produce the stem **celebrate** with the affixes *-ion* and *-s*, while the lemma for *celebrations* is the longer form **celebration**. In general, lemmas may be larger than morphological stems (e.g., *New York* or *throw up*). The intuition is that we want to have a different lemma whenever we need to have a completely different dictionary entry with its own meaning representation; we expect to have *celebrations* and *celebration* share an entry, since the difference in their meanings is mainly just grammatical, but not necessarily to share one with *celebrate*.

In the remainder of this chapter, when we refer to the meaning (or meanings) of a "word", we are generally referring to a lemma rather than a wordform.

Now that we have defined the locus of word meaning, we can proceed to different ways to represent this meaning. In the next section we introduce the idea of **word sense** as the part of a lexeme that represents word meaning. In subsequent sections we then describe ways of defining and representing these senses and introduce the lexical semantic aspects of the events defined in Chapter 17.

19.1 Word Senses

The meaning of a lemma can vary enormously given the context. Consider these two uses of the lemma *bank*, meaning something like "financial institution" and "sloping mound", respectively:

(19.3) Instead, a *bank* can hold the investments in a custodial account in the client's name.

(19.4) But as agriculture burgeons on the east *bank*, the river will shrink even more.

Word sense

We represent some of this contextual variation by saying that the lemma *bank* has two **senses**.[1] A **sense** (or **word sense**) is a discrete representation of one aspect of the meaning of a word. Loosely following lexicographic tradition, we represent each sense by placing a superscript on the orthographic form of the lemma as in **bank**^{1} and **bank**^{2}.

The senses of a word might not have any particular relation between them; it may be almost coincidental that they share an orthographic form. For example, the *financial institution* and *sloping mound* senses of bank seem relatively unrelated. In such cases we say that the two senses are **homonyms**, and the relation between the senses is one of **homonymy**. Thus **bank**^{1} ("financial institution") and **bank**^{2} ("sloping mound") are homonyms.

Homonym

Homonymy

Sometimes, however, there is some semantic connection between the senses of a word. Consider the following WSJ "bank" example:

(19.5) While some *banks* furnish sperm only to married women, others are much less restrictive.

Although this is clearly not a use of the "sloping mound" meaning of *bank*, it just as clearly is not a reference to a promotional giveaway at a financial institution. Rather, *bank* has a whole range of uses related to repositories for various biological entities, as

[1] Confusingly, the word "lemma" is itself ambiguous; it is also sometimes used to mean these separate senses, rather than the citation form of the word. You should be prepared to see both uses in the literature.

in *blood bank*, *egg bank*, and *sperm bank*. So we could call this "biological repository" sense **bank**^{3}. Now this new sense **bank**^{3} has some sort of relation to **bank**^{1}; both **bank**^{1} and **bank**^{3} are repositories for entities that can be deposited and taken out; in **bank**^{1} the entity is monetary, whereas in **bank**^{3} the entity is biological.

Polysemy

When two senses are related semantically, we call the relationship between them **polysemy** rather than homonymy. In many cases of polysemy, the semantic relation between the senses is systematic and structured. For example, consider yet another sense of *bank*, exemplified in the following sentence:

(19.6) The bank is on the corner of Nassau and Witherspoon.

This sense, which we can call **bank**^{4}, means something like "the building belonging to a financial institution". It turns out that these two kinds of senses (an organization and the building associated with an organization) occur together for many other words as well (*school*, *university*, *hospital*, etc.). Thus, there is a systematic relationship between senses that we might represent as

BUILDING $\leftrightarrow$ ORGANIZATION

Metonymy

This particular subtype of polysemy relation is often called **metonymy**. Metonymy is the use of one aspect of a concept or entity to refer to other aspects of the entity or to the entity itself. Thus, we are performing metonymy when we use the phrase *the White House* to refer to the administration whose office is in the White House. Other common examples of metonymy include the relation between the following pairings of senses:

Author (*Jane Austen wrote Emma*) $\leftrightarrow$ Works of Author (*I really love Jane Austen*)
Animal (*The chicken was domesticated in Asia*) $\leftrightarrow$ Meat (*The chicken was overcooked*)
Tree (*Plums have beautiful blossoms*) $\leftrightarrow$ Fruit (*I ate a preserved plum yesterday*)

While it can be useful to distinguish polysemy from homonymy, there is no hard threshold for how related two senses must be to be considered polysemous. Thus, the difference is really one of degree. This fact can make it very difficult to decide how many senses a word has, that is, whether to make separate senses for closely related usages. There are various criteria for deciding that the differing uses of a word should be represented as distinct discrete senses. We might consider two senses discrete if they have independent truth conditions, different syntactic behavior, and independent sense relations, or if they exhibit antagonistic meanings.

