

Language Acquisition

Steven Pinker
Massachusetts Institute of Technology

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1 Introduction

Language acquisition is one of the central topics in cognitive science. Every theory of cognition has tried to explain it; probably no other topic has aroused such controversy. Possessing a language is the quintessentially human trait: all normal humans speak, no nonhuman animal does. Language is the main vehicle by which we know about other people's thoughts, and the two must be intimately related. Every time we speak we are revealing something about language, so the facts of language structure are easy to come by; these data hint at a system of extraordinary complexity. Nonetheless, learning a first language is something every child does successfully, in a matter of a few years and without the need for formal lessons. With language so close to the core of what it means to be human, it is not surprising that children's acquisition of language has received so much attention. Anyone with strong views about the human mind would like to show that children's first few steps are steps in the right direction.

Language acquisition is not only inherently interesting; studying it is one way to look for concrete answers to questions that permeate cognitive science:

Modularity. Do children learn language using a "mental organ," some of whose principles of organization are not shared with other cognitive systems such as perception, motor control, and reasoning (Chomsky, 1975, 1991; Fodor, 1983)? Or is language acquisition just another problem to be solved by general intelligence, in this case, the problem of how to communicate with other humans over the auditory channel (Putnam, 1971; Bates, 1989)?

Human Uniqueness. A related question is whether language is unique to humans. At first glance the answer seems obvious. Other animals communication with a fixed repertoire of symbols, or with analogue variation like the mercury in a thermometer. But none appears to have the combinatorial rule system of human language, in which symbols are permuted into an unlimited set of combinations, each with a determinate meaning. On the other hand, many other claims about human uniqueness, such as that humans were the only animals to use tools or to fabricate them, have turned out to be false. Some researchers have thought that apes have the capacity for language but never profited from a humanlike cultural milieu in which language was taught, and they have thus tried to teach apes language-like systems. Whether they have succeeded, and whether human children are really "taught" language themselves, are questions we will soon come to.

Language and Thought. Is language simply grafted on top of cognition as a way of sticking communicable labels onto thoughts (Fodor, 1975; Piaget, 1926)? Or does learning a language somehow mean learning to think in that language? A famous hypothesis, outlined by Benjamin Whorf (1956), asserts that the categories and relations that we use to understand the world come from our particular

language, so that speakers of different languages conceptualize the world in different ways. Language acquisition, then, would be learning to think, not just learning to talk.

This is an intriguing hypothesis, but virtually all modern cognitive scientists believe it is false (see Pinker, 1994a). Babies can think before they can talk (Chapter X). Cognitive psychology has shown that people think not just in words but in images (see Chapter X) and abstract logical propositions (see the chapter by Larson). And linguistics has shown that human languages are too ambiguous and schematic to use as a medium of internal computation: when people think about "spring," surely they are not confused as to whether they are thinking about a season or something that goes "boing" -- and if one word can correspond to two thoughts, thoughts can't be words.

But language acquisition has a unique contribution to make to this issue. As we shall see, it is virtually impossible to show how children could learn a language unless you assume they have a considerable amount of nonlinguistic cognitive machinery in place before they start.

Learning and Innateness. All humans talk but no house pets or house plants do, no matter how pampered, so heredity must be involved in language. But a child growing up in Japan speaks Japanese whereas the same child brought up in California would speak English, so the environment is also crucial. Thus there is no question about whether heredity or environment is involved in language, or even whether one or the other is "more important." Instead, language acquisition might be our best hope of finding out how heredity and environment interact. We know that adult language is intricately complex, and we know that children become adults. Therefore something in the child's mind must be capable of attaining that complexity. Any theory that posits too little innate structure, so that its hypothetical child ends up speaking something less than a real language, must be false. The same is true for any theory that posits too much innate structure, so that the hypothetical child can acquire English but not, say, Bantu or Vietnamese.

And not only do we know about the output of language acquisition, we know a fair amount about the input to it, namely, parent's speech to their children. So even if language acquisition, like all cognitive processes, is essentially a "black box," we know enough about its input and output to be able to make precise guesses about its contents.

The scientific study of language acquisition began around the same time as the birth of cognitive science, in the late 1950's. We can see now why that is not a coincidence. The historical catalyst was Noam Chomsky's review of Skinner's *Verbal Behavior* (Chomsky, 1959). At that time, Anglo-American natural science, social science, and philosophy had come to a virtual consensus about the answers to the questions listed above. The mind consisted of sensorimotor abilities plus a few simple laws of learning governing gradual changes in an organism's behavioral repertoire. Therefore language must be learned, it cannot be a module, and thinking must be a form of verbal behavior, since verbal behavior is the prime manifestation of "thought" that can be observed externally. Chomsky argued that language acquisition falsified these beliefs in a single stroke: children learn languages that are governed by highly subtle and abstract principles, and they do so without explicit instruction or any other environmental clues to the nature of such principles. Hence language acquisition depends on an innate, species-specific module that is distinct from general intelligence. Much of the debate in language acquisition has attempted to test this once-revolutionary, and still controversial, collection of ideas. The implications extend to the rest of human cognition.

2 The Biology of Language Acquisition

Human language is made possible by special adaptations of the human mind and body that occurred in

the course of human evolution, and which are put to use by children in acquiring their mother tongue.

2.1 Evolution of Language

Most obviously, the shape of the human vocal tract seems to have been modified in evolution for the demands of speech. Our larynxes are low in our throats, and our vocal tracts have a sharp right angle bend that creates two independently-modifiable resonant cavities (the mouth and the pharynx or throat) that defines a large two-dimensional range of vowel sounds (see the chapter by Liberman). But it comes at a sacrifice of efficiency for breathing, swallowing, and chewing (Lieberman, 1984). Before the invention of the Heimlich maneuver, choking on food was a common cause of accidental death in humans, causing 6,000 deaths a year in the United States. The evolutionary selective advantages for language must have been very large to outweigh such a disadvantage.

It is tempting to think that if language evolved by gradual Darwinian natural selection, we must be able to find some precursor of it in our closest relatives, the chimpanzees. In several famous and controversial demonstrations, chimpanzees have been taught some hand-signs based on American Sign Language, to manipulate colored switches or tokens, and to understand some spoken commands (Gardner & Gardner, 1969; Premack & Premack, 1983; Savage-Rumbaugh, 1991). Whether one wants to call their abilities "language" is not really a scientific question, but a matter of definition: how far we are willing to stretch the meaning of the word "language".

The scientific question is whether the chimps' abilities are homologous to human language -- that is, whether the two systems show the same basic organization owing to descent from a single system in their common ancestor. For example, biologists don't debate whether the wing-like structures of gliding rodents may be called "genuine wings" or something else (a boring question of definitions). It's clear that these structures are not homologous to the wings of bats, because they have a fundamentally different anatomical plan, reflecting a different evolutionary history. Bats' wings are modifications of the hands of the common mammalian ancestor; flying squirrels' wings are modifications of its rib cage. The two structures are merely analogous: similar in function.

Though artificial chimp signaling systems have some analogies to human language (e.g., use in communication, combinations of more basic signals), it seems unlikely that they are homologous. Chimpanzees require massive regimented teaching sequences contrived by humans to acquire quite rudimentary abilities, mostly limited to a small number of signs, strung together in repetitive, quasi-random sequences, used with the intent of requesting food or tickling (Terrace, Petitto, Sanders, & Bever, 1979; Seidenberg & Petitto, 1979, 1987; Seidenberg, 1986; Wallman, 1992; Pinker, 1994a). This contrasts sharply with human children, who pick up thousands of words spontaneously, combine them in structured sequences where every word has a determinate role, respect the word order of the adult language, and use sentences for a variety of purposes such as commenting on interesting objects.

This lack of homology does not, by the way, cast doubt on a gradualistic Darwinian account of language evolution. Humans did not evolve directly from chimpanzees. Both derived from common ancestor, probably around 6-7 million years ago. This leaves about 300,000 generations in which language could have evolved gradually in the lineage leading to humans, after it split off from the lineage leading to chimpanzees. Presumably language evolved in the human lineage for two reasons: our ancestors developed technology and knowledge of the local environment in their lifetimes, and were involved in extensive reciprocal cooperation. This allowed them to benefit by sharing hard-won knowledge with their kin and exchanging it with their neighbors (Pinker & Bloom, 1990).

2.2 Dissociations between Language and General Intelligence

Humans evolved brain circuitry, mostly in the left hemisphere surrounding the sylvian fissure, that appears to be designed for language, though how exactly their internal wiring gives rise to rules of language is unknown (see the Chapter by Zurif). The brain mechanisms underlying language are not just those allowing us to be smart in general. Strokes often leave adults with catastrophic losses in language (see the Chapter by Zurif, and Pinker, 1994a), though not necessarily impaired in other aspects of intelligence, such as those measured on the nonverbal parts of IQ tests. Similarly, there is an inherited set of syndromes called Specific Language Impairment (Gopnik and Crago, 1993; Tallal, Ross, & Curtiss, 1989) which is marked by delayed onset of language, difficulties in articulation in childhood, and lasting difficulties in understanding, producing, and judging grammatical sentences. By definition, Specifically Language Impaired people show such deficits despite the absence of cognitive problems like retardation, sensory problems like hearing loss, or social problems like autism.

