CHAPTER 14

Language Development

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Language provides a remarkably clear window onto the complex workings of the human psyche and the human brain. By studying people's names for animals and foods, we can learn how they think about the biological world. By examining and testing people who have suffered from a brain lesion, we can identify parts of the brain that are important for particular cognitive and emotional functions. By studying infant babbling, we can understand how the brain comes to control the vocal apparatus. By observing how people learn a second language, we can come to understand ways in which the mind and brain change over time and experience. By studying how people describe their solutions to problems, we can track the details of problem solving in activities, such as chess, architecture, medicine, and law. In these and many other ways, we can use language as a window onto the mind and the brain.

Language is also a window onto human society and social relations. Each day, we spend an enormous amount of time engaged in linguistic interactions. Some of this time is spent receiving communications from media such as television, books, or radio. For other blocks of time, we are actively involved in producing conversation. Workers in professions such as law, sales, medicine, education, or public relations spend many of their waking hours using language. When it is time to relax, we do not stop talking. Instead, we seek out friends and go to parties, restaurants, or bars where we can spend still more time talking. This enormous involvement with spoken language has important consequences for development across the life span.

Because we spend so much time talking, it should come as no surprise that the language we end up acquiring is full of great complexity and detail. On the one hand, much of language is rule-governed. We consistently form plurals in English by adding the suffix "-s" or "-es." We consistently place the adjective before the noun. But underneath this level of consistency is a bubbling sea of idiosyncratic, inconsistent partial patterns. Language is rich in frozen expressions, formulas, exceptions, and irregularities. We use the phrases "how about X" and "what about X" happily enough, but would never dream of using "when about X" or "how under X." We pronounce the "ough" in "plough," "tough," and "slough" in three totally different ways, despite the similar orthography. When we are in Boston, we expect to hear "car" pronounced without the final /r/; when we are in Pittsburgh, we expect to hear "oil" pronounced as "earl." We know that we should not say "good night" to someone until we leave, even if it is late at night, whereas we have no problem using "good morning" and "good evening" as greetings on arrival.

Language is a vast quilt of irregularities, variations, and special cases set against a backdrop of partial regularities (MacWhinney, 1975b; Pinker, 1991). A sure guide to all of these patterns is the modicum that, in language, "all rules leak." Plurals, such as *oxen, sheep,* and *leaves,* break the otherwise well-behaved plural rule. The rule for forming double-object constructions such as *Pat gave John the ball* or *Sarah mailed her Mom the chocolates* seems quite tidy. But then we find that it is impossible to say *Tom delivered the fraternity the pizza* or *He recommended me his book.* This coexistence of regularity with exceptions reflects the fact that language is used for so many purposes across so many complex social situations. When we ask sarcastically, *What is this fly doing in my soup*? we do not expect a literal answer such as "the backstroke" (Kay & Fillmore, 1999). Instead, we are using this unique and rather limited construction to express a very specific type of meaning appropriate in a very narrow context.

Language is a collection of special purpose devices for dealing with a myriad of narrow contexts, complemented by general devices for dealing with broad contexts. We learn how to use language for singing songs, imitating foreign accents, describing mathematical formulas using Greek letters, naming fish, and encoding the hundreds of names of cities, buildings, and streets we encountered on our last trip abroad. In a very basic way, language becomes a faithful record of the entire journey of our lives. When I know that someone knows how to get from Kolozsvár (Cluj) to Kalotaszeg in Romania, I know a great deal about the travels of that person. When I know that someone understands the symptoms of *polycythemia vera* (Frederiksen, Donin, Koschmann, & Myers Kelson, 2004), I know a great deal about the medical training of that person. If they can recite in Sanskrit the first lines of the Bhagavad Gita, I know still more.

Language conveys not just experience and training. It also reveals secrets about our wishes, dreams, fears, and commitments. Applying the methods of Conversation Analysis (Schegloff, 2007), we can study the ways in which pauses and drops in pitch indicate disalignments or misunderstandings between speakers. Words like *just, even*, or *sure* can betray ways in which we question other people's values or refrain from stating our own. In these various ways, the language we acquire across the life span of our development comes to represent the sum of our past experiences and our hopes for the future. Along the way to what we are now, we often pick up pieces of language that we later shed. When I was young, I referred to something interesting as being "a real trip." It has probably been 40 years since I last used that phrase, although I occasionally hear it used still, almost always sardonically.

UNIVERSAL GRAMMAR

As we survey this vast complexity of language, we wonder how children could learn all of this. One answer to this question is that the core shape of language is engraved in our genetics. According to this view, promulgated most famously by Noam Chomsky, language is not learned—it is acquired. This view of language as a Special Gift has led some researchers (Bickerton, 1990) to believe that language arose from a small set of evolutionary events. According to this view, the capacity to learn language is a unique property of the human mind represented neurologically in a separate cognitive module (Chomsky, 1980; Fodor, 1983). Studies of language learning stimulated by this perspective have tended to focus on a small set of syntactic structures that are thought to constitute the core of Universal Grammar (Chomsky, 1965). According to the "principles and parameters" model of language structure (Hyams & Wexler, 1993), the learning of particular languages occurs through the process of parameter setting. During parameter setting, children identify the exact shape of their mother tongue by choosing the proper settings on a small set of binary oppositions. For example, a positive setting on the pronoun omission parameter will select for languages like Italian or Chinese, whereas a negative setting will select for English.

This belief in a core genetic basis for human language is supported by the fact that no other animal species has ever developed a system of communication as rich and complex as human language. Unlike the communication systems of other species, language allows humans to create complete and open-ended descriptions of all manner of objects and activities outside of the here and now. This marked contrast between our species and our nearest primate relatives suggests that, over the 6-million-year course of human evolution, there must have been important genetic changes that allowed humans to develop this particular species-specific ability. Further proof of this genetic basis comes from the fact that children learn their first language "like a duck takes to water," whereas learning of a second language is often slow and incomplete. The claim is that, after some critical period, the species-specific gift for language learning expires, thereby making second language learning difficult or even impossible.

What might be at the core of this uniquely human ability? Hauser, Chomsky, and Fitch (2002) speculated that what makes human language unique is its capacity for recursion. This idea fits in nicely with the emphasis on the centrality of the recursive application of rules that has been at the core of generative grammar since its introduction (Chomsky, 1957). Early on, Miller (1965) showed that structures like relative clauses can be added at will to sentences, making the number of possible sentences in a language uncountably large. Perhaps there is some simple genetic change that occurred in recent human evolutionary history that led to the introduction of this new capacity.

The idea that there might be a gene for recursion seems attractive, because it offers the possibility of linking together facts from linguistics, cultural anthropology, neurology, genetics, and evolution. However, this proposal generates predictions that are problematic. One prediction is that all human language should display recursion. However, many languages make far less use of things like relative or complement clauses than we do in English. Languages of North America, such as Navajo or Mohawk, can break a sentence such as *The boy who shot the arrow dropped the stone*, into components like *That boy, he shot the arrow*, and *That one, he dropped the stone.* In this way, discourse can replace syntactic recursion. In his account of his work with the isolated Pirahã of the Amazon, Everett (2007) explains how these people communicate effectively without relying on recursive syntactic devices at all. In the world of this group of hunter-gatherers, what is important is an accurate description of events, rather than the recursive linkage of events into bigger discourse structures.

The view of language as a species-specific ability linked to a critical period is also problematic. Studies of the neural basis of communication in organisms such as crickets (Wyttenback, May, & Hoy, 1996), quail, and song birds (Marler, 1991) have emphasized the extent to which species-specific communication patterns are stored in highly localized hardwired neurologic structures. However, in many bird species, the consolidation of the song pattern emerges gradually over the first weeks and remains plastic or mutable for several more weeks (Konishi, 1995). When we look at human language learning, we see even more evidence for plasticity and gradual emergence, rather than strong initial canalization. There is little evidence that child language development follows a tight biological timetable of the type that we see in the development of communication systems in other organisms. In fact, children can learn language even when they have been isolated up to the age of 6 (Davis, 1947).

The nativist account of language acquisition emphasizes the idea that language learning is almost trivially easily. In truth, children find language learning not nearly as easy as the nativists suggest. Even with consistent and massive input, children struggle for three full years to acquire the core aspects of articulation in their native language. Children learn language gradually and inductively across a period of many years, rather than abruptly and deductively through the setting of a few simple parameters. No one has ever been able to present evidence for some discrete moment at which a child sets some crucial linguistic parameter (Hyams, 1995; MacWhinney & Bates, 1989). Moreover, it is difficult to use standard experimental methods to prove that children have acquired some of the abstract categories and structures required by Universal Grammar, such as argument chains, empty categories, landing sites, or dominance relations (Gopnik, 1990; van der Lely, 1994).

Language learning is not finished at age three. Rather, the acquisition of new words and constructions continues throughout our lives. In this sense, the view of human language as linked to some core genetic feature fails to tell us what we really want to know about language development across the life span.

EMERGENTISM

For a richer understanding of language development, we can turn to the theory of emergentism, which is a key component of general systems theory (von Bertalanffy, 1968) and its current developmental version—relational developmental systems theory (Lerner, 2006; Lerner & Overton, 2008; Overton, 2006). As an example of an emergent process, consider the forces that determine the length of checkout lines at a supermarket. Over time, you will find that the number of people queued up in each line stays roughly the same. There are rarely six people in one line and two in the next, unless there is a line with special rules. There is no socially articulated rule governing this pattern. Instead, the uniformity of this simple social structure emerges from other basic facts about the goals and behavior of shoppers and supermarket managers. The general principle here is that the emergence of patterns in one domain typically arises from patterns or constraints derived from a separate domain.

Honeybees are certainly no smarter than shoppers. However, working together, bees are able to construct an even more complex structure. When a bee returns to the hive after collecting pollen, she deposits a drop of wax-coated honey. Each of these honey balls has approximately the same globular shape and size. As these balls get packed together, they take on the familiar hexagonal shape that we see in the honeycomb. There is no gene in the bee that codes for hexagonality in the honeycomb, nor any overt communication regarding the shaping of the cells of the honeycomb. Rather, this hexagonal form emerges from the application of packing rules to a collection of honey balls of roughly the same size.

Nature abounds with such examples of emergence. The shapes of crystals emerge from the ways in which atoms can pack into sheets. Crystalline lattice structures (cubic, hexagonal, monoclinic, orthorhombic) emerge as packing solutions based on the relative size of the atoms in ionic compounds. The outlines of beaches emerge from interactions between geology and ocean currents. Consider the shape of Cape Cod near Provincetown, where the northeasterly drift of the Gulf Stream works to push the outline of the cape toward the mainland. Weather patterns like the Jet Stream or El Niño emerge from interactions between the rotation of the Earth, solar radiation, and the shapes of the ocean bodies. Biological patterns emerge in similar ways. For example, the shapes of the spots on a leopard or the stripes on a tiger emerge from the timing of the expression of a pair of competing genes expressing color as they set up standing waves governed by B-Z equilibria across the developing leopard or tiger embryo (Murray, 1988). No single gene directly controls these patterns. Rather, the stripes emerge from the interactions of the genes on the physical surface of the embryo. The shape of the brain is very much the same. For example, Miller, Keller, and Stryker (1989) have shown how the ocular dominance columns that Hubel and Weisel (1963) described emerge from the competition between projections from the two optic areas during synaptogenesis in striate cortex.

In 1794, Huygens demonstrated that two pendulums moving at different periods would couple together to find a single periodicity if they are mounted on a board with springs. During this coupling, one pendulum serves as the strong attractor that entrains the other pendulum to its periodicity. This form of resonant coupling also occurs within language. For example, studies of the mechanics of infant babbling have demonstrated that there is an early period when the child moves the jaw with a consistent rhythm (MacNeilage, 1998). During babbling, the periodicity of this movement then serves to entrain a similar periodicity in the opening and closing of the glottis. The result of this coupling is the emergence of canonical babbling (Vihman, 1996).

The study of interactions between hierarchically structured emergent levels is a familiar theme in sciences, such as biology, astronomy, and physics. Our biological existence is grounded on the operations of thousands of proteins, each with a subtlety different geometry, determined on four emergent levels. The primary structure of a protein is determined by its sequence of amino acids, which is, in turn, a function of the order of base pairs in a codon of DNA. This is the structure that is most tightly linked to evolution and natural selection. The secondary structure of proteins involves coils, fold, and pleats that arise from the formation of hydrogen bonds between CO and NH groups along the polypeptide backbone. Tertiary structure, leading to the folding of single polypeptides, derives from hydrophobic interactions and disulfide bridges that produce bonding between side chains. Quaternary structure emerges from the aggregation of polypeptide subunits, as in the combination of four subunits in hemoglobin. Altogether, "the specific function of a protein is an emergent property that arises from the architecture of the molecule" (Campbell, Reece, & Mitchell, 1999, p. 74).

Emergentist thinking is basic to the natural sciences. However, it applies equally well to the social, neural, and behavioral sciences (Lerner, 2006; Overton, 2006). The application of emergentism to the study of language and language development over the last two decades has proven to be particularly rewarding. In this chapter, we will explore how emergentist theory helps us understand the growth of language across the life span. Two major preliminary issues need to be examined. The first is the way in which language forms emerge in parallel across multiple *time frames.* The second is how language development is facilitated by a variety of core *mechanisms of emergence.*

TIME FRAMES

Lorenz (1958) argued that animal behavior is constrained by processes that operate across four times frames. In the case of human language, we can distinguish seven distinct time frames for emergent processes and structures.

1. *Phylogenetic emergence.* The slowest moving language structures are those that are encoded in the genes. Changes across this time frame are controlled by natural selection (Darwin, 1871). The core engine of emergence is the generation of variation through mutation, followed then by natural selection through both mate choice and differential mortality. Natural selection utilizes the possibilities for reorganization shaped by the DNA and the interactions of polypeptides that it specifies. Emergentist accounts in this area have emphasized

the ways in which language, society, and cognition have undergone coevolution (MacWhinney, 2002) based on the linking of dynamic systems. Changes in linguistic abilities must arise in parallel with advances in cognitive or social abilities to trigger this coevolutionary advantage. Moreover, both effects must interact at the moment of speaking. When this happens in a way that favors reproductive fitness, the mutation will be preserved.

2. *Epigenetic emergence.* The codification of information in the DNA represents a precise meshing between the slow-moving process of evolution and the faster moving process of epigenesis (Waddington, 1957). Embryologists have shown that biological structures emerge from processes of induction between developing tissue structures in the embryo. The shape of these interactions is not hard-coded in the DNA. Instead, the DNA encodes information that can push the process of differentiation in particular directions at crucial epigenetic choice points. The precursors of autism in the embryo can be traced to particular epigenetic effects, as can the formation of stripes in the tiger (Murray, 1988). Epigenetic emergence continues throughout the life span. Later forms of epigenetic emergence include changes such as puberty, menopause, or disorders such as schizophrenia and Huntington chorea. Before birth, epigenetic interactions with the environment are confined to forces that impinge on the uterus and the embryonic fluid. After birth, the environmental interactions can trigger patterns such as diabetes or brain reorganization for language in the deaf (Bellugi, Poizner, & Klima, 1989).

3. *Developmental emergence.* Jean Piaget's genetic psychology (Piaget, 1954) was the first fully articulated emergentist view of development. Impressively complete in its coverage, it failed to specify details regarding mechanisms of development. Current emergentist accounts of development rely on connectionism, embodiment, and dynamic systems theory to provide this missing processing detail (Quinlan, 2003). Emergentist theory has been used to characterize two different, but interrelated, aspects of development. The first is the basic learning process that involves the continual learning of new facts, forms, relations, names, and procedures. Basic models of language learning, such as those that deal with learning of the past tense (MacWhinney & Leinbach, 1991), often focus on this type of development. A second type of development involves the learning of new strategies and frameworks that can alter the overall shape of language and cognition, often through cue focusing (Colunga & Smith, 2000; Regier, 2005). Work linking these two strands together has just begun.

4. *Processing emergence.* The most fast-acting pressures on language form are those that derive from online processing constraints (MacWhinney, 1999b). The basic constraint here is the need to produce language that keeps our listeners' attention and effectively communicates what we want to say. To achieve this, we rely on a variety of well-coordinated mechanisms for attentional focusing, coordination of sentence planning, code switching between languages, and motor control. Many of the pressures we sense in the current moment are themselves driven by long-term processes. For example, a child's failure to understand the meaning of the word *dependability* in a discussion of the reliability of batteries may be the result of problems in understanding previous classroom and computerized lessons on numeric distributions. Similarly, the failure in lexical retrieval that occurs in aphasia is driven by changes to neural tissue subsequent to a stroke. Thus, online processing emergence can reflect the current status of longer term developmental, neuronal, and physiologic processes.