Consider the following uses of the verb *serve* from the WSJ corpus:

(19.7) They rarely *serve* red meat, preferring to prepare seafood, poultry or game birds.

(19.8) He *served* as U.S. ambassador to Norway in 1976 and 1977.

(19.9) He might have *served* his time, come out and led an upstanding life.

The *serve* of *serving red meat* and that of *serving time* clearly have different truth conditions and presuppositions; the *serve* of *serve as ambassador* has the distinct subcategorization structure *serve as NP*. These heuristic suggests that these are probably three distinct senses of *serve*. One practical technique for determining if two senses are distinct is to conjoin two uses of a word in a single sentence; this kind of conjunction of antagonistic readings is called **zeugma**. Consider the following ATIS examples:

Zeugma

(19.10) Which of those flights serve breakfast?

(19.11) Does Midwest Express serve Philadelphia?

(19.12) ?Does Midwest Express serve breakfast and Philadelphia?

We use (?) to mark those examples that are semantically ill-formed. The oddness of the invented third example (a case of zeugma) indicates there is no sensible way to make a single sense of *serve* work for both breakfast and Philadelphia. We can use this as evidence that *serve* has two different senses in this case.

Dictionaries tend to use many fine-grained senses so as to capture subtle meaning differences, a reasonable approach given that the traditional role of dictionaries is aiding word learners. For computational purposes, we often don't need these fine distinctions, so we may want to group or cluster the senses; we have already done this for some of the examples in this chapter.

We generally reserve the word **homonym** for two senses which share both a pronunciation and an orthography. A special case of multiple senses that causes problems for speech recognition and spelling correction is a homophone. **Homophones** are senses that are linked to lemmas with the same pronunciation but different spellings, such as *wood/would* or *to/two/too*. A related problem for speech synthesis are **homographs** (Chapter 8). **Homographs** are distinct senses linked to lemmas with the same orthographic form but different pronunciations, such as these homographs of *bass*:

Homophone

Homograph

(19.13) The expert angler from Dora, Mo., was fly-casting for **bass** rather than the traditional trout.

(19.14) The curtain rises to the sound of angry dogs baying and ominous **bass** chords sounding.

How can we define the meaning of a word sense? Can we just look in a dictionary? Consider the following fragments from the definitions of *right*, *left*, *red*, and *blood* from the *American Heritage Dictionary* (Morris, 1985).

right	*adj.* located nearer the right hand esp. being on the right when facing the same direction as the observer.
left	*adj.* located nearer to this side of the body than the right.
red	*n.* the color of blood or a ruby.
blood	*n.* the red liquid that circulates in the heart, arteries and veins of animals.

Note the circularity in these definitions. The definition of *right* makes two direct references to itself, and the entry for *left* contains an implicit self-reference in the phrase *this side of the body*, which presumably means the *left* side. The entries for *red* and *blood* avoid this kind of direct self-reference by instead referencing each other in their definitions. Such circularity is, of course, inherent in all dictionary definitions; these examples are just extreme cases. For humans, such entries are still useful since the user of the dictionary has sufficient grasp of these other terms.

For computational purposes, one approach to defining a sense is to make use of a similar approach to these dictionary definitions; defining a sense through its relationship with other senses. For example, the above definitions make it clear that *right* and *left* are similar kinds of lemmas that stand in some kind of alternation, or opposition,

to one another. Similarly, we can glean that *red* is a color, that it can be applied to both *blood* and *rubies*, and that *blood* is a *liquid*. **Sense relations** of this sort are embodied in on-line databases like **WordNet**. Given a sufficiently large database of such relations, many applications are quite capable of performing sophisticated semantic tasks (even if they do not *really* know their right from their left).

A second computational approach to meaning representation is to create a small finite set of semantic primitives, atomic units of meaning, and then create each sense definition out of these primitives. This approach is especially common when defining aspects of the meaning of *events* such as *semantic roles*.