More interestingly, there are syndromes showing the opposite dissociation, where intact language coexists with severe retardation. These cases show that language development does not depend on fully functioning general intelligence. One example comes from children with Spina Bifida, a malformation of the vertebrae that leaves the spinal cord unprotected, often resulting in hydrocephalus, an increase in pressure in the cerebrospinal fluid filling the ventricles (large cavities) of the brain, distending the brain from within. Hydrocephalic children occasionally end up significantly retarded but can carry on long, articulate, and fully grammatical conversations, in which they earnestly recount vivid events that are, in fact, products of their imaginations (Cromer, 1992; Curtiss, 1989; Pinker, 1994a). Another example is Williams Syndrome, an inherited condition involving physical abnormalities, significant retardation (the average IQ is about 50), incompetence at simple everyday tasks (tying shoelaces, finding one's way, adding two numbers, and retrieving items from a cupboard), social warmth and gregariousness, and fluent, articulate language abilities (Bellugi, et al., 1990).

2.3 Maturation of the Language System

As the chapter by Newport and Gleitman suggests, the maturation of language circuits during a child's early years may be a driving force underlying the course of language acquisition (Pinker, 1994, Chapter 9; Bates, Thal, & Janowsky, 1992; Locke, 1992; Huttenlocher, 1990). Before birth, virtually all the neurons (nerve cells) are formed, and they migrate into their proper locations in the brain. But head size, brain weight, and thickness of the cerebral cortex (gray matter), where the synapses (junctions) subserving mental computation take place, continue to increase rapidly in the year after birth. Long-distance connections (white matter) are not complete until nine months, and they continue to grow their speed-inducing myelin insulation throughout childhood. Synapses continue to develop, peaking in number between nine months and two years (depending on the brain region), at which point the child has 50% more synapses than the adult. Metabolic activity in the brain reaches adult levels by nine to ten months, and soon exceeds it, peaking around the age of four. In addition, huge numbers of neurons die in utero, and the dying continues during the first two years before leveling off at age seven. Synapses wither from the age of two through the rest of childhood and into adolescence, when the brain's metabolic rate falls back to adult levels. Perhaps linguistic milestones like babbling, first words, and grammar require minimum levels of brain size, long-distance connections, or extra synapses, particularly in the language centers of the brain.

Similarly, one can conjecture that these changes are responsible for the decline in the ability to learn a language over the lifespan. The language learning circuitry of the brain is more plastic in childhood; children learn or recover language when the left hemisphere of the brain is damaged or even surgically removed (though not quite at normal levels), but comparable damage in an adult usually leads to permanent aphasia (Curtiss, 1989; Lenneberg, 1967). Most adults never master a foreign language, especially the phonology, giving rise to what we call a "foreign accent." Their development often fossilizes into permanent error patterns that no teaching or correction can undo. There are great

individual differences, which depend on effort, attitudes, amount of exposure, quality of teaching, and plain talent.

Many explanations have been advanced for children's superiority: they can exploit the special ways that their mothers talk them, they make errors unself-consciously, they are more motivated to communicate, they like to conform, they are not xenophobic or set in their ways, and they have no first language to interfere. But some of these accounts are unlikely, based on what we learn about how language acquisition works later in this chapter. For example, children can learn a language without the special indulgent speech from their mothers; they make few errors; and they get no feedback for the errors they do make. And it can't be an across-the-board decline in learning. There is no evidence, for example, that learning words (as opposed to phonology or grammar) declines in adulthood.

The chapter by Newport and Gleitman shows how sheer age seems to play an important role. Successful acquisition of language typically happens by 4 (as we shall see in the next section), is guaranteed for children up to the age of six, is steadily compromised from then until shortly after puberty, and is rare thereafter. Maturational changes in the brain, such as the decline in metabolic rate and number of neurons during the early school age years, and the bottoming out of the number of synapses and metabolic rate around puberty, are plausible causes. Thus, there may be a neurologically-determined "critical period" for successful language acquisition, analogous to the critical periods documented in visual development in mammals and in the acquisition of songs by some birds.

3 The Course of Language Acquisition

Although scholars have kept diaries of their children's speech for over a century (Charles Darwin was one of the first), it was only after portable tape-recorders became available in the late 1950's that children's spontaneous speech began to be analyzed systematically within developmental psychology. These naturalistic studies of children's spontaneous speech have become even more accessible now that they can be put into computer files and can be disseminated and analyzed automatically (MacWhinney & Snow, 1985, 1990; MacWhinney, 1991). They are complemented by experimental methods. In production tasks, children utter sentences to describe pictures or scenes, in response to questions, or to imitate target sentences. In comprehension tasks, they listen to sentences and then point to pictures or act out events with toys. In judgement tasks, they indicate whether or which sentences provided by an experimenter sound "silly" to them.

As the chapter by Werker shows, language acquisition begins very early in the human lifespan, and begins, logically enough, with the acquisition of a language's sound patterns. The main linguistic accomplishments during the first year of life are control of the speech musculature and sensitivity to the phonetic distinctions used in the parents' language. Interestingly, babies achieve these feats before they produce or understand words, so their learning cannot depend on correlating sound with meaning. That is, they cannot be listening for the difference in sound between a word they think means bit and a word they think means beet, because they have learned neither word. They must be sorting the sounds directly, somehow tuning their speech analysis module to deliver the phonemes used in their language (Kuhl, et al., 1992). The module can then serve as the front end of the system that learns words and grammar.

Shortly before their first birthday, babies begin to understand words, and around that birthday, they start to produce them (see Clark, 1993; Ingram, 1989). Words are usually produced in isolation; this one-word stage can last from two months to a year. Children's first words are similar all over the planet. About half the words are for objects: food (juice, cookie, body parts (eye, nose), clothing (diaper, sock), vehicles (car, boat), toys (doll, block), household items (bottle, light, animals (dog, kitty), and people

(dada, baby). There are words for actions, motions, and routines, like (up, off, open, peekaboo, eat, and go, and modifiers, like hot, allgone, more, dirty, and cold. Finally, there are routines used in social interaction, like yes, no, want, bye-bye, and hi -- a few of which, like look at that and what is that, are words in the sense of memorized chunks, though they are not single words for the adult. Children differ in how much they name objects or engage in social interaction using memorized routines, though all children do both.

Around 18 months, language changes in two ways. Vocabulary growth increases; the child begins to learn words at a rate of one every two waking hours, and will keep learning that rate or faster through adolescence (Clark, 1993; Pinker, 1994). And primitive syntax begins, with two-word strings like the following:

All dry.	All messy.	All wet.
I sit.	I shut.	No bed.
No pee.	See baby.	See pretty.
More cereal.	More hot.	Hi Calico.
Other pocket.	Boot off.	Siren by.
Mail come.	Airplane allgone.	Bybebye car.
Our car.	Papa away.	Dry pants.

Our car. Papa away. Dry pants. Children's two-word combinations are highly similar across cultures. Everywhere, children announce when objects appear, disappear, and move about, point out their properties and owners, comment on people doing things and seeing things, reject and request objects and activities, and ask about who, what, and where. These sequences already reflect the language being acquired: in 95% of them, the words are properly ordered (Braine, 1976; Brown, 1973; Pinker, 1984; Ingram, 1989).

Even before they put words together, babies can comprehend a sentence using its syntax. For example, in one experiment, babies who spoke only in single words were seated in front of two television screens, each of which featured a pair of adults dressed up as Cookie Monster and Big Bird from Sesame Street. One screen showed Cookie Monster tickling Big Bird; the other showed Big Bird tickling Cookie Monster. A voice-over said, "OH LOOK!!! BIG BIRD IS TICKLING COOKIE MONSTER!! FIND BIG BIRD TICKLING COOKIE MONSTER!!" (Or vice-versa.) The children must have understood the meaning of the ordering of subject, verb, and object, because they looked more at the screen that depicted the sentence in the voice-over (Hirsh-Pasek & Golinkoff, 1991).

Children's output seems to meet up with a bottleneck at the output end (Brown, 1973; Bloom, 1970; Pinker, 1984). Their two- and three-word utterances look like samples drawn from longer potential sentences expressing a complete and more complicated idea. Roger Brown, one of the founders of the modern study of language development, noted that although the three children he studied intensively never produced a sentence as complicated as Mother gave John lunch in the kitchen, they did produce strings containing all of its components, and in the correct order: (Brown, 1973, p. 205):

Agent	Action	Recipient	Object	Location
(Mother	gave	John	lunch	in the kitchen.)
Mommy	fix.		pumpkin.	table.
Mommy				
Baby		doggie.		
Give	Put		light.	
	Put			floor.
I	ride		horsie.	

Tractor	go			floor.
	Give	doggie	paper.	
	Put		truck	window.
Adam	put		it	box.

Between the late two's and mid-three's, children's language blooms into fluent grammatical conversation so rapidly that it overwhelms the researchers who study it, and no one has worked out the exact sequence. Sentence length increases steadily, and because grammar is a combinatorial system, the number of syntactic types increases exponentially, doubling every month, reaching the thousands before the third birthday (Ingram, 1989, p. 235; Brown, 1973; Limber, 1973; Pinker, 1984). For example, here are snapshots of the development of one of Brown's longitudinal subjects, Adam, in the year following his first word combinations at the age of 2 years and 3 months (Pinker, 1994a):

2;3: Play checkers. Big drum. I got horn.

2;4: See marching bear go? Screw part machine.

2;5: Now put boots on. Where wrench go? What that paper clip doing?

2;6: Write a piece a paper. What that egg doing? No, I don't want to sit seat.

2;7: Where piece a paper go? Dropped a rubber band. Rintintin don't fly, Mommy.

2;8: Let me get down with the boots on. How tiger be so healthy and

fly like kite? Joshua throw like a penguin.

2;9: Where Mommy keep her pocket book? Show you something funny.

2;10: Look at that train Ursula brought. You don't have paper. Do you want little bit, Cromer?

2;11: Do want some pie on your face? Why you mixing baby chocolate? I said why not you coming in? We going turn light on so you can't - see.

3;0: I going come in fourteen minutes. I going wear that to wedding. Those are not strong mens. You dress me up like a baby elephant.