5. *Social emergence.* Many aspects of language are shaped by social mimetics (Mesoudi, Whiten, & Laland, 2006). Our choice of vocabulary, slang, phonetic form, and topics is determined by the nature of the relations we perceive with the people we meet. We can select these options to emphasize solidarity (Brown & Gilman, 1960), impose our power, or seek favors (Brown & Levinson, 1978). The time course of changes in these social commitments is often measured in terms of years or decades, with many remaining constant across the life span.

6. *Interactional emergence.* Apart from our long-term commitments to dialects, languages, and subgroup themes, we also make more short-term commitments to ongoing social interactions. For example, we may engage a real-estate agent to help us purchase a house. Our linguistic interactions with this agent are then shaped by the current status of the buying process. Even after we terminate one set of transactions with this agent, we will maintain an ongoing relation that will then shape our further interactions, days or weeks later (Keenan, MacWhinney, & Mayhew, 1977).

7. *Diachronic emergence.* We can also use emergentist thinking to understand the changes that languages have undergone across the centuries (Bybee & Hopper, 2001). These changes emerge from a further complex interaction of the previous three levels of emergence (evolutionary, developmental, and online).

MECHANISMS OF EMERGENCE

Emergentism agrees with Universal Grammar (UG) on one core issue: the idea that human language is uniquely well adapted to human nature. The fact that all people succeed in learning to use language, whereas not all people learn to swim or do calculus, demonstrates how fully language conforms to our human nature. Languages avoid sounds that people cannot produce, words they cannot learn, or sentence patterns they cannot parse. Emergentism differs from UG in that it attributes this match to general versus specific mechanisms. In the UG account, specific genetic mechanisms arose over recent evolutionary history that support this uniquely human ability. In the emergentist account, language depends on a set of domain-general mechanisms that ground language on the shape of the human body, brain, and society. This is the core difference between UG and emergentism.

As noted earlier, much of the complexity of language arises from the shape of society. However, we can also point to a rich array of domain-general mechanisms that serve to support the learning and processing of language. Some of these mechanisms include:

1. *Homeorrhesis:* All neurobiological processes are grounded on the brain's ability to maintain homeorrhesis and homeostasis to provide underlying stability in neural function, despite the fact that cells and protoplasm are continually undergoing change.
2. *Competition:* Like other biological systems, the brain relies on variation and competition (Edelman, 1987) to learn the appropriate matching of responses to stimuli.
3. *Control:* Systems such as the basal ganglia circuit involving the striatum, thalamus, cortex, globus pallidus, and substantia nigra provide multiple loop-back levels (von Bertalanffy, 1968) for attentional control, proceduralization, and error-based learning (Rumelhart & McClelland, 1986).
4. *Topological organization:* The brain depends on a system for connecting areas through topological (tonotopic, somatotopic, retinotopic, etc.) organization that emerges during embryogenesis. This system links to methods for self-organization in feature maps (Kohonen, 2001) and topological sheets (Elman, 1999; Shrager & Johnson, 1995).
5. *Item basis:* The brain links episodic (McClelland, McNaughton, & O'Reilly, 1995) and procedural systems to support item-based learning (MacWhinney, 1975a; Tomasello, 2000a) of grammatical constructions (Goldberg, 1999).
6. *Statistical learning:* Statistical learning allows both children and adults to learn patterns of sounds, tones, or visual forms (Jusczyk, 1997; Saffran, Aslin, & Newport, 1996), as constituted in sequential groups (Gupta & MacWhinney, 1997; Houghton, 1990).
7. *Redundancy:* The brain supports multiple systems for redundancy to provide plasticity and recovery from injury. For example, the brain can compensate for damage to language areas in the left hemisphere through reorganization to the right hemisphere (Booth et al., 1999; Corina, Vaid, & Bellugi, 1992; MacWhinney, Feldman, Sacco, & Valdes-Perez, 2000).
8. *Learning to learn:* Competition, statistical learning, and control loops can guide learners' attention to cues that have proved useful in learning previous similar forms (Smith, 1999). This then confirms the importance of these cues for further learning.
9. *Analogy:* The interactive and connected nature of neural processing allows problem solvers and learners to structure domains and relations in parallel alignment (Gentner & Markman, 1997).
10. *Resonance:* The consolidation of new learning, particularly in second language learning, can rely on the development of resonance between alternative systems (orthography, phonology, mnemonics) for encoding across multiple languages (MacWhinney, 2005a). For example, when we code-switch from English to Spanish, the initial moments of speaking in Spanish are still under the influence of resonance operating in English (Grosjean & Miller, 1994).

LEVELS OF LANGUAGE

Unlike certain basic systems such as smell or balance, language processing depends on the coordination of activities between many cortical regions. Linguistic theory has traditionally analyzed language across the levels of auditory phonology, articulatory phonology, lexicon, morphology, syntax, and pragmatics. Research in cognitive neurolinguistics (MacWhinney & Li, 2008) provides additional support for this analysis, as summarized in Table 14.1.

TABLE 14.1 The Six Subsystems of Language

Subsystem	Cortical Area	Processes	Theory
Audition	Auditory cortex	Extracting phonemes	Statistical learning
Articulation	Motor cortex	Targets, timing	Resonance, gating
Lexicon	Wernicke's area	Phonology to meaning	DevLex
Syntax	Inferior frontal gyrus	Slots, sequences	Item-based patterns
Mental models	Dorsal cortex	Deixis, perspective	Perspective
Conversation	Social system	Topics, turn taking	Conversation analysis

Before beginning our study of the life-span development of these systems, let us take a quick glance over each of these six components. First, consider the relation between auditory and articulatory learning. Auditory development involves learning how to distinguish the basic sounds of the language and using them to segment the flow of speech into words. This learning involves the receptive or perceptual side of language use. Children's articulatory development, in contrast, involves learning to control the mouth, tongue, and larynx to produce sounds that imitate those produced by adults. This learning involves the productive or expressive use of language. Auditory learning and articulatory learning are the two sides of phonological development. Clearly, we cannot acquire conventional control over articulation until we have learned the target auditory contrasts. Thus, audition logically precedes articulation.

The third dimension of language development is lexical development, or the learning of words. To serve as a means of communication between people, words must have a shared or conventional meaning. Picking out the correct meaning for each new word is a major learning task for the child. But it is not enough for children to just recognize words produced by their parents. To express their own intentions, they have to be able to recall the names for things on their own and convert these forms into actual articulations. Thus, lexical development, like phonological development, includes both receptive and expressive components.

Having acquired a collection of words, children can then put them into combinations. Syntax—the fourth component of language—is the system of rules by which words and phrases are arranged to make meaningful statements. Children need to learn how to use the ordering of words to mark grammatical functions such as subject or direct object.

The fifth linguistic component that a child must learn to master is the system of mental models that relate syntactic patterns to meaningful interpretations. During production, this system takes meanings and prepares them into a form that Slobin (1996) has called "thinking for speaking." During comprehension, this system takes sentences and derives embodied mental models for the meanings underlying these sentences.

The sixth component that the child must acquire encodes the social and pragmatic principles for conversation. This is the system of patterns that determines how we can use language in particular social settings for particular communicative purposes. Because pragmatics refers primarily to the skills needed to maintain conversation and communication, child language researchers find it easiest to refer to pragmatic development as the acquisition of communicative competence and conversational competence (Ochs & Schieffelin, 1983). A major component of communicative competence involves knowing that conversations customarily begin with a greeting, require turn-taking, and concern a shared topic. Children must also learn that they need to adjust the content of their communications to match their listener's interests, knowledge, and language ability.

Auditory Development

William James (1890) described the world of the newborn as a "blooming, buzzing confusion." However, we now know that, at the auditory level at least, the newborn's world is remarkably well structured. The cochlea and auditory nerve provide extensive preprocessing of signals for frequency and intensity. By the time the signal reaches the auditory cortex, it is fairly well structured.

Perceptual Contrasts

Research on the emergence of auditory-processing abilities has identified three major streams of auditory learning and development. The first stream involves the core perceptual features of hearing. In the 1970s, researchers (Eimas, Siqueland, Jusczyk, & Vigorito, 1971) discovered that human infants were specifically adapted at birth to perceive contrasts such as that between /p/ and /b/, as in *pit* and *bit*. However, it soon became apparent that even chinchillas were capable of making this distinction (Kuhl & Miller, 1978). This suggests that much of the basic structure of the infant's auditory world might be attributed to fundamental processes in the mammalian ear and cochlear nucleus, rather than some specifically human adaptation. As infants sharpen their ability to hear the contrasts of their native language, they begin to lose the ability to hear contrasts not represented in their native language (Werker, 1995). If the infant is growing up in a bilingual world, full perceptual flexibility is maintained (Sebastián-Galles & Bosch, 2005). However, if the infant is growing up monolingual, flexibility in processing is gradually traded off for quickness and automaticity (Kilborn, 1989).

Statistical Learning

The second stream of auditory development is the ability to process the statistical regularities of spoken language. It is as if the infant has something akin to a tape recorder in the auditory cortex that records input sounds, replays them, and accustoms the ear to their patterns, well before learning the actual meanings of these words. There is now abundant evidence that both infants (Aslin, Saffran, & Newport, 1999; Marcus, 2000) and monkeys (Hauser, Newport, & Aslin, 2001) are able to use sequential statistics to extract background properties of their language involving prosodies (Thiessen & Saffran, 2007), phonotactics (Thiessen, 2007), and possible segments. These stored sequences can help the child solidify preferences for certain voices over others. Thus, a French infant will prefer to listen to French, whereas a Polish infant will prefer to listen to Polish (Jusczyk, 1997). In addition, babies demonstrate a preference for their own mother's voice, as opposed to that of other women. In fact, this learning seems to begin even before birth. DeCasper and Fifer (1980) tape-recorded mothers reading a Dr. Seuss book, and then played back these tapes to newborns before they were 3 days old. Making the playback of the tapes contingent on the sucking of a pacifier, they found that babies sucked harder for recordings from their own mothers than for those from other mothers. Moreover, newborns preferred stories their mothers had read out loud even before they were born over stories that were new (DeCasper, Lecanuet, & Busnel, 1994). Thus, it appears that their prenatal auditory experience shaped their postnatal preference.

One method (Aslin et al., 1999) for studying these early auditory processes relies on the fact that babies tend to habituate to repeated stimuli from the same perceptual class. If the perceptual class of the stimulus suddenly changes, the baby will brighten up and turn to look at the new stimulus. To take advantage of this, experimenters can play back auditory stimuli through speakers placed either to the left or right of the baby. If the experimenter constructs a set of words that share a certain property and then shifts to words that have a different property, the infant may demonstrate awareness of the distinction by turning away from the old stimulus and orienting to the more interesting, new stimulus. For example, if the 6-month-old hears a sequence such as /*badigudibagadigudigagidu*/ repeated many times, the parts that are repeated will stand out and affect later listening. In this example, the repeated string is /*digudi*/. If infants are trained on these strings, they will grow tired of this sound and will come to prefer to listen to new sound strings, rather than one with the old /*digudi*/ string. This habituation effect is strongest for stressed syllables and syllables immediately following stressed syllables (Jusczyk, 1997).

Words as Cues to Segmentation

The third stream of auditory development involves the storage of sounds as potential candidate words. This type of learning is crucial for the segmentation of speech into meaningful units. By 6 months, children are able to respond to their own name. Using the auditory codes they have developed, they can retain traces of words they have heard, although they may not yet have learned what these words mean. Recent attempts to model the growth of speech segmentation (Batchelder, 2002; Monaghan, Christiansen, & Chater, 2007) have shown that the ability to detect known words within new sequences is a crucial key to language learning. Brent and Siskind (2001) observed that nearly a quarter of the utterances presented to young children involve single words. These forms can be directly and accurately acquired without segmentation. Thus, if the mother points to a dog and says "doggie," the child can directly acquire this as a candidate word form. Then, when the child hears the combination "nice doggie," the familiar form "doggie" can be segmented out from the unfamiliar form "nice." This is what MacWhinney (1978) called the *segmentation of the known from the unknown.* The further task facing the child is then to link the unknown to a specific candidate meaning.

Articulatory Development

Although we have good experimental evidence for a growing auditory awareness in the infant, the first directly observable evidence of language-like behaviors occurs when the child vocalizes. At birth, the child is already capable of four distinct types of cries (Wäsz-Hockert, Lind, Vuorenkoski, Partanen, & Valanne, 1968): the birth cry, the pain cry, the hunger cry, and the pleasure cry. The birth cry occurs only at birth and involves the infant trying to clear out the embryonic fluid that has accumulated in the lungs and trachea. The pain cry can be elicited by pricking the baby with a pin. The hunger cry is a reliable indicator of the infant's need to be fed. The pleasure cry, which is softer and not too frequent at first, seems to be the cry from which later language develops. Moreover, using spectrographic analysis, one can distinguish children with genetic abnormalities such as *cri du chat* or Lesch–Nyan syndrome at this age through their cries (Wäsz-Hockert, Lind, Vuorenkoski, Partanen, & Valanne, 1968).

Fixed Action Patterns

Infant cry patterns can be understood from the framework of the study of animal behavior or ethology (Tinbergen, 1951). In that framework, animals are viewed as capable of producing certain fixed action patterns. For example, bucks have fixed action patterns for locking horns in combat. Birds have fixed action patterns for seed pecking and flying. In humans, fixed action patterns include sucking, crying, eye fixation, and crawling. These various fixed action patterns are typically elicited by what ethologists call *innate releasing mechanisms.* For example, the sight of the nipple of the mother's breast elicits sucking. Mothers respond to an infant's hunger cry by lactating. A pinprick on a baby's foot elicits the pain cry, and parents respond to this cry by picking up and cuddling the child. On this level, we can think of the origins of language as relatively phylogenetically ancient and stable.

During the first 3 months, a baby's vocalizations involve nothing more than cries and vegetative adaptations, such as sucking, chewing, and coughing. However, around 3 months (Lewis, 1936; McCarthy, 1954), at the time of the first social smile, babies begin to make delightful little sounds called "cooing." These sounds have no particular linguistic structure, but their well-integrated intonation makes them sure parent pleasers. During this time, the number and variety of vowel-like sounds the infant produces shows a marked increase. Unlike the vowels of crying, these vowels are produced from pleasure. Irwin (1936) noted that, up to 6 months, the infant's sounds are 90% back consonants like /*g*/ and /*k*/ and midvowels like /□/ and /ə/.

Babbling and Cortical Control

At around 6 months of age, there is shift from back to front consonants. This shift may be a result of the shift from the dominance of spinal control of grosser synergisms like swallowing to cortical control of finer movements (Berry & Eisenson, 1956; Tucker, 2002). This shift to cortical control allows the baby to produce structured vocalizations, including a larger diversity of individual vowels and consonants, mostly in the shape of the consonant-vowel (CV) syllables like /*ta*/ or /*pe*/. As the frequency of these structured syllable-like vocalizations increases, we begin to say that the infant is babbling. Neural control of early babbling is built on top of patterns of noisy lip-smacking that are present in many primates (MacNeilage, 1998). These CV vocal gestures (Hoyer & Hoyer, 1924) include some form of vocal closure followed by a release with vocalic resonance.

Until the sixth month, deaf infants babble much like hearing children (Oller & Eilers, 1988). However, well before 9 months, deaf infants lose their interest in babbling, diverging more and more from the normal pathway (Mavilya, 1972). This suggests that their earlier babbling is sustained through proprioceptive and somesthetic feedback, as the babies explore the various ways in which they can play with their mouth. After 6 months, babbling relies increasingly on auditory feedback. During this period, the infant tries to produce specific sounds to match up with specific auditory impressions. It is at this point that the deaf child no longer finds babbling entertaining, because it is not linked to auditory feedback. These facts suggest that, from the infant's point of view, babbling is essentially a process of exploring the coordinated use of the mouth, lungs, and larynx.

In the heyday of behaviorism, researchers viewed the development of babbling in terms of reinforcement theory. For example, Mowrer (1960) thought that babbling was driven by the infant's attempt to create sounds like those made by their mothers. In behaviorist terms, this involves secondary goal reinforcement. Other behaviorists thought that parents would differentially reinforce or shape babbling through smiles or other rewards. They thought that these reinforcements would lead a Chinese baby to babble the sounds of Chinese, whereas a Quechua baby would babble the sounds of Quechua. This was the theory of "babbling drift." However, closer observation has indicated that this drift toward the native language does not occur clearly until after 10 months (Boysson-Bardies & Vihman, 1991). After 12 months, we see a strong drift in the direction of the native language as the infant begins to acquire the first words. Opponents of behaviorism (Jakobson, 1968) stressed the universal nature of babbling, suggesting that all children engage in babbling all the sounds of all the world's languages. However, this alternative position also seems to be too strong. Although it is certainly true that some English-learning infants will produce Bantu clicks and Quechua implosives, not all children produce all of these sounds (Cruttenden, 1970).