We explore both of these approaches to meaning in this chapter. In the next section we introduce various relations between senses, followed by a discussion of WordNet, a sense relation resource. We then introduce a number of meaning representation approaches based on semantic primitives such as semantic roles.

19.2 Relations Between Senses

This section explores some of the relations that hold among word senses, focusing on a few that have received significant computational investigation: **synonymy**, **antonymy**, and **hypernymy**, as well as a brief mention of other relations like **meronymy**.

19.2.1 Synonymy and Antonymy

Synonym

When two senses of two different words (lemmas) are identical, or nearly identical, we say the two senses are **synonyms**. Synonyms include such pairs as

couch/sofa vomit/throw up filbert/hazelnut car/automobile

Propositional meaning

A more formal definition of synonymy (between words rather than senses) is that two words are synonymous if they are substitutable one for the other in any sentence without changing the truth conditions of the sentence. We often say in this case that the two words have the same **propositional meaning**.

While substitutions between some pairs of words like *car/automobile* or *water/*H_2O are truth preserving, the words are still not identical in meaning. Indeed, probably no two words are absolutely identical in meaning, and if we define synonymy as identical meanings and connotations in all contexts, there are probably no absolute synonyms. Besides propositional meaning, many other facets of meaning that distinguish these words are important. For example, H_2O is used in scientific contexts and would be inappropriate in a hiking guide; this difference in genre is part of the meaning of the word. In practice, the word *synonym* is therefore commonly used to describe a relationship of approximate or rough synonymy.

Instead of talking about two *words* being synonyms, in this chapter we define synonymy (and other relations like hyponymy and meronymy) as a relation between senses rather than between words. We can see the usefulness of this by considering the words *big* and *large*. These may seem to be synonyms in the following ATIS sentences, since we could swap *big* and *large* in either sentence and retain the same meaning:

(19.15) How big is that plane?

(19.16) Would I be flying on a large or small plane?

But note the following WSJ sentence in which we cannot substitute *large* for *big*:

(19.17) Miss Nelson, for instance, became a kind of big sister to Benjamin.

(19.18) ?Miss Nelson, for instance, became a kind of large sister to Benjamin.

This is because the word *big* has a sense that means being older or grown up, while *large* lacks this sense. Thus, it is convenient to say that some senses of *big* and *large* are (nearly) synonymous while other ones are not.

Antonym

Synonyms are words with identical or similar meanings. **Antonyms**, by contrast, are words with opposite meaning such as the following:

long/short big/little fast/slow cold/hot dark/light
rise/fall up/down in/out

It is difficult to give a formal definition of antonymy. Two senses can be antonyms if they define a binary opposition or are at opposite ends of some scale. This is the case for *long/short*, *fast/slow*, or *big/little*, which are at opposite ends of the *length* or *size* scale. Another group of antonyms is **reversives**, which describe some sort of change or movement in opposite directions, such as *rise/fall* or *up/down*.

From one perspective, antonyms have very different meanings since they are opposite. From another perspective, they have very similar meanings since they share almost all aspects of their meaning except their position on a scale or their direction. Thus, automatically distinguishing synonyms from antonyms can be difficult.

19.2.2 Hyponymy

Hyponym

One sense is a **hyponym** of another sense if the first sense is more specific, denoting a subclass of the other. For example, *car* is a hyponym of *vehicle*; *dog* is a hyponym of *animal*, and *mango* is a hyponym of *fruit*. Conversely, we say that *vehicle* is a

Hypernym

hypernym of *car*, and *animal* is a hypernym of *dog*. It is unfortunate that the two words (hypernym and hyponym) are very similar and hence easily confused; for this

Superordinate

reason, the word **superordinate** is often used instead of **hypernym**.

Superordinate	vehicle	fruit	furniture	mammal
Hyponym	car	mango	chair	dog

We can define hypernymy more formally by saying that the class denoted by the superordinate extensionally includes the class denoted by the hyponym. Thus, the class of animals includes as members all dogs, and the class of moving actions includes all walking actions. Hypernymy can also be defined in terms of entailment. Under this definition, a sense A is a hyponym of a sense B if everything that is A is also B, and hence being an A entails being a B, or $\forall x \; A(x) \Rightarrow B(x)$. Hyponymy is usually a transitive relation; if A is a hyponym of B and B is a hyponym of C, then A is a hyponym of C.