3;1: I like to play with something else. You know how to put it back together. I gon' make it like a rocket to blast off with. You want - to give me some carrots and some beans? Press the button and catch - it, sir. Why you put the pacifier in his mouth?

3;2: So it can't be cleaned? I broke my racing car. Do you know the light goes off? When it's got a flat tire it's need a go to the station. I'm going to mail this so the letter can't come off. I - want to have some espresso. Can I put my head in the mailbox so - the mailman can know where I are and put me in the mailbox? Can I - keep the screwdriver just like a carpenter keep the screwdriver?

Normal children can differ by a year or more in their rate of language development, though the stages they pass through are generally the same regardless of how stretched out or compressed. Adam's

language development, for example, was relatively leisurely; many children speak in complex sentences before they turn two.

During the grammar explosion, children's sentences are getting not only longer but more complex, with fuller trees, because the children can embed one constituent inside another. Whereas before they might have said Give doggie paper (a three-branch Verb Phrase) and Big doggie (a two-branch Noun Phrase), they now say Give big doggie paper, with the two-branch NP embedded inside the three-branch VP. The earlier sentences resembled telegrams, missing unstressed function words like of, the, on, and does, as well as inflections like -ed, -ing, and -s. By the 3's, children are using these function words more often than they are omitting them, many in more than 90% of the sentences that require them. A full range of sentence types flower -- questions with words like who, what and where, relative clauses, comparatives, negations, complements, conjunctions, and passives. These constructions appear to display the most, perhaps even all, of the grammatical machinery needed to account for adult grammar.

Though many of the young 3-year-old's sentences are ungrammatical for one reason or another, it is because there are many things that can go wrong in any single sentence. When researchers focus on a single grammatical rule and count how often a child obeys it and how often he or she versus flouts it, the results are very impressive: for just about every rule that has been looked at, three-year olds obey it a majority of the time (Stromswold, 1990; Pinker, 1984, 1989; Crain, 1992; Marcus, et al., 1992). As we have seen, children rarely scramble word orders and, by the age of three, come to supply most inflections and function words in sentences that require them. Though our ears perk up when we hear errors like mens, wents, Can you broke those?, What he can ride in?, That's a furniture, Button me the rest, and Going to see kitten, the errors occur in anywhere from 0.1% to 8% of the opportunities for making them; more than 90% of the time, the child is on target. The next chapter follows one of those errors in detail.

Children do not seem to favor any particular kind of language (indeed, it would be puzzling how any kind of language could survive if children did not easily learn it!). They swiftly acquire free word order, SOV and VSO orders, rich systems of case and agreement, strings of agglutinated suffixes, ergative case marking, and whatever else their language throws at them, with no lag relative to their English-speaking counterparts. Even grammatical gender, which many adults learning a second language find mystifying, presents no problem: children acquiring language like French, German, and Hebrew acquire gender marking quickly, make few errors, and never use the association with maleness and femaleness as a false criterion (Levy, 1983). It is safe to say that except for constructions that are rare, predominantly used in written language, or mentally taxing even to an adult (like The horse that the elephant tickled kissed the pig), all parts of all languages are acquired before the child turns four (Slobin, 1985/1992).

4 Explaining Language Acquisition

How do we explain children's course of language acquisition -- most importantly, their inevitable and early mastery? Several kinds of mechanisms are at work. As we saw in section (), the brain changes after birth, and these maturational changes may govern the onset, rate, and adult decline of language acquisition capacity. General changes in the child's information processing abilities (attention, memory, short-term buffers for acoustic input and articulatory output) could leave their mark as well. In the next chapter, I show how a memory retrieval limitation -- children are less reliable at recalling that broke is the past tense of break -- can account for a conspicuous and universal error pattern, overregularizations like brokeed (see also Marcus, et al., 1992).

Many other small effects have been documented where changes in information processing abilities affect language development. For example, children selectively pick up information at the ends of words

(Slobin, 1973), and at the beginnings and ends of sentences (Newport, et al, 1977), presumably because these are the parts of strings that are best retained in short term memory. Similarly, the progressively widening bottleneck for early word combinations presumably reflects a general increase in motor planning capacity. Conceptual development (see Chapter X), too, might affect language development: if a child has not yet mastered a difficult semantic distinction, such as the complex temporal relations involved in John will have gone, he or she may be unable to master the syntax of the construction dedicated to expressing it.

The complexity of a grammatical form has a demonstrable role in development: simpler rules and forms appear in speech before more complex ones, all other things being equal. For example, the plural marker -s in English (e.g. cats), which requires knowing only whether the number of referents is singular or plural, is used consistently before the present tense marker -s (he walks), which requires knowing whether the subject is singular or plural and whether it is a first, second, or third person and whether the event is in the present tense (Brown, 1973). Similarly, complex forms are sometimes first used in simpler approximations. Russian contains one case marker for masculine nominative (i.e., a suffix on a masculine noun indicating that it is the subject of the sentence), one for feminine nominative, one for masculine accusative (used to indicate that a noun is a direct object), and one for feminine accusative. Children often use each marker with the correct case, never using a nominative marker for accusative nouns or vice-versa, but don't properly use the masculine and feminine variants with masculine and feminine nouns (Slobin, 1985).

But these global trends do not explain the main event: how children succeed. Language acquisition is so complex that one needs a precise framework for understanding what it involves -- indeed, what learning in general involves.

4.1 Learnability Theory

What is language acquisition, in principle? A branch of theoretical computer science called Learnability Theory attempts to answer this question (Gold, 1967; Osherson, Stob, & Weinstein, 1985; Pinker, 1979). Learnability theory has defined learning as a scenario involving four parts (the theory embraces all forms of learning, but I will use language as the example):

1. A class of languages. One of them is the "target" language, to be - attained by the learner, but the learner does not, of course, know - which it is. In the case of children, the class of languages would - consist of the existing and possible human languages; the target - language is the one spoken in their community.
2. An environment. This is the information in the world that the learner has to go on in trying to acquire the language. In the case of children, it might include the sentences parents utter, the context in which they utter them, feedback to the child (verbal or nonverbal) in response to the child's own speech, and so on. Parental utterances can be a random sample of the language, or they might have some special properties: they might be ordered in certain ways, sentences might be repeated or only uttered once, and so on.
3. A learning strategy. The learner, using information in the environment, tries out "hypotheses" about the target language. The learning strategy is the algorithm that creates the hypotheses and determines whether they are consistent with the input information from the environment. For children, it is the "grammar-forming" mechanism in their brains; their "language acquisition device."
4. A success criterion. If we want to say that "learning" occurs, presumably it is because the learners' hypotheses are not random, - but that by some time the hypotheses are related in some systematic - way to the target language. Learners may arrive at a hypothesis - identical to the target language

after some fixed period of time; - they may arrive at an approximation to it; they may waiver among a - set of hypotheses one of which is correct.

Theorems in learnability theory show how assumptions about any of the three components imposes logical constraints on the fourth. It is not hard to show why learning a language, on logical grounds alone, is so hard. Like all "induction problems" (uncertain generalizations from instances), there are an infinite number of hypotheses consistent with any finite sample of environmental information. Learnability theory shows which induction problems are solvable and which are not.

A key factor is the role of negative evidence, or information about which strings of words are not sentences in the language to be acquired. Human children might get such information by being corrected every time they speak ungrammatically. If they aren't -- and as we shall see, they probably aren't -- the acquisition problem is all the harder. Consider Figure 1, where languages are depicted as circles corresponding to sets of word strings, and all the logical possibilities for how the child's language could differ from the adult language are depicted. There are four possibilities. (a) The child's hypothesis language (H) is disjoint from the language to be acquired (the "target language," T). That would correspond to the state of child learning English who cannot say a single well-formed English sentence. For example, the child might be able only to say things like we brokek it, and we goed, never we broke it or we went. (b) The child's hypothesis and the target language intersect. Here the child would be able to utter some English sentences, like he went. However, he or she also uses strings of words that are not English, such as we brokek it; and some sentences of English, such as we broke it, would still be outside their abilities. (c) The child's hypothesis language is a subset of the target language. That would mean that the child would have mastered some of English, but not all of it, but that everything the child had mastered would be part of English. The child might not be able to say we broke it, but he or she would be able to say some grammatical sentences, such as we went; no errors such as she brokek it or we goed would occur. The final logical possibility is (d), where The child's hypothesis language is a superset of the target language. That would occur, for example, if the child could say we broke it, we went, we brokek it and we goed.

In cases (a-c), the child can realize that the hypothesis is incorrect by hearing sentences from parental "positive evidence," (indicated by the "+" symbol) that are in the target language but not the hypothesized one: sentences such as we broke it. This is impossible in case (d); negative evidence (such as corrections of the child's ungrammatical sentences by his or her parents) would be needed. In other words, without negative evidence, if a child guesses too large a language, the world can never tell him he's wrong.

This has several consequences. For one thing, the most general learning algorithm one might conceive of -- one that is capable of hypothesizing any grammar, or any computer program capable of generating a language -- is in trouble. Without negative evidence (and even in many cases with it), there is no general-purpose, all-powerful learning machine; a machine must in some sense "know" something about the constraints in the domain in which it is learning.

More concretely, if children don't receive negative evidence (see Section) we have a lot of explaining to do, because overly large hypotheses are very easy for the child to make. For example, children actually do go through stages in which they use two or more past tense forms for a given verb, such as broke and brokek -- this case is discussed in detail in my other chapter in this volume. They derive transitive verbs from intransitives too freely: where an adult might say both The ice melted and I melted the ice, children also can say The girl giggled and Don't giggle me! (Bowerman, 1982b; Pinker, 1989). In each case they are in situation (d) in Figure 1, and unless their parents slip them some signal in every case that lets them know they are not speaking properly, it is puzzling that they eventually stop. That is, we would need to explain how they grow into adults who are more restrictive in their speech -- or another way of putting is

that it's puzzling that the English language doesn't allow don't giggle me and she eated given that children are tempted to grow up talking that way. If the world isn't telling children to stop, something in their brains is, and we have to find out who or what is causing the change.