Although vowels can be acquired directly as whole stable units in production, consonants can be articulated only in combinations with vowels, as pieces of whole syllables. The information regarding the place of articulation for all consonants except fricatives (Cole & Scott, 1974) is concentrated in the formant transitions that occur before and after the steady state of the vowel. In CV syllables like /*pa*/ or /*ko*/, each different consonant will be marked by different patterns of transitions before and after different vowels. Thus, in /*di*/, the second format rises in frequency before the steady state of the vowel, whereas in /*du*/, the second formant falls before the vowel. Massaro (1975) argued that this blending makes the syllable the natural unit of perception, as well as the likely initial unit of acquisition. By learning syllables as complete packages, the child avoids the problem of finding acoustic invariance for specific phonemes. If the syllable is, in fact, the basic unit of perception, we would expect to find that auditory storage would last at least 200 ms, or about as long as the syllable. In fact, it appears that there is a form of auditory storage that lasts about 250 ms (Massaro, 1975), indicating that it may be adapted to encode and process syllables.

Ongoing practice with whole syllables occurs throughout the babbling period that extends from around 4 months to the end of the first year. In languages like Japanese, which has only 77 syllable types, this learning may allow the child to control some significant part of adult phonology. In English, with more than 7,000 possible syllables, learning of the language through the acquisition of syllables seems to be a less realistic goal.

Infants commonly produce syllables sounding like /*ba*/ and /*di*/, but are relatively less likely to produce /*bi*/, probably because making a /*b*/ results in a tongue position well suited to following with /*a*/ but not /*i*/ (MacNeilage, Davis, Kinney, & Matyear, 2000). Vihman (1996) studied infants and toddlers learning Japanese, French, Swedish, and English. A very small number of syllables accounted for half of those produced in all the groups, and the two most frequent syllables, /*da*/ and /*ba*/, were used by all language groups. These patterns suggest that infants use a basic motor template to produce syllables. These same constraints also affect the composition of the first words (Oller, 2000).

Between 6 and 10 months of age, there seems to be a tight linkage between babbling and general motoric arousal. The child will move arms, head, and legs while babbling, as if babbling is just another way of getting exercise while aroused. During the last months of the first year, the structure of babbling becomes clearer, more controlled, and more organized. Some children produce repetitive syllable strings, such as /*badibadibadibadigu*/; others seem to be playing around with intonation and the features of particular articulations.

Circular Reactions

Piaget's (1952) theory of sensorimotor learning provides an interesting account of many of these developments. Piaget viewed much of early learning as based on circular reactions in which the child learned to coordinate the movements of one process or schema with another. In the case of babbling, the child is coordinating the movements of the mouth with their proprioceptive and auditory effects. In these circular reactions, the child functions as a "little scientist" who is observing and retracing the relations between one schema and another. For example, in the first month, the newborn will assimilate the schema of hand motion to the sucking schema. In babbling, the child assimilates the schema of mouth motions to the perceptual schema of audition, proprioception, and oral somesthesia. There is much to support this view. It seems to be particularly on the mark for those periods of late babbling when the child is experimenting with sounds that are found in other languages. Also, the fact that deaf babies continue to babble normally until about 6 months also tends to support this view.

Phonotactic Processes

The child's first words can be viewed as renditions of adult forms that have gone through a series of simplifications and transformations. Some of these simplifications lead to the dropping of difficult sounds. For example, the word *stone* is produced as *tone.* In other cases, the simplifications involve making one sound similar to those around it. For example, *top* may be produced as *pop* through regressive assimilation. Assimilation is a process that results in the features of one sound being adapted or assimilated to resemble those of another sound. In this case, the labial quality of the final /*p*/ is assimilated backward to the initial /*t*/, replacing its dental articulation with a labial articulation. We can refer to these various types of assimilations and simplifications as "phonological processes" (Menn & Stoel-Gammon, 1995; Stampe, 1973). Many of these processes or predispositions seem to be based on something like the principle of "least effort" (Ponori, 1871). A proper theory of least effort has to be grounded on an independent phonetic account of effort expenditure. Ohala (1974, 1981, 1994) has explored many of the components of this theory. However, most child phonologists have not yet made use of phonetically grounded principles, preferring to construct abstract accounts based on Optimality Theory (Kager, 1999).

The child's problems with phonological form are very much focused on production, rather than perception. An illustration of this comes from the anecdote in which a father and his son are watching boats in the harbor. The child says, "Look at the big sip." Echoing his son's pronunciation, the father says, "*Yes, it's quite a big sip.*" To this, the child protests, saying, "No, Daddy say 'sip' not 'sip.'" Such anecdotes underscore the extent to which the child's auditory forms for words line up with the adult standard, even if their actual productions are far from perfect.

Detailed observations of the course of phonological development have shown that the development of individual word forms does not follow a simple course toward the correct adult standard. Sometimes there are detours and regressions from the standard. For example, a child may start by producing *step* accurately. Later, under the influence of pressures for simplification of the initial consonant cluster, the child will regress to production of *step* as *tep.* Finally, *step* will reassert itself. This pattern of good performance, followed by poorer performance, and then finally good performance again is known as "U-shaped learning," because a graph of changes in accuracy across time resembles the letter U. The same forces that induce U-shaped learning can also lead to patterns in which a word is systematically pronounced incorrectly, even though the child is capable of the correct pronunciation. For example, Smith (1973) reported that his son systematically produced the word *puddle* as *puggle*. However, he showed that he was able to produce *puddle* as an incorrect attempt at *puzzle.* One possible interpretation of this pattern is that the child produces *puggle* in an attempt to distinguish it from *puddle* as the incorrect pronunciation of *puzzle.* Here, as elsewhere in language development, the child's desire to mark clear linguistic contrasts may occasionally lead to errors.

Word Learning

The emergence of the first word is based on three earlier developments. The first is the infant's growing ability to record the sounds of words. The second is the development of an ability to control vocal productions that occurs in the late stages of babbling. The third is the general growth of the symbolic function, as represented in play, imitation, and object manipulation. Piaget (1954) characterized the infant's cognitive development in terms of the growth of representation or the "object concept." In the first 6 months of life, the child is unable to think about objects that are not physically present. However, a 12-month-old will see a dog's tail sticking out from behind a chair and realize that the rest of the dog is hiding behind the chair. This understanding of how parts relate to wholes supports the child's first major use of the symbolic function. When playing with toys, the 12-month-old will begin to produce sounds such as *vroom* or *bam-bam* that represent properties of these toys and actions. Often, these phonologically consistent forms appear before the first real words. Because they have no clear conventional status, parents may tend to ignore these first symbolic attempts as nothing more than spurious productions or babbling.

Even before producing the first conventional word, the 12-month-old has already acquired an ability to comprehend perhaps a dozen conventional forms. During this period, parents often realize that the prelinguistic infants are beginning to understand what they say. However, it is difficult for parents to provide convincing evidence of this ability. Researchers deal with this problem by bringing infants into the laboratory, placing them into comfortable highchairs, and asking them to look at pictures, using the technique of visually reinforced preferential looking. A word such as *dog* is broadcast across loudspeakers. Pictures of two objects are then displayed. In this case, a dog may be on the screen to the right of the baby and a car may be on the screen to the left. If the child looks at the picture that matches the word, a toy bunny pops up and does an amusing drum roll. This convinces babies that they have chosen correctly and they then continue looking at the named picture on each trial. Some children get fussy after only a few trials, but others last for 10 trials or more at one sitting and provide reliable evidence that they know a few words. Many children demonstrate this level of understanding by the 10th month—2 or 3 months before they have produced their first recognizable word.

Given the fact that the 10-month-old is already able to comprehend several words, why is the first recognizable conventional word not produced until several months later? Undoubtedly, many of the child's first attempts to match an articulation with an auditory target fall on deaf ears. Many are so far away from the correct target that even the most supportive parent cannot divine the relation. Eventually, the child produces a clear articulation that makes clear sense in context. The parent is amazed and smiles. The child is reinforced and the first word is officially christened. But all is still not smooth sailing. The challenges of word production discussed earlier make early words difficult to recognize. Rather than having to go through sessions of repeated noncomprehension, children may spend a month or two consolidating their conceptual and phonological systems in preparation for an attack on the adult target. However, most children do not go through this silent period. Instead, late babbling tends to coexist with the first words in most cases.

One way of understanding the challenge presented by the first words views the problem from the perspective of the infant. When babbling, the only constraints infants face are those arising from their own playfulness and interest. There are no socially defined constraints on the range of variation of those sounds. Some babies may try to get each sound "just right," but they do this to match their own goals and not ones imposed from outside. When the task shifts to making use of conventional words, the constraints come from unclarity about meaning, variability in the perception of the sound, and the problem of matching the adult articulations. Thus, babbling provides the child with only a small part of the foundation for use of the first words.

It is easy to assume that children have some innate knowledge that tells them that words will always involve some spoken verbal form. However, an innate constraint of this type would severely limit the learning of sign language by deaf children. It would also inhibit gestural learning by hearing children. Rather than obeying some narrow view of the possible shape of a word, children are willing to learn all sorts of meaningful relations between signs and the objects that they represent. For example, Namy and Waxman (1998) found that normal 18-month-olds are happy to learn gestures as object labels. Similarly, Woodward and Hoyne (1999) found that 13-month-olds are happy to respond to the sound produced by an object as if it were its name.

Discovering Meanings

From Plato to Quine, philosophers have considered the task of figuring out word meaning to be a core intellectual challenge. For example, if the child were to allow for the possibility that word meanings might include disjunctive Boolean predicates (Hunt, 1962), then it might be the case that the word grue would have the meaning "green before the year 2000 and blue thereafter." Similarly, it might be the case that the name for any object would refer not to the object itself, but to its various undetached parts. When one thinks about word learning in this abstract way, it appears to be impossibly hard.

Quine (1960) illustrated the problem by imagining a scenario in which a hunter is out on safari with a native guide. Suddenly, the guide shouts "Gavagai" and the hunter, who does not know the native language, has to quickly infer the meaning of the word. Does it mean "shoot now," or "there's a rhino," or perhaps even "it got away"? If the word refers to the rhino, does it point to the horn, the hooves, the skin, or the whole animal? Worse still, the word could refer to the horn of a rhino if it is before noon and the tail of a jackal after noon. Without some additional cues regarding the likely meaning of the word, how can the poor hunter figure this out?

Fortunately, the toddler has more cues to rely on than the hunter. The first person to recognize the shape of these cues was Augustine, the great Church father, who wrote this in his *Confessions* (1952):

> This I remember; and have since observed how I learned to speak. It was not that my elders taught me words (as, soon after, other learning) in any set method; but I, longing by cries and broken accents and various motions of my limbs to express my thoughts, that so I might have my will, and yet unable to express all I willed or to whom I willed, did myself, by the understanding which Thou, my God, gavest me, practice the sounds in my memory. When they named anything, and as they spoke turned towards it, I saw and remembered that they called what they would point out by the name they uttered. And that they meant this thing, and no other, was plain from the motion of their body, the natural language, as it were, of all nations, expressed by the countenance, glances of the eye, gestures of the limbs, and tones of the voice, indicating the affections of the mind as it pursues, possesses, rejects, or shuns. And thus by constantly hearing words, as they occurred in various sentences, I collected gradually for what they stood; and, having broken in my mouth to these signs, I thereby gave utterance to my will. Thus I exchanged with those about me these current signs of our wills, and so launched deeper into the stormy intercourse of human life, yet depending on parental authority and the beck of elders. (1952, p. 8)

Augustine's reflections are remarkable for several reasons. First, he emphasizes the natural, emergent nature of word learning situated directly in situational contexts. Second, he understood the importance of a preliminary period of auditory learning, followed then by an arduous process of articulatory control. Third, he focused on the learning of words in the direct presence of the referent

(Cartwright & Brent, 1997; Huttenlocher, 1974). Fourth, to further confirm shared attention on a candidate referent, he made use of a variety of gestural and postural cues from his elders.

Recent research has supported and elaborated Augustine's intuitions. The ability to follow eye gaze appears to rely on fundamental developments in the visual system that emerge in the first 4 months of life (Johnson, 1992). These developmental changes involve the linkage of basic phylogenetic abilities to ongoing epigenesis. Similar changes arise in the tracking of postural cues and pointing. By the time the child comes to learn the first words, these cues are generally accessible. Baldwin (1991; Baldwin & Markman, 1989) has shown that children try to acquire names for the objects that adults are attending to. Similarly, Akhtar, Carpenter, and Tomasello (1996) and Tomasello and Akhtar (1995) have emphasized the crucial role of mutual gaze between mother and child in the support of early word learning. Bates, Benigni, Bretherton, Camaioni, and Volterra (1979) showed how 10-month-olds would reliably follow eye gazes, pointing, and gesturing. Gogate, Bahrick, and Watson (2000) showed that, when mothers teach infants a name for a novel toy, they tend to move the toy as they name it, much as Augustine suggested.

One hardly needs to conduct studies to demonstrate the role of gaze, intonation, and pointing, because these cues are so obvious to all of us. However, a second aspect of Augustine's analysis is subtler and less fully appreciated. This is the extent to which children seek to divine the intention of the adult as a way of understanding a word's meaning. They want to make sure that the adult is directly attending to an object, before they decide to learn a new word (Baldwin et al., 1996). If the adult is speaking from behind a screen, children are uncertain about the adult's intentions and fail to learn the new word. Tomasello and Ahktar (1995) illustrated this by teaching 2-year-olds a new verb such as *hoisting.* In some of the trials, the toy character would inadvertently swing away and the experimenter would say "whoops." In those trials, the children would not associate *hoisting* with the failed demonstration. Generalizing from these studies, Tomasello (1999, 2003) and Bloom (2002) have argued that word learning depends primarily on the child's ability to decode the parent's intentions. Further support for this view comes from the fact that autistic children have problems picking up on both gestural and intentional cues, possibly because of the fact that they have incompletely constructed models of the goals and intentions of other people (Baron-Cohen, Baldwin, & Crowson, 1997; Frith & Frith, 1999).

Initial Mapping

Laboratory studies of word learning typically rely on a process of relatively fast initial mapping of a new word to a new meaning. This is the type of quick, but superficial, word learning that occurs when a child encounters a new word for the first time. The initial mapping process involves the association of auditory units to conceptual units (Naigles & Gelman, 1995; Reznick, 1990). For example, the 14-month-old can be brought into the laboratory (Schafer & Plunkett, 1998) and shown a picture of an animal called a "tiv." The child will then demonstrate understanding of the new word by turning to a picture of the new animal, rather than a picture of a dog, when hearing the word "tiv." In these laboratory experiments, children are learning a new concept in parallel with a new word. However, in the real world, children often have developed a clear idea about a concept well before they have learned the word for that concept. The child comes to the task of word learning already possessing a fairly well-structured coding of the basic objects in the immediate environment (Piaget, 1954; Stiles-Davis, Sugarman, & Nass, 1985; Sugarman, 1982). Children treat objects such as dogs, plates, chairs, cars, baby food, water, balls, and shoes as fully structured, separate categories (Mervis, 1984). They also show good awareness of the nature of particular activities such as falling, bathing, eating, kissing, and sleeping. This means that, in reality, conceptual organization often precedes lexical mapping. Thus, word learning is usually not the mapping of a new word to a new meaning, but the mapping of a new word to an old meaning. Moreover, in some cases, the sound of the word may already be a bit familiar and the learning really involves the mapping of an old form to an old meaning. Because natural learning is difficult to control, there have been relatively few studies of this more natural process.

Undergeneralization, Generalization, and Overgeneralization

Because of this specificity, early word uses are often highly *undergeneralized* (Dromi, 1987; Kay & Anglin, 1982). For example, a child may think that *dog* is the name for the family pet or that *car* refers only to vehicles parked at a specific point outside a particular balcony (L. Bloom, 1973). It is sometimes difficult to detect undergeneralization, because it never leads to errors. Instead, it simply leads to a pattern of idiosyncratic limitations on word usage. Early undergeneralizations are gradually corrected as the child hears the words used in a variety of contexts. Each new context is compared with the current meaning. Those features that match are strengthened (MacWhinney, 1989) and those that do not match are weakened. When a feature becomes sufficiently weak, it drops out altogether.

This process of generalization is guided by the same cues that led to initial attention to the word. For example, it could be the case that every time the child hears the word *apple*, some light is on in the room. However, in none of these cases do the adults focus their attention on the light. Thus, the presence or absence of a light is not a central element of the meaning of *apple.* The child may also occasionally hear the word *apple* used even when the object is not present. If, at that time, attention is focused on some other object that was accidentally associated with *apple*, the process of generalization could derail. However, cases of this type are rare. The more common case involves use of *apple* in a context that totally mismatches the earlier uses. In that case, the child simply assumes nothing and ignores the new exemplar (Stager & Werker, 1997).

Gradually, the process of generalization leads to a freeing of the word from irrelevant aspects of the context. Over time, words develop a separation between a "confirmed core" (MacWhinney, 1984, 1989) and a peripheral area of potential generalization. As the confirmed core of the meaning of a word widens and as irrelevant contextual features are pruned out, the word begins to take on a radial or prototype form (Lakoff, 1987; Rosch & Mervis, 1975). In the center of the category, we find the best instances that display the maximum category match. At the periphery of the category, we find instances whose category membership is unclear and which compete with neighboring categories (MacWhinney, 1989).