The concept of hyponymy is closely related to a number of other notions that play central roles in computer science, biology, and anthropology. As discussed in Chapter 17, an **ontology** usually refers to a set of distinct objects resulting from an analysis

Microworld of a single domain, or **microworld**. A **taxonomy** is a particular arrangement of the
Taxonomy elements of an ontology into a tree-like class inclusion structure. Normally, there is a set of well-formedness constraints on taxonomies that go beyond their component class inclusion relations. For example, the lexemes *hound*, *mutt*, and *puppy* are all hyponyms of *dog*, as are *golden retriever* and *poodle*, but it would be odd to construct a taxonomy from all those pairs since the concepts motivating the relations are different in each case. Instead, we normally use the word **taxonomy** to talk about the hypernymy relation between *poodle* and *dog*; by this definition, **taxonomy** is a subtype of hypernymy.

19.2.3 Semantic Fields

So far we've seen the relations of synonymy, antonymy, hypernomy, and hyponymy.
Meronymy Another common relation is **meronymy**, the **part-whole** relation. A *leg* is part of a
Part-whole *chair*; a *wheel* is part of a *car*. We say that *wheel* is a **meronym** of *car*, and *car* is a
Meronym **holonym** of *wheel*.
Holonym

But there is a more general way to think about sense relations and word meaning. Whereas the relations we've defined so far have been binary relations between two
Semantic field senses, a **semantic field** is a model of a more integrated, or holistic, relationship among entire sets of words from a single domain. Consider the following set of words:

reservation, flight, travel, buy, price, cost, fare, rates, meal, plane

We could assert individual lexical relations of hyponymy, synonymy, and so on between many of the words in this list. The resulting set of relations does not, however, add up to a complete account of how these words are related. They are clearly all defined with respect to a coherent chunk of common-sense background information concerning air travel. Background knowledge of this kind has been studied under a
Frame variety of frameworks and is known variously as a **frame** (Fillmore, 1985), **model**
Model (Johnson-Laird, 1983), or **script** (Schank and Abelson, 1977) and plays a central role
Script in a number of computational frameworks.
FrameNet

We discuss in Section 19.4.5 the **FrameNet** project (Baker et al., 1998), which is an attempt to provide a robust computational resource for this kind of frame knowledge. In the FrameNet representation, each of the words in the frame is defined with respect to the frame and shares aspects of meaning with other frame words.

19.3 WordNet: A Database of Lexical Relations

WordNet The most commonly used resource for English sense relations is the **WordNet** lexical database (Fellbaum, 1998). WordNet consists of three separate databases, one each for nouns and verbs and a third for adjectives and adverbs; closed class words are not included. Each database consists of a set of lemmas, each one annotated with a set of senses. The WordNet 3.0 release has 117,097 nouns, 11,488 verbs, 22,141 adjectives, and 4,601 adverbs. The average noun has 1.23 senses, and the average verb has 2.16 senses. WordNet can be accessed on the Web or downloaded and accessed locally.

The noun "bass" has 8 senses in WordNet.
1. bass^1 - (the lowest part of the musical range)
2. bass^2, bass part^1 - (the lowest part in polyphonic music)
3. bass^3, basso^1 - (an adult male singer with the lowest voice)
4. sea bass^1, bass^4 - (the lean flesh of a saltwater fish of the family Serranidae)
5. freshwater bass^1, bass^5 - (any of various North American freshwater fish with lean flesh (especially of the genus Micropterus))
6. bass^6, bass voice^1, basso^2 - (the lowest adult male singing voice)
7. bass^7 - (the member with the lowest range of a family of musical instruments)
8. bass^8 - (nontechnical name for any of numerous edible marine and freshwater spiny-finned fishes)

The adjective "bass" has 1 sense in WordNet.
1. bass^1, deep^6 - (having or denoting a low vocal or instrumental range) *"a deep voice"; "a bass voice is lower than a baritone voice"; "a bass clarinet"*

Figure 19.1 A portion of the WordNet 3.0 entry for the noun *bass*.

A typical lemma entry for the noun and adjective *bass* are shown in Fig. 19.1. Note that there are eight senses for the noun and one for the adjective, each of which has a *Gloss* **gloss** (a dictionary-style definition), a list of synonyms for the sense (called a **synset**), and sometimes also usage examples (shown for the adjective sense). Unlike dictionaries, WordNet doesn't represent pronunciation, so doesn't distinguish the pronunciation [b ae s] in **bass^4**, **bass^5**, and **bass^8** from the other senses pronounced [b ey s].