Let's now examine language acquisition in the human species by breaking it down into the four elements that give a precise definition to learning: the target of learning, the input, the degree of success, and the learning strategy.

5 What is Learned

To understand how X is learned, you first have to understand what X is. Linguistic theory is thus an essential part of the study of language acquisition (see the Chapter by Lasnik). Linguistic research tries to do three things. First, it must characterize the facts of English, and all the other languages whose acquisition we are interested in explaining. Second, since children are not predisposed to learn English or any other language, linguistics has to examine the structure of other languages. In particular, linguists characterize which aspects of grammar are universal, prevalent, rare, and nonexistent across languages. Contrary to early suspicions, languages do not vary arbitrarily and without limit; there is by now a large catalogue of language universals, properties shared exactly, or in a small number of variations, by all languages (see Comrie, 1981; Greenberg, 1978; Shopen, 1985). This obviously bears on what children's language acquisition mechanisms find easy or hard to learn.

And one must go beyond a mere list of universals. Many universal properties of language are not specific to language but are simply reflections of universals of human experience. All languages have words for "water" and "foot" because all people need to refer to water and feet; no language has a word a million syllables long because no person would have time to say it. But others might be specific to the innate design of language itself. For example, if a language has both derivational suffixes (which create new words from old ones, like -ism) and inflectional suffixes (which modify a word to fit its role in the sentence, like plural -s), then the derivational suffixes are always closer to the word stem than the inflectional ones. For example, in English one can say Darwinisms (derivational -ism closer to the stem than inflectional -s) but not Darwinsism. It is hard to think of a reason how this law would fit in to any universal law of thought or memory: why would the concept of two ideologies based on one Darwin should be thinkable, but the concept of one ideology based on two Darwins (say, Charles and Erasmus) not be thinkable (unless one reasons in a circle and declares that the mind must find -ism to be more cognitively basic than the plural, because that's the order we see in language). Universals like this, that are specifically linguistic, should be captured in a theory of Universal Grammar (UG) (Chomsky, 1965, 1981, 1991). UG specifies the allowable mental representations and operations that all languages are confined to use. The theory of universal grammar is closely tied to the theory of the mental mechanisms children use in acquiring language; their hypotheses about language must be couched in structures sanctioned by UG.

To see how linguistic research can't be ignored in understanding language acquisition, consider the sentences below. In each of the examples, a learner who heard the (a) and (b) sentences could quite sensibly extract a general rule that, when applied to the (c) sentence, yield version (d). Yet the result is an odd sentence that no one would say:

1. (a) John saw Mary with her best friend's husband.
 (b) Who did John see Mary with?
 (c) John saw Mary and her best friend's husband.
 (d) *Who did John see Mary and?

2. (a) Irv drove the car into the garage.
(b) Irv drove the car.

(c) Irv put the car into the garage.
(d) *Irv put the car.
3. (a) I expect the fur to fly.
(b) I expect the fur will fly.

(c) The fur is expected to fly.
(d) *The fur is expected will fly.
4. (a) The baby seems to be asleep.
(b) The baby seems asleep.

(c) The baby seems to be sleeping.
(d) *The baby seems sleeping.
5. (a) John liked the pictures of Bill that Mary took.
(b) John liked Mary's pictures of Bill.

(c) John liked the pictures of himself that Mary took.
(d) *John liked Mary's pictures of himself.

The solution to the problem must be that children's learning mechanisms ultimately don't allow them to make what would otherwise be a tempting generalization. For example, in (1), constraints that prevent extraction of a single phrase out of a coordinate structure (phrases joined by a word like and or or) would block what otherwise be a natural generalization from other examples of extraction, such as 1(a-b). The other examples presents other puzzles that the theory of universal grammar, as part of a theory of language acquisition, must solve. It is because of the subtlety of these examples, and the abstractness of the principles of universal grammar that must be posited to explain them, that Chomsky has claimed that the overall structure of language must be innate, based on his paper-and-pencil examination of the facts of language alone.

6 Input

To understand how children learn language, we have to know what aspects of language (from their parents or peers) they have access to.

6.1 Positive Evidence

Children clearly need some kind of linguistic input to acquire a language. There have been occasional cases in history where abandoned children have somehow survived in forests, such as Victor, the Wild Boy of Aveyron (subject of a film by Francois Truffaut). Occasionally other modern children have grown up wild because depraved parents have raised them silently in dark rooms and attics; the chapter by Newport and Gleitman discuss some of those cases. The outcome is always the same: the children, when found, are mute. Whatever innate grammatical abilities there are, they are too schematic to generate concrete speech, words, and grammatical constructions on their own.

Children do not, however, need to hear a full-fledged language; as long as they are in a community with other children, and have some source for individual words, they will invent one on their own, often in a single generation. Children who grew up in plantations and slave colonies were often exposed to a crude pidgin that served as the lingua franca in these Babels of laborers. But they grew up to speak genuinely new languages, expressive "creoles" with their own complex grammars (Bickerton, 1984; see also the Chapter by Newport and Gleitman). The sign languages of the deaf arose in similar ways. Indeed, they arise spontaneously and quickly wherever there is a community of deaf children (Senghas, 1994; Kegl, 1994).

Children most definitely do need to hear an existing language to learn that language, of course. Children with Japanese genes do not find Japanese any easier than English, or vice-versa; they learn whichever language they are exposed to. The term "positive evidence" refers to the information available to the child about which strings of words are grammatical sentences of the target language.

By "grammatical," incidentally, linguists and psycholinguists mean only those sentences that sound natural in colloquial speech, not necessarily those that would be deemed "proper English" in formal written prose. Thus split infinitives, dangling participles, slang, and so on, are "grammatical" in this sense (and indeed, are as logical, systematic, expressive, and precise as "correct" written English, often more so; see Pinker, 1994a). Similarly, elliptical utterances, such as when the question Where are you going? is answered with To the store), count as grammatical. Ellipsis is not just random snipping from sentences, but is governed by rules that are part of the grammar of one's language or dialect. For example, the grammar of casual British English allows you to answer the question Will he go? by saying He might do, whereas the grammar of American English doesn't allow it.

Given this scientific definition of "grammatical," do we find that parents' speech counts as "positive evidence"? That is, when a parent uses a sentence, can the child assume that it is part of the language to be learned, or do parents use so many ungrammatical sentences random fragments, slips of the tongue, hesitations, and false starts that the child would have to take much of it with a grain of salt? Fortunately for the child, the vast majority of the speech they hear during the language-learning years is fluent, complete, and grammatically well-formed: 99.93%, according to one estimate (Newport, Gleitman, & Gleitman, 1977). Indeed, this is true of conversation among adults in general (Labov, 1969).

Thus language acquisition is ordinarily driven by a grammatical sample of the target language. Note that this is true even for forms of English that people unthinkingly call "ungrammatical," "fractured," or "bad English," such as rural American English (e.g., them books; he don't; we ain't; they drug him away) and urban black English (e.g., She walking; He be working; see the Chapter by Labov). These are not corrupted versions of standard English; to a linguist they look just like different dialects, as rule-governed as the southern-England dialect of English that, for historical reasons, became the standard several centuries ago. Scientifically speaking, the grammar of working-class speech -- indeed, every human language system that has been studied -- is intricately complex, though different languages are complex in different ways.

6.2 Negative Evidence

Negative evidence refers to information about which strings of words are not grammatical sentences in the language, such as corrections or other forms of feedback from a parent that tell the child that one of his or her utterances is ungrammatical. As mentioned in Section), it's very important for us to know whether children get and need negative, because in the absence of negative evidence, any child who hypothesizes a rule that generates a superset of the language will have no way of knowing that he or she is wrong Gold, 1967; Pinker, 1979, 1989). If children don't get, or don't use, negative evidence, they

must have some mechanism that either avoids generating too large a language the child would be conservative -- or that can recover from such overgeneration.

Roger Brown and Camille Hanlon (1970) attempted to test B. F. Skinner's behaviorist claim that language learning depends on parents' reinforcement of children's grammatical behaviors. Using transcripts of naturalistic parent-child dialogue, they divided children's sentences into ones that were grammatically well-formed and ones that contained grammatical errors. They then divided adults' responses to those sentences into ones that expressed some kind of approval (e.g., "yes, that's good") and those that expressed some kind of disapproval. They looked for a correlation, but failed to find one: parents did not differentially express approval or disapproval to their children contingent on whether the child's prior utterance was well-formed or not (approval depends, instead, on whether the child's utterance was true). Brown and Hanlon also looked at children's well-formed and badly-formed questions, and whether parents seemed to answer them appropriately, as if they understood them, or with non sequiturs. They found parents do not understand their children's well-formed questions better than their badly-formed ones.

Other studies (e.g. Hirsh-Pasek, Treiman, and Schneiderman, 1984; Demetras, Post, and Snow, 1986; Penner, 1987; Bohannon & Stanowicz, 1988) have replicated that result, but with a twist. Some have found small statistical contingencies between the grammaticality of some children's sentence and the kind of follow-up given by their parents; for example, whether the parent repeats the sentence verbatim, asks a follow-up question, or changes the topic. But Marcus (1993) has found that these patterns fall far short of negative evidence (reliable information about the grammatical status of any word string). Different parents react in opposite ways to their children's ungrammatical sentences, and many forms of ungrammaticality are not reacted to at all -- leaving a given child unable to know what to make of any parental reaction. Even when a parent does react differentially, a child would have to repeat a particular error, verbatim, hundreds of times to eliminate the error, because the parent's reaction is only statistical: the feedback signals given to ungrammatical signals are also given nearly as often to grammatical sentences.