According to this core-periphery model of lexical structure, overgeneralizations arise from the pressures that force the child to communicate about objects that are not inside any confirmed core. Frequently enough, children's overgeneralizations are corrected when the parent provides the correct name for the object (Brown & Hanlon, 1970). The fact that feedback is so consistently available for word learning increases our willingness to believe that the major determinants of word learning are social feedback, rather than innate constraints or even word learning biases.

This process of initial undergeneralization and gradual generalization is the primary stream of semantic development. However, often children need to go outside this primary stream to find ways of expressing meanings that they do not yet fully control. When they do this, they produce *overgeneralizations.* For example, children may overgeneralize (and alarm their parents) by referring to tigers as *kitties.* Although overgeneralizations are not as frequent as undergeneralizations, they are easier to spot because they always produce errors. Overgeneralization errors arise because they have not yet learned the words they need to express their intentions. It is not that the child actually thinks that the tiger is a kitty. It is just that the child has not yet learned the word *tiger* and would still like to be able to draw the parent's attention to this interesting catlike animal.

The smaller the child's vocabulary, the more impressionistic and global will be the nature of these overgeneralizations. For example, Ament (1899) reported that his son learned the word *duck* when seeing some birds on a lake. Later, he used the word to refer to other ponds and streams, other birds, and coins with birds on them. Bowerman (1978b) reports that her daughter Eve used *moon* to talk about a lemon slice, the moon, the dial of a dishwasher, pieces of toenail on a rug, and a bright street light. But this does not necessarily mean that the child actually thinks that *duck* refers to both lakes and birds or that *moon* refers to both lemon slices and hangnails. Rather, the child is using one of the few words available to describe features of new objects. As the child's vocabulary grows in size, overgeneralization patterns of this type disappear, although more restricted forms of overgeneralization continue throughout childhood.

This model of overgeneralization assumes that the child understands the difference between a *confirmed core* of features for a word and the area of potential further generalization. The confirmed core extends to referents that have been repeatedly named with the relevant word. The area of extension is an area outside this core where no other word directly competes and where extension is at least a possibility.

Flexible Learning

As the child begins to learn new words, the process of learning itself produces new generalizations (Smith, 1999). For example, children soon come to realize that new words almost always refer to whole objects. There is no reason to think that this is some genetically determined, species-specific constraint. Early on, children realize that objects typically function as perceptual wholes. However, a cautious learner will always realize that this assumption can sometimes be wrong. For example, one evening, I was sitting on a Victorian couch in our living room with my son Ross, aged 2;0, when he pointed to the arm of the couch, asking "couch?"

He then pointed at the back and then the legs, again asking if they were also "couch." Each time, I assured him that the part to which he was attending was, indeed, a part of a *couch*. After verifying each component, he seemed satisfied. In retrospect, it is possible that he was asking me to provide names for the subparts of the couch. However, like most parents, I tried to focus his attention on the whole object, rather than the parts. Perhaps, I should have first taught him that all of the parts were pieces of couch and then gone on to provide additional names for the subparts, such as *arm, seat, back*, and *edge*, ending with a reaffirmation of the fact that all of these parts composed a *couch.*

Learning to learn can also induce the child to treat early word meanings in terms of common object functions. For example, Brown (1958) noted that parents typically label objects at the level of their most common function. Thus, parents will refer to *chairs*, but avoid *furniture* or *stool*, because *chair* best captures the level of prototypical usage of a class of objects (Adams & Bullock, 1986). As a result, children also come to realize that the names for artificial objects refer to their functions and not to their shape, texture, or size.

Children are also quick to pick up on a variety of other obvious correlations. They learn that the color of artificial objects such as cars and dresses can vary widely, but that many animals have unique colorings and patterns. They learn that any new word for an object can also refer to a toy characterizing that object or a picture of the object. They learn that people can have multiple names, including titles and nicknames. They learn that actions are mapped onto the human perspective (MacWhinney, 1999a), and that the meanings of adjectives are modulated by the baseline nature of the object modified. Generally speaking, children must adopt a highly flexible, bottom-up approach to the learning of word meanings (Maratsos & Deak, 1995), attending to all available cues, because words themselves are such flexible things.

This flexibility also shows up in the child's handling of cues to object word naming. Because shape is a powerful defining characteristic for so many objects, children learn to attend closely to this attribute. However, children can easily be induced to attend instead to substance, size, or texture, rather than shape. For example, Smith (1999) was able to show how children could be induced, through repeated experiences with substance, to classify new words not in terms of their shape but in terms of their substance.

Children's Agenda

The view of the child as a flexible word learner has to be balanced against the view of the child as having definite personal agenda. Like Augustine, children often see language as a way of expressing their own desires, interests, and opinions. In some extreme cases, children may adopt the position espoused by Humpty Dumpty, when he chastises Alice for failing to take charge over the meanings of words. As Humpty Dumpty puts it, "When I use a word, it means just what I choose it to mean—neither more nor less."

Fortunately, the agenda that children seek to express through early words match up closely with what their parents expect them to express. During the months before the first words, the child may use certain gestures and intonational patterns to express core agenda items such as desire, question, and attention focusing (Halliday, 1975). Later, children seem to seek out words for talking about fingers, hands, balls, animals, bottles, parents, siblings, and food. Much of this early agendum appears to focus initially on the learning of nouns, rather than verbs or other parts of speech. Gentner (1982) argues that this is because it is easier to map a noun to a constant referent. A variant of Gentner's position holds that nouns are learned more readily because it is easier for children to figure out what people are talking about when they use nouns than when they use verbs. Moreover, nouns tend to be used the same categorical and taxonomic ways (Sandhofer, Smith, & Luo, 2000), whereas verbs refer to a wider range of conceptual structures, including wishes, movements, states, transitions, and beliefs.

Input factors play a role as well. Studies of languages other than English show that sometimes children do not produce more nouns than verbs. For example, children learning Korean (Gopnik & Choi, 1995) and Mandarin Chinese (Tardif, 1996) may produce more verbs than nouns under certain conditions of elicitation. Two plausible explanations for this phenomenon have been offered. First, in both Korean and Mandarin, verbs are much more likely to appear at the ends of utterances than in English, where the last word in input sentences tends to be a noun (Nicoladis, 2001). Perceptual studies (Jusczyk, 1997) have shown that it is easier for children to recognize familiar words at the ends of sentences, suggesting that this structural feature of languages influences rates of word learning as well. Second, Korean and Mandarin mothers tend to talk about actions more than do English mothers, who tend to focus on labeling things. Goldfield (1993) showed that American mothers who used more nouns tended to have infants with a higher proportion of nouns in their vocabularies.

Whorf versus Humpty Dumpty

As learning progresses, the child's agendum becomes less important than the shape of the resources provided by the language. For example, languages like Salish or Navajo expect the child to learn verbs instead of nouns. Moreover, the verbs children will learn focus more on position, shape, and containment than do verbs in English. For example, the verb "'ahéénishtiih" in Navajo refers to "carrying around in a circle any long straight object such as a gun." The presence of obligatory grammatical markings in languages for concepts such as tense, aspect, number, gender, and definiteness can orient the child's thinking in certain paths at the expense of others. Whorf (1967) suggested that the forms of language may end up shaping the structure of thought. Such effects are directly opposed to the Humpty Dumpty agenda-based approach to language. Probably the truth involves a dynamic interaction between Whorf and Humpty-Dumpty. Important though language-specific effects may be, all children end up being able to express basic ideas equally well, no matter what language they learn.

Learning from Syntactic Contexts

Shared reference is not the only cue toddlers can use to delineate the meanings of words. They can also use the form of utterances to pick out the correct referents for new words. Consider these contexts:

1. Here is a pum. — count noun
2. Here is Pum. — proper noun
3. I am pumming. — intransitive verb
4. I pummed the duck. — transitive (causative) verb
5. I need some pum. — mass noun
6. This is the pum one. — adjective

Each of these sentential contexts provides clear evidence that *pum* is a particular part of speech. Other sentential frames can give an even more precise meaning. If the child hears, "This is not green, it is pum," it is clear that *pum* is a color. If the child hears, "Please don't cover it, just pum it lightly," then the child knows that *pum* is a verb of the same general class as *cover.* The use of cues of this type leads to a fast, but shallow, mapping of new words to new meanings. Learning of this type was first identified in 3-year-olds by Brown (1973) and later in children younger than 2 by Katz, Baker, and Macnamara (1974). Carey (1978) later used the term *fast mapping* to refer to this induction of word meaning from syntactic context. The idea here is that the child can quickly pick up a general idea of the meaning of a new word in this way, although it may take additional time to acquire the fuller meaning of the word. Fast learning has also been identified in much younger children (Schafer & Plunkett, 1998). However, before age 2, fast mapping depends only on memory for the referent itself and not on induction from syntactic frames.

Words as Invitations to Learning

In a very real sense, words function as invitations for the construction of new categories. The child soon realizes that each new word is a pointer into a whole set of related objects or events that share some discoverable similarity. The more words the child learns, the clearer this effect becomes. New words for animals, like *hedgehog* and *dolphin* invite an exploration of the habits, shapes, colors, and activities of that animal. New words for physical actions, like *gallop* and *knit*, invite an exploration of the ways in which the body can use these motions to act on other objects. Research has shown that the mere presence of a word can induce sharper and more consistent concept formation. For example, Waxman and Kosowski (1990) gave children two stories. In the first story, they used the word *dobutsu* as a label, saying, "There's a being from another planet who wants some dobutsus. I don't know what dobutsus means, but he likes things like a dog, a duck, or a horse. Can you find him something he wants?" In the second story, they provided no label, saying, "This puppet only likes things like dogs, ducks, and horses. Can you find him something he likes?" Children were much more likely to point to another animal when the label *dobutsu* was used than when no label was provided. This effect has also been demonstrated for infants (Waxman & Markow, 1995) and echoed in several further studies, all of which emphasize the role that words play as invitations to categorization and cognition (Gentner, in press).

Competition and Mutual Exclusivity

Even the most complete set of syntactic cues and the fullest level of shared attention cannot completely preclude the occasional confusion about word meanings. Some of the most difficult conflicts between words involve the use of multiple words for the same object. For example, a child may know the word *hippo* and hear a hippo toy referred to as a *toy*. But this does not lead the child to stop calling the toy a *hippo* and start calling it a *toy*. Some have suggested that children are prevented from making this type of error by the presence of a universal constraint called *mutual exclusivity.* This constraint holds that each object can have only one name. If a child hears a second name for the old object, they can either reject the new name as wrong or else find some distinction that disambiguates the new name from the old. If mutual exclusivity were an important constraint on word meaning, we would expect children to show a strong tendency toward the first solution—rejection. However, few children illustrate such a preference. The fact is that objects almost always have more than one name. For example, a *fork* is also *silverware* and a *dog* is also an *animal.* Linguistic structures expressing a wide variety of taxonomic and metonymic relations represent a fundamental and principled violation of the proposed mutual exclusivity constraint. The most consistent violations occur for bilingual children who learn that everything in their world must, by necessity, have at least two names. Mutual exclusivity is clearly not a basic property of natural language.

One reason why researchers have devoted so much attention to mutual exclusivity stems from the shape of the laboratory situation in which word learning is studied. The child is presented with a series of objects, some old and some new, given a word that is either old or new, and then asked to match up the word with an object. For example, the child may be given a teacup, a glass, and a demitasse. She already knows the words *cup* and *glass.* The experimenter asks her, "Give me the demitasse." She will then correctly infer that *demitasse* refers to the object for which she does not have a well-established name. In this context, it makes sense to use the new name as the label for some new object.

Instead of thinking in terms of mutual exclusivity, the child appears to be thinking in terms of competition between words, with each word vying for a particular semantic niche (Merriman, 1999). At the same time, the child is thinking in terms of the pragmatics of mutual cooperation (Clark, 1987). When two words are in head-on conflict and no additional disambiguating cues are provided, it makes sense for the child to assume that the adult is being reasonable and using the new name for the new object (Golinkoff, Hirsh-Pasek, & Hollich, 1999). The child assumes that the cooperative experimenter knows that the child has words for cups and glasses, so it only makes sense that the new word is for the new object.

In the real world, competition forces the child to move meanings around so that they occupy the correct semantic niche. When the parent calls the toy hippo a *toy*, the child searches for something to disambiguate the two words. For example, the parent may say, "Can you give me another toy?" or even "Please clean up your toys." In each case, *toy* refers not just to the hippo, but also potentially to many other toys. This allows the child to shift perspective and to understand the word *toy* in the framework of the shifted perspective. Consider the case of a rocking horse. This object may be called *toy, horsey,* or even *chair,* depending on how it is being used at the moment (Clark, 1997). This flexible use of labeling is an important ingredient in language learning. By learning how to shift perspectives, children develop powerful tools for dealing with the competitions between words. In this way, conflicts between meanings create complex structures and cognitive flexibility.

Building Theories

As children learn more and more words, they begin to develop clearer ideas about the ways in which words can refer to objects, properties, and events. The meanings of organized groups of words come to represent many aspects of the cognitive structure of the child's world. Children begin to realize that certain properties of objects are more fundamental and inherent than others. For example, Keil and Batterman (1984) talked to children about a cat that had been given a skunk's tail, nose, and fur. Before the age of 5, children believed that this animal would now actually be a skunk. After age 5, children began to realize that mere addition of these features would not change the fact that the animal was still inherently a cat. In effect, children are beginning to develop belief in a scientific theory that holds that animals cannot change their genetic status through simple transformations. Theories also provide children with conceptual structures they can use to infer the properties of new words. For example, if a child is told that a *dobro* is a fish, then they can also infer that the *dobro* swims and has gills (Gelman, 1998).

Milestones in Vocabulary Growth

Typically, the child demonstrates new language abilities first in comprehension and then only later in production. For example, children comprehend their first words by 9 months or even earlier, but produce the first word only after 12 months. Children are able to comprehend 50 words by about 15 months but do not produce 50 words in their own speech until about 20 months. More generally, children acquire words into their receptive vocabulary more than twice as fast as into their productive vocabulary.

Children tend to produce their first words sometime between 9 and 12 months. One-year-olds have about 5 words in their vocabulary, on average, although individual children may have none or as many as 30; by 2 years, average vocabulary size is more than 150 words, with a range among individual children from as few as 10 to as many as 450 words. Children possess a vocabulary of about 14,000 words by 6 years of age (Templin, 1957); adults have an estimated average of 40,000 words in their working vocabulary at age 40 (McCarthy, 1954). To achieve such a vocabulary, a child must learn to say at least three new words each day from birth.

The growth of children's vocabulary is heavily dependent on specific conversational input. The more input the child receives, the larger the vocabulary (Huttenlocher, Haight, Bryk, Seltzer, & Lyons, 1991). Children from higher socioeconomic status groups tend to have more input and a more advanced vocabulary (Arriaga, Fenson, Cronan, & Pethick, 1998). More educated families provide as much as three times more input than less educated families (Hart & Risley, 1995). Social interaction (quality of attachment, parent responsiveness, involvement, sensitivity, control style) and general intellectual climate (providing enriching toys, reading books, encouraging attention to surroundings) predict developing language competence in children as well (van IJzendoorn, Dijkstra, & Bus, 1995). Children with verbally responsive mothers achieve the vocabulary spurt and combine words into simple sentences sooner than do children with less verbally responsive mothers (Tamis-LeMonda & Bornstein, 2002). These facts have led educators to suspect that basic and pervasive differences in the level of social support for language learning lie at the root of many learning problems in the later school years.

Word Learning in School

Researchers have been focusing on word learning in the first 5 years. This focus on preschoolers tends to ignore the extent to which schooling shapes word meanings. Even for basic concepts such as "cat," schooling can bring about fundamental changes in conceptual structure. For example, Keil (1989) asked children whether a cat that had the fur of a skunk and the shape of a skunk would still be a cat. Preschoolers concluded that the cat would now be a skunk. However, 7-year-olds refused to accept the idea that the change of fur and shape would alter the internal nature of the cat. Schoolchildren will first support their position by just saying that once you are a cat you are always a cat. However, later, they will make reference to scientific constructs such as genetics and DNA to support their view. There is good reason to believe that schooling supports this shift toward essentialism (Astuti, Solomon, & Carey, 2004).

To understand how schooling operates in real time, researchers have begun to rely on detailed analyses of classroom conversations about mathematical and scientific concepts. These analyses are based on transcripts linked to video, which can be viewed directly from http://talkbank.org (using the online browser, the materials discussed in the current example are in ClassBank/JLS). Let us consider one particular instance of a detailed study of lessons by Paul McCabe and Kay McClain in a seventh-grade classroom studying terminology for describing statistical distributions. The students have been interacting for several weeks with a computer interface that allows them to vary treatments and observe outcome effects. In the current lesson, the teacher is discussing a projected graph of battery life for two types of flashlight batteries. Tests of 30 units of the Always Ready batteries showed that 8 lasted longer than 6 hours, although 10 lasted less than 4 hours. Tests of 20 units of the Tough Cells batteries showed that none of them lasted less than 4 hours, although only 3 lasted longer than 6 hours.