Synset The set of near-synonyms for a WordNet sense is called a **synset** (for **synonym set**); synsets are an important primitive in WordNet. The entry for *bass* includes synsets like *bass^1, deep^6*, or *bass^6, bass voice^1, basso^2*. We can think of a synset as representing a concept of the type we discussed in Chapter 17. Thus, instead of representing concepts in logical terms, WordNet represents them as lists of the word senses that can be used to express the concept. Here's another synset example:

{chump^1, fool^2, gull^1, mark^9, patsy^1, fall guy^1, sucker^1, soft touch^1, mug^2}

The gloss of this synset describes it as *a person who is gullible and easy to take advantage of.* Each of the lexical entries included in the synset can, therefore, be used to express this concept. Synsets like this one actually constitute the senses associated with WordNet entries, and hence it is synsets, not wordforms, lemmas, or individual senses, that participate in most of the lexical sense relations in WordNet.

Let's turn now to these lexical sense relations, some of which are illustrated in Fig. 19.2 and Fig. 19.3. WordNet hyponymy relations correspond to the notion of immediate hyponymy discussed on page 650. Each synset is related to its immediately more general and more specific synsets through direct hypernym and hyponym relations. These relations can be followed to produce longer chains of more general or more specific synsets. Figure 19.4 shows hypernym chains for **bass^3** and **bass^7**.

In this depiction of hyponymy, successively more general synsets are shown on successive indented lines. The first chain starts from the concept of a human bass singer. Its immediate superordinate is a synset corresponding to the generic concept

Relation	Also Called	Definition	Example
Hypernym	Superordinate	From concepts to superordinates	*breakfast*^{1} → *meal*^{1}
Hyponym	Subordinate	From concepts to subtypes	*meal*^{1} → *lunch*^{1}
Instance Hypernym	Instance	From instances to their concepts	*Austen*^{1} → *author*^{1}
Instance Hyponym	Has-Instance	From concepts to concept instances	*composer*^{1} → *Bach*^{1}
Member Meronym	Has-Member	From groups to their members	*faculty*^{2} → *professor*^{1}
Member Holonym	Member-Of	From members to their groups	*copilot*^{1} → *crew*^{1}
Part Meronym	Has-Part	From wholes to parts	*table*^{2} → *leg*^{3}
Part Holonym	Part-Of	From parts to wholes	*course*^{7} → *meal*^{1}
Substance Meronym		From substances to their subparts	*water*^{1} → *oxygen*^{1}
Substance Holonym		From parts of substances to wholes	*gin*^{1} → *martini*^{1}
Antonym		Semantic opposition between lemmas	*leader*^{1} ⟺ *follower*^{1}
Derivationally Related Form		Lemmas w/same morphological root	*destruction*^{1} ⟺ *destroy*^{1}

Figure 19.2 Noun relations in WordNet.

Relation	Definition	Example
Hypernym	From events to superordinate events	*fly*^{9} → *travel*^{5}
Troponym	From events to subordinate event (often via specific manner)	*walk*^{1} → *stroll*^{1}
Entails	From verbs (events) to the verbs (events) they entail	*snore*^{1} → *sleep*^{1}
Antonym	Semantic opposition between lemmas	*increase*^{1} ⟺ *decrease*^{1}
Derivationally Related Form	Lemmas with same morphological root	*destroy*^{1} ⟺ *destruction*^{1}

Figure 19.3 Verb relations in WordNet.

of a singer. Following this chain leads eventually to concepts such as *entertainer* and *person*. The second chain, which starts from musical instrument, has a completely different path leading eventually to such concepts as musical instrument, device, and physical object. Both paths do eventually join at the very abstract synset *whole, unit*, and then proceed together to *entity* which is the top (root) of the noun hierarchy (in WordNet this root is generally called the **unique beginner**).

Unique beginner

19.4 Event Participants

An important aspect of lexical meaning has to do with the semantics of events. When we discussed events in Chapter 17, we introduced the importance of predicate-argument structure for representing an event and the use of Davidsonian reification of events to represent each participant distinctly from the event itself. We now turn to representing the meaning of these *participants* or *arguments*. We introduce two kinds of semantic constraints on the arguments of event predicates: **semantic roles** and **selectional restrictions**. We begin with a particular model of semantic roles called **thematic roles**.