Stromswold (1994) has an even more dramatic demonstration that parental feedback cannot be crucial. She studied a child who, for unknown neurological reasons, was congenitally unable to talk. He was a good listener, though, and when tested he was able to understand complicated sentences perfectly, and to judge accurately whether a sentence was grammatical or ungrammatical. The boy's abilities show that children certainly do not need negative evidence to learn grammatical rules properly, even in the unlikely event that their parents provided it.

These results, though of profound importance, should not be too surprising. Every speaker of English judges sentences such as *I dribbled the floor with paint* and *Ten pounds was weighed by the boy* and *Who do you believe the claim that John saw?* and *John asked Mary to look at himself* to be ungrammatical. But it is unlikely that every such speaker has at some point uttered these sentences and benefited from negative feedback. The child must have some mental mechanisms that rule out vast numbers of "reasonable" strings of words without any outside intervention.

6.3 Motherese

Parents and caretakers in most parts of the world modify their speech when talking to young children, one example of how people in general use several "registers" in different social settings. Speech to children is slower, shorter, in some ways (but not all) simpler, higher-pitched, more exaggerated in intonation, more fluent and grammatically well-formed, and more directed in content to the present situation, compared to speech among adults (Snow & Ferguson, 1977). Many parents also expand their

children's utterances into full sentences, or offer sequences of paraphrases of a given sentence.

One should not, though, consider this speech register, sometimes called "Motherese," to be a set of "language lessons." Though mother's speech may seem simple at first glance, in many ways it is not. For example, speech to children is full of questions -- sometimes a majority of the sentences. If you think questions are simple, just try to write a set of rules that accounts for the following sentences and non-sentences:

1. He can go somewhere.
Where can he go?
*Where can he go somewhere?
*Where he can go?
*Where did he can go?
2. He went somewhere.
Where did he go?
He went WHERE?
*Where went he?
*Where did he went?
*Where he went?
*He did go WHERE?
3. He went home.
Why did he go home?
How come he went home?
*Why he went home?
*How come did he go home?

Linguists struggle over these facts (see the Chapters by Lasnik and Larson), some of the most puzzling in the English language. But these are the constructions that infants are bombarded with and that they master in their preschool years.

The chapter by Newport and Gleitman gives another reason for doubting that Motherese is a set of language lessons. Children whose mothers use Motherese more consistently don't pass through the milestones of language development any faster (Newport, et al, 1977). Furthermore, there are some communities with radically different ideas about children's proper place in society. In some societies, for example, people tacitly assume that that children aren't worth speaking to, and don't have anything to say that is worth listening to. Such children learn to speak by overhearing streams of adult-to-adult speech (Heath, 1983). In some communities in New Guinea, mothers consciously try to teach their children language, but not in the style familiar to us, of talking to them indulgently. Rather, they wait until a third party is present, and coach the child as to the proper, adultlike sentences they should use (see Schieffelin & Eisenberg, 1981). Nonetheless, those children, like all children, grow up to be fluent language speakers. It surely must help children when their parents speak slowly, clearly, and succinctly to them, but their success at learning can't be explained by any special grammar-unveiling properties of parental babytalk.

6.4 Prosody

Parental speech is not a string of printed words on a ticker-tape, nor is it in a monotone like science-fiction robots. Normal human speech has a pattern of melody, timing, and stress called prosody. And

motherese directed to young infants has a characteristic, exaggerated prosody of its own: a rise and fall contour for approving, a set of sharp staccato bursts for prohibiting, a rise pattern for directing attention, and smooth, low legato murmurs for comforting. Fernald (1992) has shown that these patterns are very widespread across language communities, and may be universal. The melodies seem to attract the child's attention, mark the sounds as speech as opposed to stomach growlings or other noises, and might distinguish statements, questions, and imperatives, delineate major sentence boundaries, and highlight new words. When given a choice, babies prefer to listen to speech with these properties than to speech intended for adults (Fernald, 1984, 1992; Hirsh-Pasek, Nelson, Jusczyk, Cassidy, Druss, & Kennedy, 1987).

In all speech, a number of prosodic properties of the speech wave, such as lengthening, intonation, and pausing, are influenced by the syntactic structure of the sentence (Cooper & Paccia-Cooper, 1980). Just listen to how you would say the word like in the sentence The boy I like slept compared to The boy I saw likes sleds. In the first sentence, the word like is at the boundary of a relative clause and is drawn out, exaggerated in intonation, and followed by a pause; in the second, it is in the middle of a verb phrase and is pronounced more quickly, uniformly in intonation, and is run together with the following word. Some psychologists (e.g., Gleitman & Wanner, 1984; Gleitman, 1990) have suggested that children use this information in the reverse direction, and read the syntactic structure of a sentence directly off its melody and timing. We will examine the hypothesis in Section .

6.5 Context

Children do not hear sentences in isolation, but in a context. No child has learned language from the radio; indeed, children rarely if ever learn language from television. Ervin-Tripp (1973) studied hearing children of deaf parents whose only access to English was from radio or television broadcasts. The children did not learn any speech from that input. One reason is that without already knowing the language, it would be difficult for a child to figure out what the characters in the unresponsive televised worlds are talking about. In interacting with live human speakers, who tend to talk about the here and now in the presence of children, the child can be more of a mind-reader, guessing what the speaker might have meant (Macnamara, 1972, 1982; Schlesinger, 1971). That is, before children have learned syntax, they know the meaning of many words, and they might be able to make good guesses as to what their parents are saying based on their knowledge of how the referents of these words typically act (for example, people tend to eat apples, but not vice-versa). In fact, parental speech to young children is so redundant with its context that a person with no knowledge of the order in which parents' words are spoken, only the words themselves, can infer from transcripts, with high accuracy, what was being said (Slobin, 1977).

Many models of language acquisition assume that the input to the child consists of a sentence and a representation of the meaning of that sentence, inferred from context and from the child's knowledge of the meanings of the words (e.g. Anderson, 1977; Berwick, 1986; Pinker, 1982, 1984; Wexler & Culicover, 1980). Of course, this can't literally be true -- children don't hear every word of every sentence, and surely don't, to begin with, perceive the entire meaning of a sentence from context. Blind children, whose access to the nonlinguistic world is obviously severely limited, learn language without many problems (Landau & Gleitman, 1985). And when children do succeed in guessing a parent's meaning, it can't be by simple temporal contiguity. For example, Gleitman (1990) points out that when a mother arriving home from work opens the door, she is likely to say, "What did you do today?," not I'm opening the door. Similarly, she is likely to say "Eat your peas" when her child is, say, looking at the dog, and certainly not when the child is already eating peas.

Still, the assumption of context-derived semantic input is a reasonable idealization, if one considers the

abilities of the whole child. The child must keep an updated mental model of the current situation, created by mental faculties for perceiving objects and events and the states of mind and communicative intentions of other humans. The child can use this knowledge, plus the meanings of any familiar words in the sentence, to infer what the parent probably meant. In Section we will discuss how children might fill the important gaps in what they can infer from context.

7 What and When Children Learn

People do not reproduce their parents' language exactly. If they did, we would all still be speaking like Chaucer. But in any generation, in most times, the differences between parents' language and the one their children ultimately acquire is small. And remember that, judging by their spontaneous speech, we can conclude that most children have mastered their mother tongue (allowing for performance errors due to complexity or rarity of a construction) some time in their threes. It seems that the success criterion for human language is something close to full mastery, and in a short period of time.

To show that young children really have grasped the design plan of language, rather than merely approximating it with outwardly-convincing routines or rules of thumb which would have to be supplanted later in life, we can't just rely on what they say; we need to use clever experimental techniques. Let's look at two examples that illustrate how even very young children seem to obey the innate complex design of Universal Grammar.

Earlier I mentioned that in all languages, if there are derivational affixes that build new words out of old ones, like -ism, -er, and -able, and inflectional affixes that modify a word according to its role in the sentence, like -s, -ed, and -ing, then the derivational affix appears inside the inflectional one: Darwinisms is possible, Darwinism is not. This and many other grammatical quirks were nicely explained in a theory of word structure proposed by Paul Kiparsky (1982).

Kiparsky showed that words are built in layers or "levels." To build a word, you can start with a root (like Darwin). Then you can rules of a certain kind to it, called "Level 1 Rules," to yield a more complex word. For example, there is a rule adding the suffix -ian, turning the word into Darwinian. Level 1 Rules, according to the theory, can affect the sound of the stem; in this case, the syllable carrying the stress shifts from Dar to win. Level 2 rules apply to a word after any Level 1 rules have been applied. An example of a Level 2 rule is the one that adds the suffix -ism, yielding, for example, Darwinism. Level 2 rules generally do not affect the pronunciation of the words they apply to; they just add material onto the word, leaving the pronunciation intact. (The stress in Darwinism is the same as it was in Darwin.) Finally, Level 3 rules apply to a word after any Level 2 rules have been applied. The regular rules of inflectional morphology are examples of Level 3 rules. An example is the rule that adds an -s to the end of a noun to form its plural -- for example, Darwinians or Darwinisms.

Crucially, the rules cannot apply out of order. The input to a Level 1 rules must be a word root. The input to a level 2 rule must be either a root or the output of Level 1 rules. The input to a Level 3 rule must be a root, the output of Level 1 rules, or the output of Level 2 rules. That constraint yields predictions about what kinds of words are possible and which are impossible. For example, the ordering makes it impossible to derive Darwinianism and Darwinianisms, but not Darwinian, Darwinism, and Darwinismian.