The teacher begins the discussion by asking which of the two batteries is more *dependable.* Caesara responds that the Always Ready batteries are more *dependable* because they yielded more "good ones." This interpretation of the concept of *dependability* fails to pay attention to the notion of a minimal performance standard. For example, if you were exploring a cave with a flashlight, you might want to make sure that your battery would not give out in the middle of your 4-hour exploration. If it did, you would call it *undependable.* Understanding this perspective, Blake counters Caesara's position when he notes that, "All of the Tough Cell is above 80." At this point, the teacher asks other students to clarify Caesara's position. Sequoria uses a set of hand gestures to draw a picture of the distribution of batteries in the air and to then point deictically to the segment of the distribution that Caesara is emphasizing. Although Caesara does not overtly withdraw her analysis during this discussion, Blake's provision of a clear account of the meaning of *dependable* and *dependability* helped the class move toward a fuller, statistically grounded understanding of these terms.

In this video interaction, we see a wide range of social forces impinging on the collaborative process of discovering meanings. Forces of gender, age, ethnicity, and group membership are evident in the discussion. The teacher plays a unique role in terms of her ability to recognize students who want to make contributions, revoice their contributions, and question their positions. In this study, Sfard and McClain (2002) tracked learning and reasoning from graphs and charts over several weeks. By examining the growth of interlocked concepts such as "distribution," "effectiveness," and "dependability" over this entire period across various students, we can gain a clearer idea of the process of word learning in the school years.

Increased input during early childhood leads to increases in vocabulary growth and other aspects of language structure. These differences in input quantity and quality continue to widen as children get older, with children from higher socioeconomic status and more educated families receiving more instruction both in the home and in the school in language forms, reading, literature, and composition (Dickinson & Moreton, 1993).

As children move on to higher stages of language development and the acquisition of literacy, they depend increasingly more on wider social institutions. They may rely on Sunday school teachers as their source of knowledge about biblical language, prophets, and the geography of the Holy Land. They will rely on science teachers to gain vocabulary and understandings about friction, molecular structures, the circulatory system, and DNA (Keil, 1989). The vocabulary demands placed by such materials can be enormous, with textbooks in biology requiring the learning of as many as 800 technical terms.

Students will rely on peers to introduce them to the language of the streets, verbal dueling, and the use of language for courtship. They will rely on the media for exposure to the verbal expressions of other ethnic groups and religions. When they enter the workplace, they will rely on their coworkers to develop a literate understanding of work procedures, union rules, and methods for furthering their status. By reading to their children, by telling stories, and by engaging in supportive dialogues, parents set the stage for their child's entry into the world of literature and schooling (Snow, 1999). Here, again, the parent and teacher must teach by displaying examples of the execution and generation of a wide variety of detailed literate practices, ranging from learning to write through outlines to taking notes in lectures (Connors & Epstein, 1995).

It is important to recognize that the literate practices used in today's schools are specific adaptations to the requirements of our current educational system. In the past, a great deal of emphasis was placed on the learning of Greek, Latin, and Hebrew. Today, we see a relatively greater emphasis on the acquisition of technical vocabulary, including programming languages. If foreign languages are taught, they are no longer the classics but rather major living languages such as Spanish or Chinese.

Educators and parents often complain about the decrease in young people's abilities to recall culturally significant facts (Hirsch, 1987; Hirsch, Kett, & Trefil, 1988). However, with the advent of tools for web searching, students have access to an encyclopedia of knowledge far greater than that of their parents. In truth, the very concept of literate practices is undergoing continual transformation as technologic advances in video, telecommunications, and computers allow us to explore new modes of communication (McLuhan & Fiore, 1967). However, to maintain cultural continuity, students will still need to be able to appreciate the structure of a Greek drama, the rules of formal debate, and the allegorical features in the *Divine Comedy.*

Neural Network Models of Word Learning

Ideally, we would like to have precise neurocomputational models that integrate across all of these time frames and cue types. But building such models is a tall task, and no current models can capture all these cues and interactions. However, one framework that allows us to model the core aspects of lexical learning is the self-organizing feature map (SOFM) architecture (Kohonen, 2001), as expressed in the DevLex model of Li, Farkas, and MacWhinney (2004). SOFM networks model initial word learning as patterns of organization in cortical maps. Three local maps are involved in word learning: an auditory map, an articulatory map, and a lexical map (see Figure 14.1). Emergent self-organization on each of these three maps uses the same learning algorithm. Word learning involves the association of elements between these three maps. What makes this mapping process self-organizing is the fact that there is no pre-established pattern for these mappings, and no preordained relation between particular nodes and particular feature patterns.

Evidence regarding the importance of syllables in early child language (Bijeljac, Bertoncini, & Mehler, 1993; Jusczyk, Jusczyk, Kennedy, Schomberg, & Koenig, 1995) suggests that the nodes on the auditory map may best be viewed as corresponding to full syllabic units, rather than separate consonant and vowel phonemes. The demonstration by Saffran et al. (1996) of memory for auditory patterns in 4-month-old infants indicates that children are not only encoding individual syllables but are also remembering sequences of syllables. In effect, prelinguistic children are capable of establishing complete representations of the auditory forms of words. Within the DevLex self-organizing framework, these capabilities can be represented in two ways. The auditory map uses a slot-and-frame feature notation from MacWhinney, Leinbach, Taraban, and McDonald (1989). The articulatory map combines this representation with a sequence-encoding mechanism based on the work of Gupta and MacWhinney (1997). This model treats the

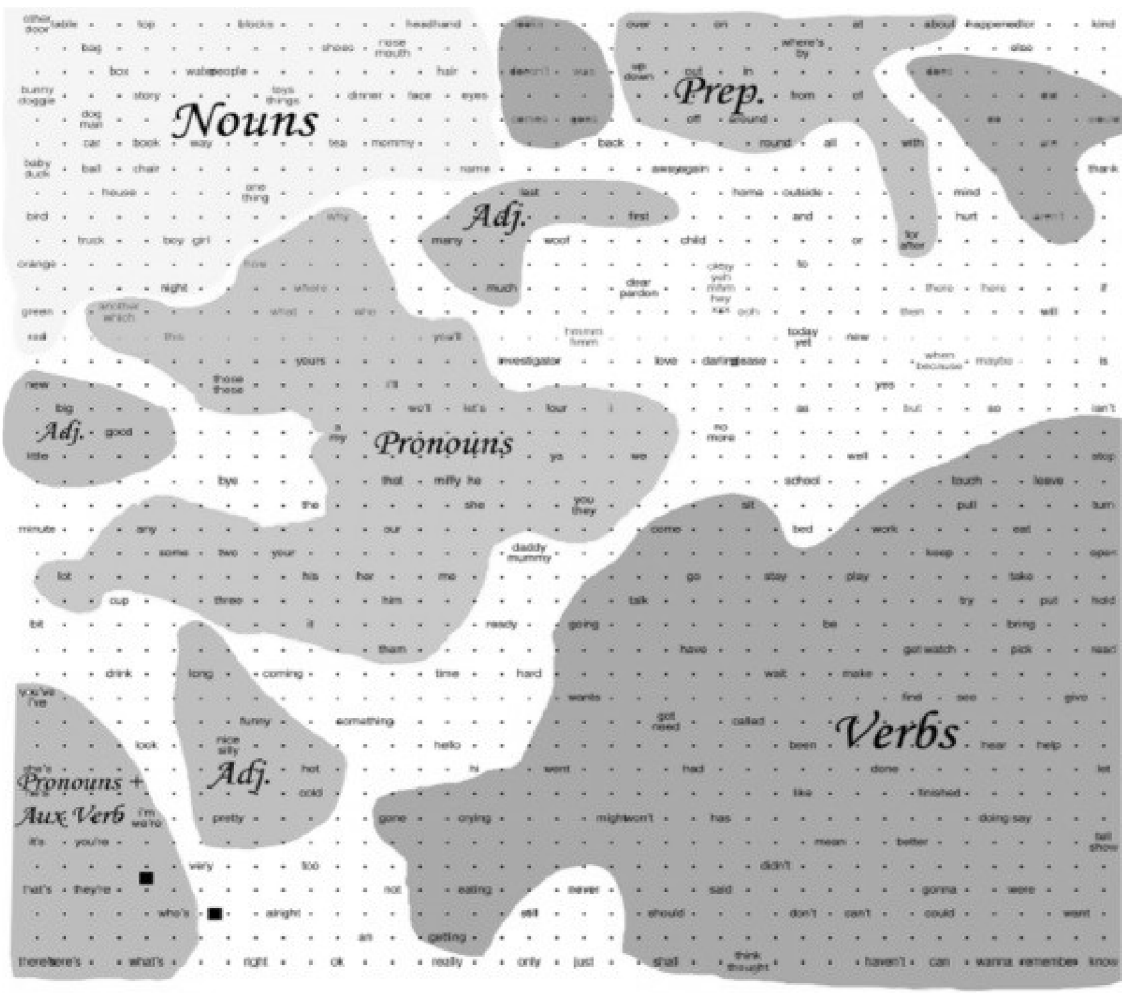

Figure 14.1 Lexical map extracted by DevLex. Organization by parts of speech is suggested by shading patterns. Within each part of speech, words are located next to other semantically similar words.

neural encoding of words as an "avalanche" (Grossberg, 1978) that controls the order of syllables within the word. Each new word is learned as a new avalanche.

The input to the DevLex model includes compressed representations of actual sentences spoken to children as taken from the Child Language Data Exchange System (CHILDES) database (http://childes.psy.cmu.edu). This information tells the child about the words with which a new lexical item co-occurs in the input. In addition, for each word, the model receives semantic features extracted from WordNet (Harm, 2002; Miller, Beckwith, Fellbaum, Gross, & Miller, 1990). After some 500 cycles of training on this input, newly learned words organize themselves into groups in the lexical map. As illustrated in Figure 14.1, this organization follows the part of speech organization described by standard linguistic analyses (Sagae, Davis, Lavie, MacWhinney, & Wintner, 2007). This emergent process allows the SOFM to extract part of speech information implicitly and to encode it in the topology of the lexical map. As discussed later, this topological information is crucial for the linkage of the lexicon to sequential, syntactic processing in the inferior frontal cortex.

The DevLex model focuses on the linkage of the two phonological maps to the lexicon and says nothing about links between the two phonological maps. However, there are now several well-articulated models of the development of these linkages between articulation and audition. These models (Guenther, 2006; Lacerda, 1998; Westermann & Miranda, 2004) use the same SOFM architecture of DevLex but emphasize the ways in which units in auditory space come to be constrained by the possible articulations produced by the child. Lindblom, Diehl, Park, and Salvi (in press) argue that, to work effectively across contexts, this learning has to rely on the fact that the brain is able to compute motor equivalence between targets. This allows the learner to link together a targeted sound with an auditory effect, even when the actual details of the sound production vary radically across contexts. During this learning, the ambient language is providing ongoing input to auditory organization, and this input provides new targets for the process of articulation. In the end, the structures encoded in auditory space become the strongest forces in this coupled system.

In the DevLex self-organizing framework, the learning of a word is viewed as the emergence of an association between a pattern on the auditory map and a pattern on the concept map through Hebbian learning (Hebb, 1949; Kandel & Hawkins, 1992). When the child hears a given auditory form and sees an object at the same time, the coactivation of the neurons that respond to the sound and the neurons that respond to the visual form produces an association across a third pattern of connections that maps auditory forms to conceptual forms. Initially, the pattern of these interconnections is unknown, because the relation between sounds and meanings is arbitrary (de Saussure, 1915/1966). This means that most of the many potential connections between the auditory and conceptual maps will never be used, making it a sparse matrix (Kanerva, 1993). In fact, it is unlikely that all units in the two maps are fully interconnected (Shrager & Johnson, 1995). To support the initial mapping, some researchers (Schmajuk & DiCarlo, 1992; Wittenberg, Sullivan, & Tsien, 2002) have suggested that the hippocampus may provide a means of maintaining the association until additional cortical connections have been established. As a result, a single exposure to a new word is enough to lead to one-trial learning. However, if this initial association is not supported by later repeated exposure to the word in relevant social contexts, the child will no longer remember the word.

Syntax

The transition from the first words to the first sentences is nearly imperceptible. After learning the first words, children begin to produce more and more single-word utterances. As their vocabulary grows, children begin saying words in close approximation (Branigan, 1979). For example, they may say *wanna,* followed by a short pause and then *cookie.* If the intonational contour of *wanna* is not closely integrated with that of *cookie,* adults tend to perceive this as two successive single-word utterances. However, the child may already have in mind a clear syntactic relation between the two words.

As the clarity of the relations between single words strengthens, the temporal gap between the words will decrease. However, the transition from successive single-word utterances to true word combinations requires more than just faster timing. Two other achievements must occur. First, the child has to figure out how to join words together into a single intonational package or breath group. Second, the child also has to figure out which words can be meaningfully combined and in what order.

The level of successive single-word utterances is one that chimpanzees also reach when they learn signed language. Domesticated chimps like Sarah, Washoe, or Kanzi can learn about a hundred conventional signs or tokens. They can then combine these words to produce meaningful communication. However, the combinations that chimpanzees produce never really get beyond the stage of successive single-word utterances. For example, the chimpanzee Washoe, who was raised by the Gardners (Allen & Gardner, 1969), produced strings such as "Open, now, me, now, open, door, please, open, please, me" to express the request to have a door opened. In a sequence like this, the chimp is basically using every item in her lexicon that might apply to the current scene without paying much attention to particular binary combinations of items (Terrace, Petitto, Sanders, & Bever, 1980).

Item-Based Patterns

Eventually, children come to take a more systematic approach to the process of combining words. The description of the growth of this process is the task of the theory of syntactic development. In the early days of psycholinguistic theory, Braine (1963, 1971) explored ways of applying learning theory to the study of syntactic development. The formulation he devised focused on the idea that function words tend to appear in fixed positions vis-à-vis content words. For example, *the* appears before nouns, and the suffix -*ing* appears after verbs. Many of these positional patterns involved combinations of predicates such as *want*, *more*, or *go* with arguments such as *cookie* or *flower.* Braine found that a small set of semantic combination types could be used to account for nearly all of the sentences in the small corpora that he studied. In some cases, the positional occurrence of the words involved was quite fixed. For example, children always said *my* + *X* and never *X* + *my* to express the possession relation. However, in other cases, the order was more variable. Like Harris (1951) or Tesniére (1959), Braine analyzed these constituent structures in terms of slots that could be filled by items of a certain class. Formulating a set of 12 such positional patterns for a small corpus of child utterances, he referred to his account as a "pivot-open" grammar, because it specified the position of pivot words vis-à-vis the open class. However, in the spirit of Chomsky's (1959) critique of Skinner's *Verbal Behavior*, this model was criticized as failing to pay adequate attention to semantic patterning (Bloom, 1971). Later, Braine (1976) revised his account, emphasizing the role of "groping patterns" that established links based not on lexical class, but semantic relations (Schlesinger, 1974, 1975).

Sticking more closely to Braine's original formulations, MacWhinney (1975a) introduced the notion of the item-based pattern (IBP), in contrast with Braine's later concept of groping patterns. Rather than viewing the combination of *more* and *milk* as expressing a pattern such as *recurrence + object*, MacWhinney interpreted the combination as evidence of the IBP *more + X,* where the italicization of the word *more* indicates that it is a particular lexical item and not a general concept. This analysis stresses the extent to which the IBP first emerges as a highly limited construction based on the single lexical item *more.*

In this account, the grammar of the child's first word combinations is extremely concrete. The child learns that each predicate should appear in a constant position with respect to the arguments it requires. For example, in English, the word *more* appears before the noun it modifies and the verb *run* appears after the subject with which it combines. The combination is based on a slot-filler relation. Consider the combination *more milk*, which is generated from the IBP *more + X*. In this combination, *milk* is a filler for the slot that is represented by the X.

MacWhinney (1975a) examined the word order of 11,077 utterances produced by two Hungarian children between the ages of 17 and 29 months. He found that between 85% and 100% of the utterances in these samples could be generated by a set of 42 IBPs. Some examples of these patterns in English translation are*: X + too, no + X, where + X, dirty + X, and see + X.* The IBP model is able to achieve a remarkably close match to the child's output because it postulates an extremely concrete set of abilities that are directly evidenced in the child's output.

