a whole range of conclusions (such as “I will not be able to print the next chapter”, or “We will have to call an engineer”), without particular questions being posed. The problem here is that while the range of inferences drawn is large, it is not as large as it could be (it could be infinite, since every conclusion will typically lead to new chains of inferences being started), and it is not clear how to control this process.

3 We have not given any indication of how one would solve the actual problems raised by the examples in (18). One could, of course, simply record information about the relative sizes of known objects as facts, and in the same way associate with other classes of objects default sizes (e.g. sparrows are typically less than 10cms tall), but this does not look very plausible as a model of how humans represent this knowledge.

4 We have not said anything about how one might reasonably set about encoding all the knowledge that seems to be needed, even assuming that one had the ‘right’ format. The problem is that we cannot anticipate just what particular pieces of real world knowledge a system may need in general. The amount of knowledge that human writers assume, and readers supply without apparent effort or reflection is simply vast, and highly unpredictable, and the effort involved in actually encoding it in this sort of way is prohibitive. Far more feasible is the aim of equipping a computer with facts about a specific domain. As we will describe in Chapter 10, some advanced so-called Knowledge-Based systems are attempting to do just that.

7.5 Summary

In this chapter we have looked at three kinds of knowledge that seem to be involved in solving some sorts of translation problems, namely: semantic, pragmatic, and real world knowledge. Particular problems we have looked at include the translation of prepositions, of tense and aspect, and of pronouns. As we stated at the beginning of the chapter, the point to stress as regards such knowledge is that its representation and manipulation pose many unsolved problems, and one should not expect to find techniques which exploit it in existing commercial MT systems (it follows that, for the most part, existing commercial MT systems may be expected to lack adequate or general treatments of the sorts of problem which require such knowledge). On the other hand, such processing is not *totally* beyond the reach of current theory. In particular, within certain limits, and in restricted domains, techniques of semantic, pragmatic, and ‘real world’ knowledge processing can be exploited with some success.

7.6 Further Reading

Introductions to linguistic semantics include Hurford and Heasley (1983); Kempson (1977), and, at a rather more advanced level Cann (1993); Chierchia and McConnell-Ginet (1990).

The discussion of tense and aspect given here is inspired by that used in the EUROTRA project, which is described in Allegranza et al. (1991); Van Eynde (1993a). This, in its turn, is inspired by the work of Bruce (1972), and ultimately Reichenbach (1947).

As regards pragmatics, Levinson (1983); Leech (1983) are useful introductions. Relevant work on discourse structure includes Grosz and Sidner (1986); Pustejovsky (1987). The treatment of common sense inference and real world knowledge is the field of Artificial Intelligence, see for example Rich (1983); Tennant (1981); Barr and Fiegenbaum (1981); Shapiro (1987). On semantic nets, see Sowa (1984). The perspective we have taken in this Chapter is rather that suggested by the programming language Prolog. For an easy introduction to this see Rogers (1986). For more advanced material directed at AI applications, see Bratko (1986), for material focussed on NLP applications, see Gazdar and Mellish (1989).

The *play-pen – writing-pen* example is from Bar-Hillel Bar-Hillel (1951).