Now, irregular inflection, such as the pairing of mouse with mice, belongs to Level 1, whereas regular inflectional rules, such as the one that relates rat to rats, belongs to Level 3. Compounding, the rule that would produce Darwin-lover and mousetrap, is a Level 2 rule, in between. This correctly predicts that an irregular plural can easily appear inside a compound, but a regular plural cannot. Compare the

following:

ice-infested (OK); rats-infested (bad)
 men-bashing (OK); guys-bashing (bad)
 teethmarks (OK); clawsmarks (bad)
 feet-warmer (OK); hand-warmer (bad)
 purple people-eater (OK); purple babies-eater (bad)

Mice-infested is a possible word, because the process connecting mouse with mice comes before the rule combining the noun with infested. However, rats-infested, even though it is cognitively quite similar to mice-infested, sounds strange; we can say only rat-infested (even though by definition one rat does not make an infestation).

Peter Gordon (1986) had children between the ages of 3 and 5 participate in an elicited-production experiment in which he would say, "Here is a puppet who likes to eat _____. What would you call him?" He provided a response for several singular mass nouns, like mud, beforehand, so that the children were aware of the existence of the "x-eater" compound form. Children behaved just like adults: a puppet who likes to eat a mouse was called a mouse-eater, a puppet who likes to eat a rat was called a rat-eater, a puppet who likes to eat mice was called either a mouse-eater or a mice-eater -- but -- a puppet who likes to eat rats was called a rat-eater, never a rats-eater. Interestingly, children treated their own overregularizations, such as mouses, exactly as they treated legitimate regular plurals: they would never call the puppet a mouses-eater, even if they used mouses in their own speech.

Even more interestingly, Gordon examined how children could have acquired the constraint. Perhaps, he reasoned, they had learned the fact that compounds can contain either singulars or irregular plurals, never regular plurals, by paying keeping track of all the kinds of compounds that do and don't occur in their parents' speech. It turns out that they would have no way of learning that fact. Although there is no grammatical reason why compounds would not contain irregular plurals, the speech that most children hear does not contain any. Compounds like toothbrush abound; compounds containing irregular plurals like teethmarks, people-eater, and men-bashing, though grammatically possible, are statistically rare, according to the standardized frequency data that Gordon examined, and he found none that was likely to appear in the speech children hear. Therefore children were willing to say mice-eater and unwilling to say rats-eater with no good evidence from the input that that is the pattern required in English. Gordon suggests that this shows that the constraints on level-ordering may be innate.

Let's now go from words to sentences. Sentence are ordered strings of words. No child could fail to notice word order in learning and understanding language. But most regularities of language govern hierarchically-organized structures -- words grouped into phrases, phrases grouped into clauses, clauses grouped into sentences (see the Chapters by Lasnik, by Larson, and by Newport & Gleitman). If the structures of linguistic theory correspond to the hypotheses that children formulate when they analyze parental speech and form rules, children should create rules defined over hierarchical structures, not simple properties of linear order such as which word comes before which other word or how close two words are in a sentence. The chapter by Gleitman and Newport discusses one nice demonstration of how adults (who are, after all, just grown-up children) respect constituent structure, not simple word order, when forming questions. Here is an example making a similar point that has been tried out with children.

Languages often have embedded clauses missing a subject, such as John told Mary to leave, where the embedded "downstairs" clause to leave has no subject. The phenomenon of control governs how the missing subject is interpreted. In this sentence it is Mary who is understood as having the embedded subject's role, that is, the person doing the leaving. We say that the phrase Mary "controls" the missing

subject position of the lower clause. For most verbs, there is a simple principle defining control. If the upstairs verb has no object, then the subject of the upstairs verb controls the missing subject of the downstairs verb. For example, in John tried to leave, John is interpreted as the subject of both try and leave. If the upstairs verb has a subject and an object, then it is the object that controls the missing subject of the downstairs verb, as we saw in John told Mary to leave.

In 1969, Carol Chomsky published a set of classic experiments in developmental psycholinguistics. She showed that children apply this principle quite extensively, even for the handful of verbs that are exceptions to it. In act-out comprehension experiments on children between the ages of 5 and 10, she showed that even relatively old children were prone to this kind of mistake. When told "Mickey promised Donald to jump; Make him jump," the children made Donald, the object of the first verb, do the jumping, in accord with the general principle. The "right answer" in this case would have been Mickey, because promise is an exception to the principle, calling for an unusual kind of control where the subject of the upstairs verb, not the object of the upstairs verb, should act as controller.

But what, exactly, is the principle that children are over-applying? One possibility can be called the Minimal Distance Principle: the controller of the downstairs verb is the noun phrase nearest to it in the linear string of words in the sentence. If children analyze sentences in terms of linear order, this should be a natural generalization. However, it isn't right for the adult language. Consider the passive sentence Mary was told by John to leave. The phrase John is closest to the subject position for leave, but adult English speakers understand the sentence as meaning that Mary is the one leaving. The Minimal Distance Principle gives the wrong answer here. Instead, for the adult language, we need a principle sensitive to grammatical structure, such as the "c-control" structural relation discussed in the Chapter by Lasnik [?]. Let's consider a simplified version, which we can call the Structural Principle. It might say that the controller of a missing subject is the grammatical object of the upstairs verb if it has one; otherwise it is the grammatical subject of the upstairs verb (both of them c-command the missing subject). The object of a preposition in the higher clause, however, is never allowed to be a controller, basically because it is embedded "too deeply" in the sentence's tree structure to c-command the missing subject. That's why Mary was told by John to leave has Mary as the controller. (It is also why, incidentally, the sentence Mary was promised by John to leave is unintelligible -- it would require a prepositional phrase to be the controller, which is ruled out by the Structural Principle.)

It would certainly be understandable if children were to follow the Minimal Distance Principle. Not only is it easily stated in terms of surface properties that children can easily perceive, but sentences that would disconfirm it like Mary was told by John to leave are extremely rare in parents' speech. Michael Maratsos (1974) did the crucial experiment. He gave children such sentences and asked them who was leaving. Of course, on either account children would have to be able to understand the passive construction to interpret these sentences, and Maratsos gave them a separate test of comprehension of simple passive sentences to select out only those children who could do so. And indeed, he found that those children interpreted passive sentences with missing embedded subjects just as adults would. That is, in accord with the Structural Principle and in violation of the Minimal Distance Principle, they interpreted Mary was told by John to leave as having the subject, Mary, do the leaving; that is, as the controller. The experiment shows how young children have grasped the abstract structural relations in sentences, and have acquired a grammar of the same design as that spoken by their parents.

8 The Child's Language-Learning Algorithm

Here is the most basic problem in understanding how children learn a language: The input to language acquisition consists of sounds and situations; the output is a grammar specifying, for that language, the order and arrangement of abstract entities like nouns, verbs, subjects, phrase structures, control, and c-

command (see the Chapters by Lasnik and Larson, and the demonstrations in this chapter and the one by Gleitman and Newport). Somehow the child must discover these entities to learn the language. We know that even preschool children have an extensive unconscious grasp of grammatical structure, to the experiments on discussed in the previous section, but how has the child managed to go from sounds and situations to syntactic structure?

Innate knowledge of grammar itself is not sufficient. It does no good for the child to have written down in his brain "There exist nouns"; children need some way of finding them in parents' speech, so that they can determine, among other things, whether the nouns come before the verb, as in English, or after, as in Irish. Once the child finds nouns and verbs, any innate knowledge would immediately be helpful, because the child could then deduce all kinds of implications about how they can be used. But finding them is the crucial first step, and it is not an easy one.

In English, nouns can be identified as those things that come after articles, get suffixed with -s in the plural, and so on. But the infant obviously doesn't know that yet. Nouns don't occur in any constant position in a sentence across the languages of the world, and they aren't said with any particular tone of voice. Nor do nouns have a constant meaning -- they often refer to physical things, like dogs, but don't have to, as in *The days of our lives* and *The warmth of the sun*. The same is true for other linguistic entities, such as verbs, subjects, objects, auxiliaries, and tense. Since the child must somehow "lift himself up by his bootstraps" to get started in formulating a grammar for the language, this is called the "bootstrapping problem" (see Pinker, 1982, 1984, 1987b, 1989, 1994; Morgan, 1986; Gleitman, 1990; and the contributors to Morgan and Demuth, 1995). Several solutions can be envisioned.

8.1 Extracting Simple Correlations

One possibility is that the child sets up a massive correlation matrix, and tallies which words appear in which positions, which words appear next to which other words, which words get which prefixes and suffixes in which circumstances, and so on. Syntactic categories would arise implicitly as the child discovered that certain sets of properties are mutually intercorrelated in large sets of words. For example, many words tend to occur between a subject and an object, are inflected with -s when the subject is singular and in the third person and the tense is present, and often appear after the word *to*. This set of words would be grouped together as the equivalent of the "verb" category (Maratsos & Chalkley, 1981).

There are two problems with this proposal. The main one is that the features that the prelinguistic child is supposed to be cross-referencing are not audibly marked in parental speech. Rather, they are perceptible only to child who has already analyzed the grammar of the language -- just what the proposal is trying to explain in the first place! How is a prelinguistic child supposed to find the "subject" of the sentence in order to correlate it with the ending on the words he or she is focusing on? A subject is not the same thing as the first word or two of the sentence (e.g., *The big bad wolf huffed and puffed*) or even the first phrase (e.g., *What did the big bad wolf do?*). We have a dilemma. If the features defining the rows and columns of the correlation matrix are things that are perceptible to the child, like "first word in a sentence," then grammatical categories will never emerge, because they have no consistent correlation with these features. But if the features are the things that do define grammatical categories, like agreement and phrase structure position, the proposal assumes just what it sets out to explain, namely that the child has analyzed the input into its correct grammatical structures. Somehow, the child must break into this circle. It is a general danger that pops up in cognitive psychology whenever anyone proposes a model that depends on correlations among features: there is always a temptation to glibly endow the features with the complex, abstract representations whose acquisition one is trying to explain.