MacWhinney made no general claims about a pivot or open class, focusing instead on the idea that the first syntactic patterns involve links between individual lexical items and other words with which they are prone to combine. An example of an IBP is the structure *the + X.* This pattern states that the word *the* occurs before another word with which it is semantically related. In addition to these positional facts, the IBP encodes the shape of the words that can occupy the slot determined by X and the nature of the semantic relation between *the* and *X.* This is to say that an IBP is a predicate-argument relation that encodes:

- the lexical identity of the predicate
- the lexical category of the argument(s)
- the sequential position of the predicate vis-à-vis its argument(s)
- the semantic relation between the predicate and its argument(s)

The predicates of IPBs can specify one, two, or even three arguments. A word such as *want* needs to be completed with two other words to form a complete, meaningful predication. First, there must be a nominal that serves as a direct object, as in *want cookie.* Second, there must be a nominal that serves as the subject, as in *I want cookie.* Because *want* expects these two additional words, we call it a two-argument predicate. Other predicates, such as *under* or *my,* take only one argument, and a few such as *give* take three (*John gave Bill a dollar.*). We can refer to this argument structure as the valency of the predicate (Herbst, 2007), much as atoms have a valency structure in chemistry. Nouns that are derived from verbs, such as *destruction* or *remission* can take optional arguments (*the destruction of the city* or *a decline in the dollar*) to form complex noun phrases. Basic nouns such as *chair* and *goat* do not even have these expectations. However, in English, these require modification with a determiner such as *the* or *this*. Thus, in the phrase *the dog*, there is a covalent relation, because the determiner requires the noun for completion and the noun requires the determiner.

Learning Item-Based Patterns

Children learn IBPs by listening to sentences. For example, if the child's older sister says "my dolly," the child may recognize the word *dolly* from previous experience and then further notice the presence of *my* in front of *dolly.* At this point, the child can compare the phrase *my dolly* with the single word *dolly*, noticing the differences (MacWhinney, 1978). The first difference is the presence of *my* before *dolly.* From this evidence, the child can extract the IBP *my + X*.

In this case, the child is learning the word *my* at the same time as the IBP. Possibly, the older sister may be asserting her control over the doll and wrestling it from the younger sister's possession. Thus, the younger child can pick up not only the meaning of *my* and the IBP, but also the notion of a relation of possession and control between the two words. Thus, it is more accurate to speak of this IBP as combining *my + object possessed,* rather than just *my + X.* By specifying a particular semantic role for the filler, we are emphasizing the fact that the pattern encodes both syntax and semantics.

Initially, this IBP is restricted to the words *my* and *dolly,* and the relation of possession that occurs between them. However, if the older sister then says "and this is my horsey," the child can begin to realize that the open slot for the pattern based on the item *my* refers potentially to any manner of *toy.* Subsequent input will teach the child that any object can fill the slot opened up by the operator *my.* Each IBP goes through this same course of generalization (MacWhinney, 1975a; Tomasello, Akhtar, Dodson, & Rekau, 1997).

Evidence for the Reality of Item-Based Patterns

During the second and third year, children's productions provide extensive evidence for the pervasiveness and productivity of the growing systems of IBPs. One clear form of evidence comes from the application of IBPs to new words. We can also demonstrate the productivity of IBPs by teaching children novel words that serve as slot fillers. For example, we can show a child a picture of a bird-like creature that we call *a wug*. The positioning of the nonce word *wug* after the indefinite article induces the child to treat the word as a common noun. We can show the child two pictures of the strange creature and ask her, "What are these?" By responding with the answer *wugs,* children show productivity of the IBP based on the plural suffix /s/. Also, we can set up a game in which each person names some toys. This will lead the child to produce the combination *my wug,* thereby showing the productivity of the pattern *my + object possessed.* Similarly, a German-speaking child can be taught the nonce name *der Gann* (nominative, masculine, singular) for a toy. The experimenter can then pick up the toy and ask the child what he is holding. By the age of 3, children will correctly produce the accusative form *den Gann* (accusative, masculine, singular).

Although it is easy to convince children to accept new slot fillers, it is far more difficult to teach them to accept new operators. This is because new operators must establish their own new IBPs. As a result, it is difficult to convince children to use novel verbs in a fully productive fashion. Instead, children tend to be conservative and unsure about how to use verbs productively until about age 5 (Tomasello, 2000b). By then, they start to show productive use of constructions such as the double object, the passive, or the causative (Bowerman, 1988). For example, an experimenter can introduce a new verb such as *griff* in the frame *Tim griffed the ball to Frank,* and the child will productively generalize to *Tim griffed Frank the ball*.

The productivity of IBPs can also be illustrated by errors in word combination. Early child syntax is replete with examples of errors produced by the simple application of IBPs (Brown, Cazden, & Bellugi, 1968; Klima & Bellugi, 1966; Menyuk, 1969). Examples include *where Mama boot, who that, what train, no Rusty hat,* and *that no fish school.* These combinations arise from the application of IBPs such as: *where + object located,* or *no + object denied.* In these patterns, the open slot can hold single nouns, noun phrases, or simple sentences. The fact that slot fillers can themselves be formed from IBPs allows for recursive rule application that we will call *clustering.* How clustering can be implemented on the neuronal level is discussed later in this chapter.

Errors arise because children are omitting articles and auxiliaries, but over time they will learn to add these through additional IBPs. Soon, children learn to use *where's,* rather than *where* for interrogatives, producing correct combinations, such as **where's the wheel?* Some children form an overgeneralized *no + X* negation pattern in which X is not restricted to an object. Errors illustrating this incorrect overextension include: **no do this,* **no wipe finger,* **no sit there,* **no play that,* **he no bite you,* and **I no taste them.* Parallel interrogative combination errors include **where go,* **what happen,* **where put him on a chair,* **what happen me,* and **why need them more.* Interrogative errors with missing auxiliaries of the shape **what they are doing* and *where he's going* are extremely common. There are also errors, such as **where the wheel do go* and **what you did eat,* in which the auxiliary is misplaced after the subject. These errors are further evidence for patterns such as *where + S.* Later on, children replace *where + S* with *where + tense.* However, they fail to restrict the *where + tense* pattern to exclude main verbs. Overgeneralization errors attesting to the productivity of this later pattern include: **where goes the wheel,* **where could be the shopping place,* or **where's going to be the school?* After the first few months of word combination, there are no reports of errors that go against the basic item-based interrogative patterns. For example, there are no reports of errors such as *he can't do it why* (Labov & Labov, 1978).

The fact that grammatical patterns are often acquired word by word provides further evidence for the operation of IBPs. For example, Kuczaj and Brannick (1979) showed that children are quicker to show placement of the tensed auxiliary after the interrogatives *what* and *where* than after *how long* or *when.* Thus, children will produce *what is he doing*? at the same time they produce **when he coming*? Similarly, Bowerman (1978a) noted that, at 17 months, her daughter Eva used the patterns *want* + *X* and *more* + *X* productively. However, these patterns did not generalize to other words like *open, close, bite, no more,* or *all gone.*

One could argue that sentences of the type we have discussed are produced not through word combination, but through analogy. Accounts based on analogy can be used to account for virtually any particular form. However, accounts based on analogy can also predict error types that never occur. For example, Kuczaj and Brannick (1979) noted that questions like *gonna he go*? have never been reported, although children say *he's gonna go, he will go,* and *will he go*? If analogy were operating here, we would expect to find *gonna he go*? on analogy with *will he go*? On the other hand, IBPs account for these data correctly. The auxiliary *will* is combined with *he go* using the IBP *will* + *action*. This pattern does not generalize to *gonna,* because, by definition, the IBP *will* + *action* is restricted to the auxiliary *will.* Thus, the learning of IBPs is conservative in a way that correctly predicts nonoccurring overgeneralizations.

Consider another example of how lexical classes help the child avoid overgeneralization. Children may notice that both *big* and *red* pattern together in forms such as *big barn* and *red barn.* This might induce them to produce forms such as *I painted the barn big* on analogy with *I painted the barn red.* A conservative learner would stick close to facts about the verb *paint* and the arguments that it permits. If the child has heard a form like *I painted the barn white,* it would make sense to extend this frame slightly to include the resultative predicate *red.* However, to extend from the word *white* to semantically unrelated words like *happy* or *difficult* would be to go far beyond the attested construction. As a result, this type of category-leaping overgeneralization is extremely infrequent. This type of conservatism is fundamental to the Competition Model's multiple process solution to what is often referred to as the "logical problem of language acquisition" (MacWhinney, 2004, 2005c; Pinker, 1984).

Feature-Based Patterns

Although IBPs can be used to generate nearly all word combinations, there is good evidence that children soon go beyond IBPs to learn more general combinatorial rules. Consider the learning of the pattern that places the adjective before the noun in English. At first, children pick up a few IBPs such as *nice* + *object, good* + *object,* and *pretty* + *object.* They acquire these patterns during the learning of new adjectives from the input. For example, children may hear the form *nice kitty,* from which they create the pattern *nice* + *X*. At first, the slot filler is limited to the original noun *kitty,* but it is then quickly generalized to all possible objects. When the child then begins to learn the parallel patterns for *good* and *pretty,* the process of slot generalization becomes quicker, as the child begins to realize that words like *nice, good,* and *pretty* that describe characteristics of objects all accept a related object in the following syntactic position. This linking of IBPs then creates a feature-based pattern (FBP) that specifies the combination *modifier* + *object described* for English. Other early FBPs include *possessor* + *possession (John's computer)* and *locative* + *location (behind the tree).* Once children have learned these more general patterns, they apply immediately to newly learned words.

FBPs can also apply to the positioning of nouns as topics in languages like Hungarian or Chinese. These languages encourage the formation of sentences that place nominal topics in initial position, according to the FBP *topic* + *comment.* At first, children may pick this up as an IBP. For example, they might hear a Hungarian sentence of the shape *the glass # empty* with the # sign indicating an intonational break between the topic and the comment. They first encode this as a pattern linked to *glass.* However, after hearing a few more parallel patterns for other nouns, they then extract a general FBP, just as they do for the *modifier* + *object described* pattern for adjectives. Studies such as MacWhinney (1975b) and Lee (1999) have demonstrated that children use these patterns productively by age 2.

Category-Based Patterns

There is a third level of argument generalization, above the levels of the IBP and the FBP. This is the level of the category-based pattern (CBP). Just as feature-based constructions emerge from a process of generalization across IBPs, so these more global CBPs emerge from generalization across feature-based constructions. For example, in English, there are literally dozens of verb groups that share a common placement of the subject before the verb. Together, these constructions give support for a CBP supporting SV (subject-verb) word order in English. The English CBPs of SV and VO work together to produce prototypical SVO (subject-verb-object) order (MacWhinney, Bates, & Kliegl, 1984). Other languages promote different combinations of global patterns. In Hungarian and Chinese, for example, SV, OV, and VO orders operate to express alternative varieties of object definiteness, producing SVO and SOV orders. Italian combines SV and VO patterns with secondary but significant use of VS (Dell'Orletta, Lenci, Montemagni, & Pirrelli, 2005) to produce SVO and VSO orders. Other global patterns control the ordering of topic before comment or the tendency to associate animacy with agency, producing a CBP for AV or AXV.

The sequential processing system is grounded on the individual IBPs that encode all the rich detail of individual constructions. Higher level FBP and CBP constructions emerge when extending patterns to new verbs (Tomasello, 2000b), largely after age 4, and when organizing the whole network of IBPs into a more smoothly functioning whole. However, the data that support IBPs remain available throughout development.

Morphology: Between Lexicon and Syntax

One of the most vexed problems in linguistics and psycholinguistics is the status of morphological processes, such as derivation, inflection, and compounding. Although English is relatively poor in terms of inflectional morphology, it makes full use of compounding and derivational morphology. The problem with morphology is that it seems to have one foot in lexicon and one foot in syntax. Consider a form such as *knives* as the plural of *knife.* In terms of combination, we can view knives as a combination of the stem knife with the plural suffix -s. However, the fact that the stem changes its shape when joining with the suffix is not a fact about combination, but a fact about the sound shape of this lexical item. Morphology differs from syntax in another fundamental way. Earlier, we saw the difficulties involved in viewing syntactic patterns as based on analogy. This is because syntax is produced by combination, not analogy. However, the same is not true for morphology. To the extent that complex words can be stored in posterior cortex as single wholes, they can serve as the analogic bases for new word productions. Thus, *knives* can be produced on analogy with *wives.*

These properties of morphological formations have made them excellent targets for neural network models that can focus on the processes of analogy that operate within the lexicon (MacWhinney & Leinbach, 1991; MacWhinney et al., 1989; Rumelhart & McClelland, 1987). However, even in morphologically complex languages, such as Turkish or Navajo, morphemes appear in invariable position slots, suggesting that these forms are not produced by the types of free IBPs used for syntax, but rather through analogic processes operating in the lexicon.

Amalgams

Although morphological marking is fixed in sequential terms, it still poses a learning challenge to the child. At first, children seem blissfully unaware of the presence of grammatical markings, treating complex, multimorphemic words as if they were single units. For example, a child might use the word *cookies* even before learning the singular *cookie.* At this point, we can refer to the unanalyzed two-morpheme combination *cookies* as an *amalgam* (MacWhinney, 1978). The child language literature is replete with examples of uses of inflected amalgams before the child has learned the stems. For example, Brown et al. (1968, p. 41) reported use of *can't, won't,* and *don't* at a time when *can, will,* and *do* were absent. Similarly, Leopold (1949, p. 8) reported use of *sandbox* when *sand* was absent. Children also use inflected forms before they have acquired the inflections. Kenyeres (1926) reported that his daughter used the inflected Hungarian word *kenyeret* (bread + accusative) at 16 months, when there was no other evidence for productive use of the accusative *-et.* It makes sense that the word should be learned in this form, because this is how it appears in sentences such as *Do you want some bread*? Moreover, Hungarian children often use *kalapáccsal* (hammer-with) before demonstrating productive use of either the stem *kalapács* (hammer) or the instrumental suffix *-val*. Of course, for the child, the main interest value of a hammer involves its use as an instrument.

Some of the more complex units encoded by amalgams are later produced through syntax. Peters (1977) noted that when her 14-month-old subject could control only 6 to 10 words, he said quite clearly, "Open the door." Similarly, my son Ross produced "No, Mommy, I don't want to go bed" and "I like it; I love it" at a time when the first two-word combinations were just emerging. It is possible that these precocious forms derive from stored full-sentence templates that just happen to work correctly as full units or amalgams in a particular situational context. Although amalgams can produce precocious successes, they can also lead to grammatical errors. For example, if children learn *like it* and *want some* as amalgams, they can produce errors such as *I like it the ball* or *I want some a banana*. Clark

(1977, p. 350) reported the utterance "hat on gone now" in which "hat on" is apparently a unit.

Evidence for the nonproductivity of early affixes or word endings comes from the fact that, when they first appear, affixes are seldom overgeneralized (Ervin, 1964; MacWhinney, 1974, p. 653). Children begin by saying *went* and *saw,* and over-regularizations such as *goed* or *sawed* typically do not occur before correct irregular forms are produced. When errors like *goed* and *sawed* begin to appear, they serve as evidence of the productivity of the past tense suffix, as well as evidence of its earlier nonproductivity. After a few weeks, the child corrects these errors and returns to correct use of *went* and *saw.* This pattern of correct performance with an intermediate period of overgeneralization produces a U-shaped curve that has a different developmental profile for each verb. Children make fewer morphophonological errors on common irregular words than on rare irregular words (MacWhinney, 1975a, 1978). This effect indicates that children rely on rote to produce at least some inflected forms. Frequent forms can be acquired as chunks or amalgams because they are heard so often.

The absence of productivity for a suffix should not be taken as absence of the underlying concept. For example, Brown and Bellugi (1964) found that children would refer to *many shoe* and *two shoe* at a time when there is still no clear evidence for the productivity of the plural suffix. However, the words *many* and *two* by themselves show that the child not only thinks in terms of the concept of plurality but also has succeeded in finding two ways of expressing this concept. At this point, acquisition of the plural is driven not by the child's need to express concepts, but by the need to match the formal structures of the adult language.

Syntactic Processing

The Competition Model (MacWhinney, 1987) characterizes learned grammatical knowledge in terms of the system of IBPs, FBPs, and CBPs. Over time, the child learns to join these various positional patterns into a single network to control both comprehension and production. Although this network is learned, the processing principles that apply the knowledge encoded in this network are not learned. Rather, they are rather fundamental properties of the cognitive system. In this sense, syntax emerges from already existing processes.

The sequential network must communicate with both the lexicon (level 3) and mental models (level 5). In production, the representations of mental models are already active, and the work of syntax is to coordinate lexical activation in a way that will facilitate sequential output. In comprehension, words are recognized by the lexicon and the syntax has the responsibility of fitting these words together into structures that can build up coherent mental models (Gernsbacher, 1990; MacWhinney, 1977). In presenting this analysis of sequential processing, we are bringing emergentist theory to bear on the same question that has been at the center of the theory of Universal Grammar. This is the issue of the role of recursion as a unique feature of human language (Hauser, Chomsky, & Fitch, 2002). However, unlike UG, this account views recursion as an emergent property of other domain-general neural and social processes operating in collaboration, rather than as the result of some totally new structure based on a recent mutation.

The core assumptions of the Competition Model are shared with many other models in current psycholinguistics. The model specifies a series of steps for the competition between constructions during comprehension:

1. Sounds activate competing words as they are heard in speech (Brent, 1999; Marslen-Wilson & Warren, 1994; Monaghan, Christiansen, & Chater, 2007).
2. Each new word activates its own IBPs together with related FBPs (Trueswell & Tanenhaus, 1994; Trueswell, Tanenhaus, & Kello, 1993).
3. IBPs then initiate tightly specified searches for slot fillers (Ford, Bresnan, & Kaplan, 1982; MacDonald, Pearlmutter, & Seidenberg, 1994).
4. Slots may be filled either by single words or by whole phrases. In the latter case, the attachment is made to the head of the phrase (O'Grady, 2005; Taraban & McClelland, 1988).
5. To fill a slot, a word or phrase must receive support from cues for word order, prosody, affixes, or lexical class (MacWhinney, 2005a).
6. If several words compete for a slot, the one with the most cue support wins (Kempe & MacWhinney, 1999).
7. Processing commitments are made when the difference in the activation of two competitors passes over a threshold (Ratcliff, 1978; Ratcliff & Smith, 2004).

These seven design features of the processor work together to achieve fluent production and comprehension in real time. Here, the time frame of the constraints of face-to-face interaction is the critical determinant of the emergent shape of these processes. Consider the German noun phrase *am Haus meiner Mutter* (at my mother's house). The initial preposition *am* is a contraction of *an* "to" and *dem* "the." When producing *am,* the speaker must already know that the following noun will be neuter. If the following noun were feminine, then the form would be *an der,* rather than *am.* It is generally true of German that, when producing articles, adjectives, and even contracted prepositions, one must know the gender of the following noun. For a native speaker, this comes naturally, because the lexicon is organized in terms of gender categories, as suggested by the DevLex model discussed earlier. However, for a second language learner, the gender of a noun is not as obvious, and this means that the second language learner will often produce errors or disfluencies when picking the gender for forms before the noun.

Timing and the just-in-time flow of information are important throughout the processing system. Sometimes the barriers involve anticipation of information that has not yet been determined; sometimes they involve the settling of competitions between attachments. Consider the case of prepositional phrase attachment. Prepositions such as *on* take two arguments; the first argument (arg1) is the object of the preposition, and the second argument (arg2) is the head of the prepositional phrase (i.e., the word or phrase to which the prepositional phrase attaches). We can refer to arg1 as the local head and arg2 as the external head. Consider the sentence *the man positioned the coat on the rack.* Here, the local head of *on* is *rack* and its external head (the head of the whole prepositional phrase) could be either *positioned* or *the coat.* These two alternative attachment sites for the prepositional phrase are in competition with each other.

Competition also governs the interpretation of verbs as either transitive or intransitive. Verbs like *jog* that have both transitive/causative and intransitive readings can be represented by two competing lexical entries. When we hear the phrase *since John always jogs a mile,* we activate the transitive reading. However, if the full sentence then continues as *since John always jogs a mile seems like a short distance,* then the intransitive reading takes over from the transitive one. For detailed examples of the step-by-step operations of this type of processor, consult MacWhinney (1987), MacDonald et al. (1994), or O'Grady (2004).

Neurological Control

The Unified Competition Model (MacWhinney, 2009) links the processes and levels of language we have been discussing to structures in particular brain areas. Understanding the neural basis of language is important for the life-span approach to language development because it allows us to understand many otherwise puzzling aspects of first language learning, second language learning in adulthood, developmental language disorders, and aphasia. The model views the six linguistic levels (audition, articulation, lexicon, syntax, mental models, and conversation) as processed through partially separate neural structures. These structures are not viewed as modules (Fodor, 1983) but as parts of interactive neural circuits (Just & Varma, 2007).

The neural representation for the levels of articulation, audition, and lexicon was discussed in the context of our review of the DevLex model. The three separate maps of the DevLex model represent three of the six core linguistic modules. These modules are each located in separate brain regions, connected by axonal, white matter projections. DexLex trains these connections using Hebbian learning. Input phonology is processed in the auditory cortex of the superior temporal sulcus. Output phonology is controlled by parts of Broca's area, along nearby regions with motor cortex. The core semantic or lexical map is centered in Wernicke's area, although the actual meanings of words are distributed throughout the brain (Mitchell et al., 2008).

Looking first at the control of input phonology, we know that this processing is focused in primary auditory cortex. This area, which spans Brodmann areas BA41 and BA42, lies in the posterior half of the superior temporal gyrus and the transverse temporal gyri or Heschl's gyri. Within this area, there are, in fact, multiple tonotopic maps, each of which appears to represent a different view or processing slant on the whole range of the frequency spectrum. Work with rhesus monkeys has shown that the auditory system involves three levels of auditory processing with 15 different tonotopic maps. This pattern of multiple parallel isotopically organized maps is similar to the pattern of multiple parallel maps found in the motor system. Like many other cortical areas, the auditory cortex is also connected to its own specific thalamic nucleus, the medial geniculate nucleus, from which it receives input.

Syntax gates both lexical production and mental model extraction. The central role played by syntactic gating allows us to understand many features of language development and disorders. The distinction between lexicon and syntax reflects the fundamental linguistic contrast between rote and combination (MacWhinney, 1978; Pinker, 1999). Posterior lexical areas, including Wernicke's area, rely on the detailed coding facilities provided by the ventral neural system (Tucker, 2009). This system relies on the remarkable ability of the hippocampus to store huge quantities of specific episodic experiences through a system of synaptic reentry (Wittenberg, Sullivan, & Tsien, 2002). Anterior sequence-processing areas, including Broca's area, rely on the more action-oriented mechanisms of the dorsal processing system. Ullman (2004) has noted that the dorsal system is also closely allied with thalamic and striatal midbrain systems that work to set up and solidify sequential and procedural processing. Thus, this basic division between rote and combination is honored in a basic way by the brain's division into dorsal and ventral systems.

Although the division of these two processes makes great sense computationally, it leads to a fundamental problem in terms of language coordination. During comprehension, anterior syntactic areas need to listen closely to posterior lexical areas to decide when specific IBPs or FBPs can fire. During comprehension, there are often competing possible interpretations that are controlled by alternative syntactic pathways. Only by maintaining smooth contact with posterior areas can posterior areas make the right choices. During speech production, the problem is even worse. Syntactic areas, taking their cues from mental models, must control or *gate* the firing of lexical items. Multiple lexical items are often ready to fire in parallel (G. Dell, Juliano, & Govindjee, 1993; Stemberger, 1985). However, each word must wait for its appointed moment for entry into the slots opened up by IBPs. When that moment comes, the word fires the articulatory gestures that it commands in motor cortex. The sequence mechanism must gate lexical items in a smooth way that minimizes stuttering, false starts, and pauses. This means that all signals from Broca's to Wernicke's must arrive on time in a coordinated way. Failures in the timing of this gating produce disfluencies in first language learning, second language learning (Yoshimura & MacWhinney, 2007), developmental language disorders, stuttering, and aphasia (Dell, Schwartz, Martin, Saffran, & Gagnon, 1997).

The operations of this processor are not learned; rather, they are grounded on structures in the ventral and dorsal systems that have parallels in all of our primate cousins. There are at least four major anterior-posterior white matter pathways that connect primate areas homologous to those involved in human language (Schmahmann et al., 2007). Although diffusion tensor imaging with humans is in its infancy, it is likely that we will find that the integration of the anterior/dorsal system and the posterior/ventral system has been even more elaborated in recent human evolution. Friederici (in press) and others have begun to trace ways in which these partially separate white matter conduits can gate different levels of information between syntax and lexicon.

These white matter connections must deal with a fundamental issue in neural processing: the binding problem. When an IBP or FBP is activated in inferior frontal gyrus (IFG), it opens up an argument slot that is characterized by a part of speech. This means that this sequential pattern must be connected with lexical cortex in a way that activates potential slot fillers and not other lexical items. The DevLex model is organized to produce exactly this effect, because it manages to organize lexical items in a local topological map in terms of their parts of speech. This means that connections through white matter must terminate in the correct general area of lexical space, and also that the IBPs and FBPs that gate these part of speech areas must be responsive to this information. For a normal child who is learning a first language, this type of connection develops slowly, but consistently and directly. However, if the white matter pathways are damaged in any way, gating will be slow and activation will be erratic. The worst case would be in Wernicke's aphasia where the crucial terminals of these pathways are completely severed. Second language learners must also deal with the fact that they need to rely on the lexical maps and pathways of their first language, and that often these will produce incorrect transfer to L2.

So far, we have not characterized the sequential processor in mechanistic terms. To do this, we need to address two issues. The first is the way in which individual IBPs can operate in real time. The second is how IBPs combine into a coordinated system. On the first issue, there are several models of neural mechanisms for sequence detection and control. One class of models views sequential patterns as avalanches (Grossberg, 1978; McCulloch & Pitts, 1943) that fire in quick sequence without additional feedback control (Houghton, 1990). Simple chains provide a reliable solution to the sequencing problem. However, if the delay between events A and B is either less than or more than the natural timing on the synaptic connections between units A and B, the chain may fail to fire. Sequence detection can rely on additional mediating elements, configured in various ways, to avoid this type of problem (Dominey, Hoen, & Inui, 2006). Pulvermüller (2003) proposes a mechanism that includes bidirectional connections that promote reverberation within the circuit. The fact that forward sequential connections are stronger than backward ones prevents the circuit from firing in the wrong direction. When sequence unit A fires, it primes the control unit C. Unit C then primes sequence unit B, thereby triggering initial reverberation in the whole circuit. At this point, both of the items that have been detected become "visible," which means that they can then pass on information to other processing areas. However, if the unit B fires without first being primed, it fails to trigger the control unit C and activation of unit B is then suppressed. There are many other ways in which the basic sequence detection mechanism could be configured, and it is even possible that nature has utilized several of these alternative ways.

The second problem that must be addressed by a mechanistic model of sequence control for syntax is the problem of how positional patterns are linked. There is, in fact, a very standard computational framework that can serve well to explain this system. This is the finite-state automaton, which is a machine that can produce or recognize sequences as a series of state transitions. In their original formulation, finite-state machines were thought of as systems for transitioning between lexical items. However, as Hausser (1999) has shown, the pathways in this system can also be viewed as transitions between categories, such as parts of speech or grammatical categories. In this sense, an IBP can be viewed as a finite-state machine that maps the transition between a single lexical item and a category. When IBPs are generalized as FBPs, then the resulting categories can form a complete finite-state machine.

However, for this machine to work well in neural terms, there has to be a good way to implement the process of clustering described earlier. Consider a sentence such as *boys with long hair like to ride motorcycles.* Here, the initial cluster is *boys with long hair.* If this cluster can activate a node that treats it as a complex noun, then the whole cluster can fill the subject slot for the verb *ride.* The question is simply how the brain manages to control the activation of clusters as sentences become more and more complex. Gibson (1998), Just and Carpenter (1992), and others have analyzed complex sentences in detail and have concluded that complex syntax places specific burdens on the working memory system. Recent work in cognitive neuroscience has indicated that this system relies primarily on representations in dorsolateral prefrontal cortex (DLPFC; Just & Varma, 2007). But neuroscience has not yet told us exactly how DLPFC manages to perform clustering actions. The basic idea proposed here is that DLPFC interprets individual phrasal chunks in terms of a mental model grounded on embodied cognition. In this process, it assigns action roles to the various phrases in the sentence and uses these to control the process of clustering in the syntactic sequence processing areas. To understand how these roles are assigned, we next turn to the level of processing of mental models.

Mental Models

Recent work in neuroscience has benefitted from four fundamental insights, each relating to the construction of mental models. First, in the 1980s, we learned that the visual system separates processing into an image-oriented ventral stream and an action-oriented dorsal stream. Second, we have learned from imaging work through the last decade that the brain relies on a perception-action cycle to interpret incoming messages. This cycle involves the generation of mental representations for objects in terms of the ways in which we typically act on them (Knoblich, 2008). Much of this cycle is grounded on interactions that include the action-oriented processing of the dorsal stream. Third, we have learned that the brain provides specific mechanisms for mapping the body images of others onto ours. One consequence of this ability is the fact that "mirror" neurons (Rizzolatti, Fadiga, Gallese, & Fogassi, 1996) controlling actions, facial gestures, and postures can fire equally strongly when the actor is the self or the other. As we are now learning, these mirror neurons are components of a general system for social cognition. The larger system also includes mechanisms in the superior temporal cortex for facial processing (Pelphrey, Morris, & McCarthy, 2005) and eye contact (Pelphrey et al., 2003), as well as amygdala and striatal areas for empathy (Meltzoff & Decety, 2003) and projection (Adolphs & Spezio, 2006). Fourth, we have learned that the basal ganglia and hippocampus play a central role in the consolidation of memories, often driven by rewards and error minimization.

Piecing together these results, we can see that one of the additional consequences of the dorsal-ventral dichotomy is a shift of discrete processing of individual elements to the ventral stream and a shift of global model construction to the dorsal stream, with particular additional regulatory control from frontal areas. In recent articles (MacWhinney, 2005d, 2008c), I have suggested that this system provides the neurological basis for a system that constructs dynamic mental models from linguistic input. At the core of this system is the notion of the self as actor. During sentence interpretation, this fictive self is then projected onto the role of sentence subject, and the self reenacts the image underlying the sentence. These images place the self into a set of well-understood roles as agent, experiencer, and source. Even locative and temporal relations can be interpreted from the egocentric frame that begins with a projection of the self onto the object located or the event in time.

Because narrative and dialogue often involve rapid shifts between agents, this system has to be able to use linguistic devices to control perspective shifting. As a result of this core dynamics, we can refer to this system as the Perspective Shift System. This system constitutes the highest level of support for linguistic complexity. Without the mental model construction supported by this system, complex syntax would be useless. This is because the fundamental purpose of virtually all the devices of complex syntax is the marking of perspective shift. This analysis applies across all the major grammatical constructions, including passivization, relativization, clefting, pronominalization, dislocation, existentials, shift reference, split ergativity, serialization, complementation, conjunction, ellipsis, adverbialization, long-distance anaphora, reflexivization, PP-attachment, and participial ambiguity. Each of these structures allows the speaker to combine, maintain, and shift perspectives in communicatively important ways. And these devices allow the listener to trace these movements of the speaker's attention across all of these shifts.

Building Mental Models

The traditional view of mental model construction (Budiu & Anderson, 2004; Kintsch, 1998) focuses on the linking of predicates into a coherent propositional graph. This activity is much like the process of clause combining that we learned in classes in composition. For example, you can combine "the dog chased the bird" and "the bird flew away" to form "the dog chased the bird that flew away." All one needs here is a grammatical device that serves to mark the fact that *the bird* plays a role in both clauses. Language provides a variety of methods or constructions for clause linkage, including conjunction, complementation, relativization, subordination, and adverbialization, as illustrated in these sentences:

> If you go down to Shattuck, the bakery is on the corner.
>
> Jim had asked me to bring him a loaf of bread.
>
> Unfortunately, the bread I bought was stale.
>
> Although it was stale, John wanted to pay me.
>
> Shaking my head, I accepted the money.
>
> My refusal of the payment would have made him upset.

These different constructions serve to link together clauses in terms of spatial, temporal, causal, and anaphoric relations. Most of these constructions rely on both lexical and syntactic processes. Typically, there is a linking lexical element, such as a conjunction or relativizer. In some cases, the lexical element is an affix that forms nominalizations or participials. Use of this linking element then triggers additional syntactic processes, such as extraposition, deletion, constituent reordering, agreement, and so on.

Syntactic constructions rely on four key aspects of the current model. First, the lexical items involved must be stored as phonological forms within the posterior systems. These items include both full lexical items and affixes. Second, these lexical forms must be integrated by IFG into positional patterns that control the positioning of the items in the clauses, as well as movement and deletion. Third, these IFG structures must rely on frontal short-term memory (STM) mechanisms that store elements as flexible deictic representations (Ballard, Hayhoe, Pook, & Rao, 1997; Silverstein, 1976). Fourth, these STM items must be pieced together for final mental model construction.

MacWhinney (2008c) argues that mental model construction is driven by a process of perspective taking. Let use consider an example from relative clause processing. Earlier we noted how clause combining through STM joins *the dog chased the bird* and *the bird flew away* to form *the dog chased the bird that flew away*. In this case, the shift moves smoothly from *bird* as the object of chased to *bird* as the subject of *flew away.* However, if the sentence is *the dog chased the bird that the girl loved,* then perspective tracking is more difficult, because a new perspective is introduced after *bird,* and the perspectives of both *the dog* and *the bird* must then be dropped. In this case, there is a greater burden on STM for fragment storage, and hence a higher overall processing load, as reflected by slower latencies and lesser recall accuracy for object relatives. These shifts of perspective are triggered by syntactic patterns linked to lexical devices. To learn these, the child must figure out how to operate on signals from the lexicon or IFG to control the correct shifting in frontal cortex. As the developmental literature amply demonstrates, the learning of this control takes many years (Franks & Connell, 1996). We explore some of these processes in further detail later in this chapter because this is one of the primary loci of the consolidation of linguistic complexity.