The second problem is that, without prior constraints on the design of the feature-correlator, there are an astronomical number of possible intercorrelations among linguistic properties for the child to test. To take just two, the child would have to determine whether a sentence containing the word *cat* in third position must have a plural word at the end, and whether sentences ending in words ending in *d* are invariably preceded by words referring to plural entities. Most of these correlations never occur in any natural language. It would be mystery, then, why children are built with complex machinery designed to test for them -- though another way of putting it is that it would be a mystery why there are no languages exhibiting certain kinds of correlations given that children are capable of finding them.

8.2 Using Prosody

A second way in which the child could begin syntax learning would be to attend to the prosody of sentences, and to posit phrase boundaries at points in the acoustic stream marked by lengthening, pausing, and drops in fundamental frequency. The proposal seems attractive, because prosodic properties are perceptible in advance of knowing any syntax, so at first glance prosody seems like a straightforward way for a child to break into the language system.

But on closer examination, the proposal does not seem to work (Pinker, 1987, 1994b; Fernald and McRoberts, in press; Steedman, in press). Just as gold glitters, but all that glitters is not gold, syntactic structure affects aspects of prosody, but aspects of prosody are affected by many things besides syntax. The effects of emotional state of the speaker, intent of the speaker, word frequency, contrastive stress, and syllabic structure of individual words, are all mixed together, and there is no way for a child to disentangle them from the sound wave alone. For example, in the sentence *The baby ate the slug*, the main pause coincides with the major syntactic boundary between the subject and the predicate. But a child cannot work backwards and assume that the main pause in an input sentence marks the boundary between the subject and the predicate. In the similar sentence *He ate the slug*, the main pause is at the more embedded boundary between the verb and its object.

Worse, the mapping between syntax and prosody, even when it is consistent, is consistent in different ways in different languages. So a young child cannot use any such consistency, at least not at the very beginning of language acquisition, to decipher the syntax of the sentence, because it itself is one of the things that has to be learned.

8.3 Using Context and Semantics

A third possibility (see Pinker, 1982, 1984, 1989; Macnamara, 1982; Grimshaw 1981; Wexler & Culicover, 1980; Bloom, in press) exploits the fact that there is a one-way contingency between syntax and semantics in the basic sentences of most of the world's languages. Though not all nouns are physical objects, all physical objects are named by nouns. Similarly, if a verb has an argument playing the semantic role of 'agent', then that argument will be expressed as the subject of basic sentences in language after language. (Again, this does not work in reverse: the subject is not necessarily an agent. In *John liked Mary* the subject is an "experiencer"; in *John pleased Mary* it is an object of experience; in *John received a package* it is a goal or recipient; in *John underwent an operation* it is a patient.) Similarly, entities directly affected by an action are expressed as objects (but not all objects are entities affected by an action); actions themselves are expressed as verbs (though not all verbs express actions). Even phrase structure configurations have semantic correlates: arguments of verbs reliably appear as "sisters" to them inside the verb phrase in phrase structure trees (see the chapter by Lasnik).

If children assume that semantic and syntactic categories are related in restricted ways in the early input, they could use semantic properties of words and phrases (inferred from context; see Section) as

evidence that they belong to certain syntactic categories. For example, a child can infer that a word that designated a person, place or thing is a noun, that a word designating an action is a verb, that a word expressing the agent argument of an action predicate is the subject of its sentence, and so on. For example, upon hearing the sentence *The cat chased the rat*, the child can deduce that in English the subject comes before the verb, that the object comes after the verb, and so on. This would give the child the basis for creating the phrase structure trees that allow him or her to analyze the rules of the language.

Of course, a child cannot literally create a grammar that contains rules like "Agent words come before action words." This would leave the child no way of knowing how to order the words in sentences such as *Apples appeal to Mary* or *John received a package*. But once an initial set of rules is learned, items that are more abstract or that don't follow the usual patterns relating syntax and semantic could be learned through their distribution in already-learned structures. That is, the child could now infer that *Apples* is the subject of *appeal*, and that *John* is the subject of *receive*, because they are in subject position, a fact the child now knows thanks to the earlier *cat-chased-rat* sentences. Similarly, the child could infer that *appeal* is a verb to begin with because it is in the "verb" position.

9 Acquisition in Action

What do all these arguments mean for what goes on in a child's mind moment by moment as he or she is acquiring rules from parental speech? Let's look at the process as concretely as possible.

9.1 Bootstrapping the First Rules

First imagine a hypothetical child trying to extract patterns from the following sentences, without any innate guidance as to how human grammar works.

Myron eats lamb.
Myron eats fish.
Myron likes fish.

At first glance, one might think that the child could analyze the input as follows. Sentences consist of three words: the first must be Myron, the second either eats or likes, the third lamb or fish. With these micro-rules, the child can already generalize beyond the input, to the brand new sentence *Myron likes chicken*.

But let's say the next two sentences are

Myron eats loudly.
Myron might fish.

The word *might* gets added to the list of words that can appear in second position, and the word *loudly* is added to the list that can appear in third position. But look at the generalizations this would allow:

Myron might loudly.
Myron likes loudly.
Myron might lamb.

This is not working. The child must couch rules in grammatical categories like noun, verb, and auxiliary, not in actual words. That way, *fish* as a noun and *fish* as a verb can be kept separate, and the

child would not adulterate the noun rule with instances of verbs and vice-versa. If children are willing to guess that words for objects are nouns, words for actions are verbs, and so on, they would have a leg up on the rule-learning problem.

But words are not enough; they must be ordered. Imagine the child trying to figure out what kind of word can occur before the verb bother. It can't be done:

That dog bothers me. [dog, a noun]
 What she wears bothers me. [wears, a verb]
 Music that is too loud bothers me. [loud, an adjective]
 Cheering too loudly bothers me. [loudly, an adverb]
 The guy she hangs out with bothers me. [with, a preposition]

The problem is obvious. There is a certain something that must come before the verb bother, but that something is not a kind of word; it is a kind of phrase, a noun phrase. A noun phrase always contains a head noun, but that noun can be followed by many other phrases. So it is useless of try to learn a language by analyzing sentences word by word. The child must look for phrases -- and the experiments on grammatical control discussed earlier shows that they do.

What does it mean to look for phrases? A phrase is a group of words. Most of the logically possible groups of words in a sentence are useless for constructing new sentences, such as wears bothers and cheering too, but the child, unable to rely on parental feedback, has no way of knowing this. So once again, children cannot attack the language learning task like some logician free of preconceptions; they need prior constraints. We have already seen where such constraints could come. First, the child could assume that parents' speech respects the basic design of human phrase structure: phrases contain heads (e.g., a noun phrase is built around a head noun); arguments are grouped with heads in small phrases, sometimes called X-bars (see the chapter by Lasnik); X-bars are grouped with their modifiers inside large phrases (Noun Phrase, Verb Phrase, and so on); phrases can have subjects. Second, since the meanings of parents' sentences are guessable in context, the child could use the meanings to help set up the right phrase structure. Imagine that a parent says The big dog ate ice cream. If the child already knows the words big, dog, ate, and ice cream, he or she can guess their categories and grow the first branches of a tree: In turn, nouns and verbs must belong to noun phrases and verb phrases, so the child can posit one for each of these words. And if there is a big dog around, the child can guess that the and big modify dog, and connect them properly inside the noun phrase: If the child knows that the dog just ate ice cream, he or she can also guess that ice cream and dog are arguments of the verb eat. Dog is a special kind of argument, because it is the causal agent of the action and the topic of the sentence, and hence it is likely to be the subject of the sentence, and therefore attaches to the "S." A tree for the sentence has been completed: The rules and dictionary entries can be peeled off the tree:

S --> NP VP
 NP --> (det) (A) N
 VP --> V NP
 dog: N
 ice cream: N
 ate: V; eater = subject, thing eaten = object
 the: det
 big: A

This hypothetical example shows how a child, if suitably equipped, could learn three rules and five words from a single sentence in context.

The use of part-of-speech categories, phrase structure, and meaning guessed from context are powerful tools that can help the child in the daunting task of learning grammar quickly and without systematic parental feedback (Pinker, 1984). In particular, there are many benefits to using a small number of categories like N and V to organize incoming speech. By calling both the subject and object phrases "NP," rather than, say Phrase#1 and Phrase#2, the child automatically can apply knowledge about nouns in subject position to nouns in object position, and vice-versa. For example, our model child can already generalize, and use dog as an object, without having heard an adult do so, and the child tacitly knows that adjectives precede nouns not just in subjects but in objects, again without direct evidence. The child knows that if more than one dog is dogs in subject position, more than one dog is dogs in object position.

More generally, English allows at least eight possible phrasemates of a head noun inside a noun phrase, such as John's dog; dogs in the park; big dogs; dogs that I like, and so on. In turn, there are about eight places in a sentence where the whole noun phrase can go, such as Dog bites man; Man bites dog; A dog's life; Give the boy a dog; Talk to the dog; and so on. There are three ways to inflect a noun: dog, dogs, dog's. And a typical child by the time he or she is in high school has learned something like 20,000 different nouns (Miller, 1991; Pinker, 1994a). If children had to learn all the combinations separately, they would need to listen to about 140 million different sentences. At a rate of a sentence every ten seconds, ten hours a day, it would take over a century. But by unconsciously labeling all nouns as "N" and all noun phrases as "NP," the child has only to hear about twenty-five different kinds of noun phrase and learn the nouns one by one, and the millions of possible combinations fall out automatically.