Ambiguous sentences illustrate another face of perspective shifting. Consider sentences such as "John saw the Grand Canyon flying to New York." Here, the default syntactic mechanism would favor the local attachment of *flying to New York* to *Grand Canyon.* The competing attachment is to *John.* Of course, the latter perspective is far more plausible. Or consider the processing of "Visiting relatives can be a nuisance." Here, we can either take the perspective of the relatives who become a nuisance to their hosts or the perspective of an unmentioned generalized actor who visits the relatives. In this case, both readings seem plausible. Reflexivity provides another useful example of perspectival processes. Consider these sentences:

a. Jessie stole a photo of herself/her* out of the archives.
b. Jessie stole me a photo of herself/her out of the archives.
c. Jessie stole a silly photo of herself/her out of the archives.

In (a), the reflexive is required because the perspective of Jessie remains active up to the appearance of the anaphor. In (b), on the other hand, the intervening presence of "me" causes a shift of perspective away from Jessie. As a result, when interpretation reaches the anaphor, either the reflexive or the simple pronoun is acceptable. Perspective shift is sensitive not just to other intervening animate perspectives, but also to implicit perspectives triggered by adjectives such as *silly* in (c). This type of phenomena is basic to all levels of mental model construction.

Perspective and Gesture

The frontal-parietal system for perspective shifting is not a recent evolutionary adaptation. Chimpanzees (Tomasello, Call, & Gluckman, 1997), dogs, and other mammals make extensive use of symbolic behaviors in social contexts. However, lacking a lexicon and positional patterns, other animals cannot organize these behaviors into recursive structures. However, Donald (1991) and others have argued that the production of symbolic communication can rely on gestural and vocal devices that may well have been readily accessible to *Homo erectus.* Because gestures can be formed in ways that map iconically to their referents, it is relatively easy to build up communal recognition of a gestural system. As Tucker (2009) argued, such a system would rely primarily on gestures and affordances specific to the action-oriented processes in the dorsal stream. It appears that speakers of sign languages are able to use posterior lexical areas to structure a lexicon of signs, just as they use IFG in the left hemisphere to control the ordering of signs. It is possible that protosign could also have relied on these same neuronal structures for lexical organization. However, looking back 2 million years, it is likely that the depth of support for lexical storage and positional patterning of gesture was still very incomplete. As a result, it is likely that protosign was incompletely lexical and heavily reliant on dorsal processes for direct perspective taking and shifting.

Although sign may not have triggered full linguistic structure, it provided a fertile social bed that supported the development of further articulatory, lexical, and sequence systems. As Darwin (1872) noted, vocal and gestural communication coexisted as parallel streams from the beginning of human evolution. Gesture and prosody were able to keep humans engaged in protoconversations, during which the further elaboration of vocal patterns could refine and complement communication in the gestural-prosodic mode. Of course, humans are not the only primates that engage in conversation. However, as argued in MacWhinney (2008b), the shift in *Homo habilis* to a full upright posture led to two important consequences. One was the freeing of the hands for additional conversational interaction, and the other was the encouragement of full face-to-face interactions linked to full display of the hands and torso. This increasing support for gestural communication brought along with it a supportive social context for the further development of accompanying vocalizations. However, both of these modalities continue to provide important input to conversation in modern humans. Thus, we can best view the transition from a primarily gestural communication to a primarily vocal communication system as gradual, but unbroken, process with no sudden break based on the sudden introduction of an ability to process recursion.

Mental Models and Socialization

Vygotsky (1929), Mead (1934), Bruner (1987), Nelson (2000), and many others have argued that language plays a unique role in the transmission of cultural norms, frames, expectations, roles, and values. According to Vygotsky, the earliest uses of language are primarily social. This interpretation is supported in some detail by analyses from Ninio and Snow (1988) that focus on the heavy use in early vocabulary of forms such as *hi, gimme,* and *Mama*—all with clear social reflexes. Vygotsky argued that, once this initial social configuration is established, language then supports inner speech, a process that uses discourse, grammatical, and narrative forms from the ambient language to guide internal cognitive processing. It is difficult to imagine how this basic story could be wrong. In modern societies, we end up acquiring an enormously complex system of related concepts and frames, based nearly exclusively on verbal and written input. Moreover, this process of acculturation continues across the entire life span. In a very real sense, we can view culture as a roadmap or guidebook for life, and the way in which this guidebook is conveyed to new generations is largely through language and conversation.

These scripts, frames, and plans for social rules and behaviors become encoded as mental models (Fauconnier, 1994), based on the system for perspectival construction described throughout this section. These models are organized in two fundamental ways. One method uses the point of view of the human agent as protagonist. In this method, we use dorsal encoding to remember how to order food at McDonald's by encoding the perspectives of ourselves as clients, as well as those of the clerks who take the orders. These stories are further encoded in terms of the deictic frameworks of space and time supported by the ventral system. In the second method of encoding, we construct views of objects and systems as working mechanisms. This method is important for understanding science (Greeno & MacWhinney, 2006), mathematics (Nuñez & Lakoff, 2000), and mechanical devices. For this encoding, we use a variety of physicalist primitives, or p-prims, together with notions of force dynamics (Talmy, 2000) and basic causation (Hume, 1748).

Conversation

The view of acculturation presented so far suggests that society is encoded only as narrative or mechanistic. Although narrative and mechanistic organizations are fundamental to many pieces of social competence, acculturation into conversational patterns also plays a major role in our daily lives. However, unlike narratives and mechanics, the components of conversational competence are stored not as long sequences of actions and causes, but as local networks, much like the systems for encoding IBPs and FBPs. Much of conversational competence can be described in terms of simple rules for turn-taking (Sacks, Schegloff, & Jefferson, 1974), speech act adjacency pairs (Mann & Thompson, 1992), and local cues for the expression of affect (Crystal, 1975). The full system for conversational interaction involves a rich multimedia interplay between gesture, prosody, lexicon, discourse, syntax, gaze, and posture (Kendon, 1982). Perhaps the best way to think of conversation is in terms of the interface between the social and the linguistic world with all the devices of each of these worlds being made available at the time of interaction.

Babies and their parents engage in conversations even before the child has begun to produce words. These conversations may involve shared smiles, gazes, coos, and grunts (Snow, 1977). Parents of young children will speak to them as if they were real conversational participants. (For examples of this, you can browse the transcripts linked to audio at the CHILDES database: http://childes.psy.cmu.edu/data, such as the Brent corpus, or use the online browser at http://childes.psy.cmu.edu/browser.) These early dialogues are important for several reasons. First, they demonstrate the extent to which children acquire language not to just solve problems or express themselves, but also to participate fully in conversational interactions. Conversations allow us to engage socially as members of dyads and groups. To the degree that there is a fundamental urge to produce language, it is in large part an urge not to talk, but to converse.

This urge to socialize affects mothers, as well as infants. Papousek and Papousek (1991) showed that mothers use rising pitch contours to engage infant attention and elicit a response, falling contours to soothe their babies, and bell-shaped contours to maintain their attention. In general, these patterns are useful not only for directing attention to new words, but also for involving babies in the "melody" of conversation (Locke, 1995), even before they have learned "the words."

Conversations between mothers and their infants involve a variety of alternating activities. Infants tend to produce positive vocalization when gazing into their parents' eyes (Keller, Poortinga, & Schomerich, 2002). When infants produce negative vocalizations, parents often respond by touching and cuddling them. However, infants will produce more vocalizations when parents vocalize to them, rather than merely responding with touch or gesture (Bloom, Russell, & Wassenberg, 1987). A longitudinal study of naturalistic talk (Snow, Pan, Imbens-Bailey, & Herman, 1996) found a continuing increase in child speech act during 10-minutes segments from 4 at 14 months to 7 at 20 months and 11 at 32 months. This ongoing growth of participation in conversations emphasizes the extent to which infants are being mainstreamed into a world of continual conversational turn-taking.

The logic of parent–child conversational turn-taking is not fundamentally from that used between adults. The basic rule underlying all forms of turn-taking (Sacks, Schegloff, & Jefferson, 1974) is that, at any given moment, one of the participants is said to "have the floor." While that participant holds the floor, the other participants are supposed to pay attention to the conversational contribution. At some point the speaker begins to yield the floor and thereby invites a new conversational contribution. Signals that invite a new contribution include pauses, questions, and drops in intonation. Of course, conversations are not controlled as carefully as the flow of traffic through signal lights.

Often there are collisions between speakers, resulting in overlaps. At other times, there are complete breaks in the interaction. All of these features can be detected in vocal-visual interactions between mothers and children as young as 12 months. What distinguishes parent–child dialogues from adult–adult dialogs is the extent to which the parent uses specific devices to interpret children's ill-formed actions as conversational actions, and the extent to which the parent attempts to maintain and guide the interaction, both verbally and physically.

Toward the end of the first year, children develop increasing ability to control conversations through specific routines. The most well-developed routine is pointing. Children show reliable responding to pointing by about 10 months. They are able to look at their parents' faces, and use their gaze and pointing to locate objects. Soon after this, by about 12 months, children begin to produce their own communicative pointing (Lempers, 1979). In the period between 12 and 15 months of age, just before the first words, children also develop a set of intonational patterns and body postures intended to communicate other detailed meanings (Halliday, 1975).

Parents provide interpretive scaffold for many of the child's early communicative behaviors (Bruner, 1992). After the child produces a smile, the parent may then respond with a full-fledged verbal interpretation of the meaning implicit in the smile, as in, *Is David having fun?* If the child shakes a spoon, the mother will attempt to interpret this gesture, too, suggesting, *Ready for dinner?* Beginning around 9 months, this sequence of child action and maternal interpretation takes on a choral quality involving alternating, rather than overlapping, contributions (Jasnow & Feldstein, 1986). By combining verbal responses with the child's gestures, mothers are able to produce a scaffold on which children can construct a vision of communicative interactions. The transcripts with videos available from the CHILDES database (http://childes.psy.cmu.edu) provide many illustrations of choral sequences of this type.

Snow (1999) argues that early participation in conversational interactions is the primary support for the initial stages of language acquisition. She emphasizes the extent to which early words serve social functions in games and routines, rather than serving merely to request objects. Crucially, language learning depends on the construction of a shared intersubjective understanding of the intentions of the parent. Conversational sequencing is the scaffold on which this understanding develops. However, it is further supported by processes of identification (Rizzolatti et al., 1996), embodiment (MacWhinney, 2008c), and imitation (Meltzoff, 1995).

Language after Childhood

As noted earlier, certain aspects of language development continue throughout the life span. The clearest example of this is vocabulary development. Although the core vocabulary of a language is largely acquired by the end of childhood, there is continual later development in specialized areas of the lexicon. In some societies (Schieffelin & Ochs, 1987), there are special ceremonial uses of the language that are revealed to young men only after they pass through puberty rites. At this point, they are inducted into men's societies (Levi-Strauss, 1963) that reveal to them traditions that are often linked to special uses of the language. Children and adolescents also come to learn new words and constructions when they acquire specialized skills. In tribal societies, these can involve methods of hunting, names for animals and plants (Berlin & Kay, 1969), or tools for weaving and pottery. In modernized societies, these new concepts may relate to schooling, instruments used in the trades, or new social groups.

Apart from the basic increase in vocabulary, adolescents may acquire a wide range of other semiotic patterns. They may learn segments of the Bible, Torah, Koran, Constitution, or Scout Oath by heart. They may have to study the signs, symbols, and rules for driving, soccer, playing a musical instrument, or skateboarding. Teenagers and young adults often engage in innovative uses of language that introduce new slang, constructions, and phonological patterns (Labov, 1994). In young adulthood, schooling continues in the form of professional development. In areas such as biology, medicine, or chemistry, students may be responsible for learning as many as 10,000 technical terms. These terms are learned in the context of dense semantic networks explaining the role of each term in complex processes (Miller, 1978). In urban societies, we also continue to meet new people, and need to learn their names and many facts about them. In smaller, traditional societies, this type of learning often focuses instead on the learning of the names of ancestors and their life stories.

This continual expansion of language during adulthood depends on the powerful episodic encoding mechanisms of the ventral-temporal stream in the cortex. The ability of this system to store new items is virtually limitless, although some forgetting and interference does occur over time. This system provides much of the basis for the crystalline intelligence (Miller, 1978), which is largely preserved even in old age. Older adults occasionally experience word-finding problems, often revealed through tip-of-the-tongue episodes. The occurrence of effects of this type is in line with findings regarding the fan effect (Reder & Anderson, 1980), which views the growth in declarative memory structures as leading to slowdowns in retrieval and increases in interference.

The continual growth of lexical ability across the life span is not matched by a similar growth in processing ability. Instead, there is evidence for a gradual neural decline beginning in early adulthood (Kemper, 2006) that leads to slow declines in language fluency, speed, coordination, and accuracy. Even in adults who have not suffered from stroke or other neural disabilities, we can see some slowdown of processing in old age. Wear and tear on the vocal cords and loss of muscle tone can affect speech production, further slowing articulation. When evaluating this decline, we need to note that there is little room for improvement during adulthood in the core features of articulation, audition, and syntax, because these abilities are essentially perfected by the end of childhood. For abilities that are already at asymptote, the only possible direction of movement is downward. Although it is true that we do see some downward movement, this movement is relatively minor and seems to be mostly caused by an overall decline in processing speed.

Second Language Acquisition

In predominantly monolingual countries like the United States or Japan, it is easy to forget that the majority of the people in the world are bilingual or multilingual. The ways in which bilingualism can arise are highly diverse. In areas such as Southeast Asia or the Balkans, villages may be fundamentally bilingual, with people from two different language communities living next to each other and interacting on a daily basis. In multilingual countries such as Switzerland, Belgium, and Luxembourg, a child's parents may each speak a different language, and the child will speak one of these languages at home and another with their peers. In regions such as Africa, children may acquire the national language from their life in the capital city, but a local family language when they return to the countryside in vacation times to live with their rural family.

Older learners' abilities to acquire additional languages with full native fluency declines slowly (Hakuta, Bialystok, & Wiley, 2003) across the life span. Some researchers have suggested that there may be a sharp drop in learning success at puberty (Johnson & Newport, 1989). However, more comprehensive studies indicate no sharp drop at this point, but only a slow and gradual decline. A census-based study of hundreds of Chinese and Mexican immigrants to California (Hakuta et al., 2003; Wiley, Bialystok, & Hakuta, 2005) showed that the disadvantage for older learners is equal to the disadvantage arising from the lack of higher education in one's home country. Thus, educated older immigrants learn about as well as less-educated younger immigrants.

Foreign accent is usually revealed in the way in which an adult learner articulates particular sounds. The fact that some adult learners find it difficult to lose their native language accent even after many years in another country has suggested to some that there may be a specific critical period for the learning of articulation. In a study of Italian immigrants to Toronto, Flege, Yeni-Komshian, and Liu (1999) found that, if the immigrant had arrived to Canada after age 6, it was likely that they would have some trace of an Italian accent. However, it is possible that this preservation of native accent was supported, at least in part, from continued interaction with the Italian immigrant community after arrival. If we look at learners who begin second language acquisition after age 20, it is true that the majority maintain some trace of a foreign accent. However, Bongaerts (1999) found that, if these late learners had good phonetic training, they could eventually lose all trace of a foreign accent in their acquired language.

Emergentist accounts for these effects focus on the twin mechanisms of transfer and entrenchment (MacWhinney, 2005b, 2008a). When two languages are acquired in parallel from birth, neither dominates over the other and each is acquired in its own right. When a second language is learned after early childhood, the words of the weaker language are initially parasitic on those of the first (Kroll & Tokowicz, 2005). In terms of the DevLex model (Li, Zhao, & MacWhinney, 2007), this parasitism is expressed by locating the new words in the same lexical space as their translation equivalents. In terms of articulatory form, new words in the second language are initially composed of phonemes from the first languages. With time, these entrenched L1 gestures are restructured for use in L2. Similarly, syntactic patterns from the first language are also used to order sentences in the second language. Over time, as second language forms strengthen, they can compete with the stronger L1 forms and L2 gradually takes on its own independent shape. In this regard, it is particularly important that the learner starts to think and reason in the second language, thereby acquiring new attitudes, thoughts, and linguistic patterns.

SUMMARY

In this chapter, we have seen how language development across the life span emerges from interactions of the brain with input from the social environment. Both first and second languages are learned by step-by-step inductive procedures that focus on gradual, conservative extension of newly acquired words, sounds, and syntactic patterns. After initial acquisition, ongoing competition modifies the shape of individual forms and the overall system across the life span. Beyond its use for communication, language serves to structure thought and wider social relations in patterns that operate at diverse time scales (MacWhinney, 2005e) ranging from the moment, to the minute, the interaction, the life span, and the evolution of the species.

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