Indeed, if children are constrained to look for only a small number of phrase types, they automatically gain the ability to produce an infinite number of sentences, one of the hallmarks of human language. Take the phrase the tree in the park. If the child mentally labels the park as an NP, and also labels the tree in the park as an NP, the resulting rules generate an NP inside a PP inside an NP -- a loop that can be iterated indefinitely, as in the tree near the ledge by the lake in the park in the city in the east of the state In contrast, a child who was free to label in the park as one kind of phrase, and the tree in the park another, would be deprived of the insight that the phrase contains an example of itself. The child would be limited to reproducing that phrase structure alone.

With a rudimentary but roughly accurate analysis of sentence structure set up, the other parts of language can be acquired systematically. Abstract words, such as nouns that do not refer to objects and people, -- can be learned by paying attention to where they sit inside a sentence. Since situation in The situation justifies drastic measures occurs inside a phrase in NP position, it must be a noun. If the language allows phrases to be scrambled around the sentence, like Latin or the Australian aboriginal language Warlpiri, the child can discover this feature upon coming across a word that cannot be connected to a tree in the expected place without crossing branches (in Section , we will see that children do seem to proceed in this order). The child's mind can also know what to focus on in decoding case and agreement inflections: a noun's inflection can be checked to see if it appears whenever the noun appears in subject position, in object position, and so on; a verb's inflection might can be checked for tense, aspect, and the number, person, and gender of its subject and object. The child need not bother checking whether the third word in the sentence referred to a reddish or a bluish object, whether the last word was long or short, whether the sentence was being uttered indoors or outdoors, and billions of other fruitless possibilities that a purely correlational learner would have to check.

9.2 The Organization of Grammar as a Guide to Acquisition

A grammar is not a bag of rules; there are principles that link the various parts together into a functioning whole. The child can use such principles of Universal Grammar to allow one bit of

knowledge about language to affect another. This helps solve the problem of how the child can avoid generalizing to too large a language, which in the absence of negative evidence would be incorrigible. In cases where children do overgeneralize, these principles can help the child recover: if there is a principle that says that A and B cannot coexist in a language, a child acquiring B can use it to catapult A out of the grammar.

9.2.1 Blocking and Inflectional Overregularization

The next chapter presents a good example. The Blocking principle in morphology dictates that an irregular form listed in the mental dictionary as corresponding to a particular inflectional category (say, past tense), blocks the application of the corresponding general rule. For example, adults know the irregular form *broke*, and that prevents them from applying the regular "add -ed" rule to *break* and saying *breaked*. Children, who have not heard *broke* enough times to remember it reliably on demand, thus fail to block the rule and occasionally say *breaked*. As they hear *broke* enough times to recall it reliably, Blocking would suppress the regular rule, and they would gradually recover from these overgeneralization errors (Marcus, et al., 1992).

9.2.2 Interactions between Word Meaning and Syntax

Here is another example in which a general principle rules out a form in the adult grammar, but in the child's grammar, the crucial information allowing the principle to apply is missing. As the child's knowledge increases, the relevance of the principle to the errant form manifests itself, and the form can be ruled out so as to make the grammar as a whole consistent with the principle.

Every verb has an "argument structure": a specification of what kinds of phrases it can appear with (Pinker, 1989). A familiar example is the distinction between a transitive verb like *devour*, which requires a direct object (you can say *He devoured the steak* but not just *He devoured*) and an intransitive verb like *dine*, which does not (you can say *He dined* but not *He dined the steak*). Children sometimes make errors with the argument structures of verbs that refer to the act of moving something to a specified location (Bowerman, 1982b; Gropen, Pinker, Hollander, and Goldberg, 1991a):

I didn't fill water up to drink it; I filled it up for the flowers to drink it.

Can I fill some salt into the bear? [a bear-shaped salt shaker]

I'm going to cover a screen over me.

Feel your hand to that.

Terri said if this [a rhinestone on a shirt] were a diamond then people would be trying to rob the shirt.

A general principle of argument structure is that the argument that is affected in some way specified by the verb gets mapped onto the syntactic object. This is an example of a "linking rule," which links semantics with syntax (and which is an example of the contingency a young child would have employed to use semantic information to bootstrap into the syntax). For example, for adults, the "container" argument (where the water goes) is the direct object of *fill* -- *fill the glass with water*, not *fill water into the glass* -- because the mental definition of the verb *fill* says that the glass becomes full, but says nothing about how that happens (one can fill a glass by pouring water into it, by dripping water into it, by dipping it into a pond, and so on). In contrast, for a verb like *pour*, it is the "content" argument (the water) that is the object -- *pour water into the glass*, not *pour the glass with water* -- because the mental definition of the verb *pour* says that the water must move in a certain manner (downward, in a stream) but does not specify what happens to the container (the water might fill the glass, merely wet it, end up beside it, and so on). In both cases, the entity specified as "affected" ends up as the object, but for *fill*, it

is the object whose state is affected (going from not full to full), whereas for pour, it is the object whose location is affected (going from one place to a lower one).

Now, let's say children mistakenly think that fill refers to a manner of motion (presumably, some kind of tipping or pouring), instead of an end state of fullness. (Children commonly use end state verbs as manner verbs: for example, they think that mix just means stir, regardless of whether the stirred ingredients end up mixed together; Gentner, 1978). If so, the linking rule for direct objects would cause them to make the error we observe: fill x into y. How could they recover? When children observe the verb fill in enough contexts to realize that it actually encodes the end state of fullness, not a manner of pouring or any other particular manner (for example eventually they may hear someone talking about filling a glass by leaving it on a window sill during a storm), they can change their mental dictionary entry for fill. As a result, they would withdraw it from eligibility to take the argument structure with the contents as direct object, on the grounds that it violates the constraint that "direct object = specifically affected entity." The principle could have existed all along, but only been deemed relevant to the verb fill when more information about its definition had been accumulated (Gropen, et al., 1991a, b; Pinker, 1989).

There is evidence that the process works in just that way. Gropen et al. (1991a) asked preschool children to select which picture corresponded to the sentence She filled the glass with water. Most children indiscriminately chose any picture showing water pouring; they did not care whether the glass ended up full. This shows that they do misconstrue the meaning of fill. In a separate task, the children were asked to describe in their own words what was happening in a picture showing a glass being filled. Many of these children used incorrect sentences like He's filling water into the glass. Older children tended to make fewer errors of both verb meaning and verb syntax, and children who got the verb meaning right were less likely to make syntax errors and vice-versa. In an even more direct demonstration, Gropen, et al. (1991b) taught children new verbs like to pilk, referring to actions like moving a sponge over to a cloth. For some children, the motion had a distinctive zigzag manner, but the cloth remained unchanged. For others, the motion was nondescript, but the cloth changed color in a litmus-like reaction when the sponge ended up on it. Though none of the children heard the verb used in a sentence, when asked to describe the event, the first group said that the experimenter was pilking the sponge, whereas the second group said that he was pilking the cloth. This is just the kind of inference that would cause a child who finally figured out what fill means to stop using it with the wrong direct object.

Interestingly, the connections between verbs' syntax and semantics go both ways. Gleitman (1990) points out that there are some aspects of a verb's meaning that are difficult, if not impossible, for a child to learn by observing only the situations in which the verb is used. For example, verb pairs like push and move, give and receive, win and beat, buy and sell, chase and flee, and drop and fall often can be used to describe the same event; only the perspective assumed by the verb differs. Also, mental verbs like see, know, and want, are difficult to infer by merely observing their contexts. Gleitman suggests that the crucial missing information comes from the syntax of the sentence. For example, fall is intransitive (it fell, not John fell the ball); drop can be transitive (He dropped the ball). This reflects the fact that the meaning of fall involves the mere act of plummeting, independent of who if anyone caused it, whereas the extra argument of drop refers to an agent who is causing the descent. A child could figure out the meaning difference between the two by paying attention to the transitive and intransitive syntax -- an example of using syntax to learn semantics, rather than vice-versa. (Of course, it can only work if the child has acquired some syntax to begin with.) Similarly, a verb that appears with a clause as its complement (as in I think that ...) must refer to a state involving a proposition, and not, say, of motion (there is no verb like He jumped that he was in the room). Therefore a child hearing a verb appearing with a clausal complement can infer that it might be a mental verb.

Naigles (1990) conducted an experiment that suggest that children indeed can learn some of a verb's

meaning from the syntax of a sentence it is used in. Twenty-four-month-olds first saw a video of a rabbit pushing a duck up and down, while both made large circles with one arm. One group of children heard a voice saying "The rabbit is gorging the duck"; another heard "The rabbit and the duck are gorging." Then both groups saw a pair of screens, one showing the rabbit pushing the duck up and down, neither making arm circles, the other showing the two characters making arm circles, neither pushing down the other. In response to the command "Where's gorging now? Find gorging!", the children who heard the transitive sentence looked at the screen showing the up-and-down action, and the children who heard the intransitive sentence looked at the screen showing the making-circles action. For a general discussion of how children could use verb syntax to learn verb semantics, and vice-versa, see Pinker (1994b).

9.3 Parameter-Setting and the Subset Principle

A striking discovery of modern generative grammar is that natural languages seem to be built on the same basic plan. Many differences among languages represent not separate designs but different settings of a few "parameters" that allow languages to vary, or different choices of rule types from a fairly small inventory of possibilities. The notion of a "parameter" is borrowed from mathematics. For example, all of the equations of the form " $y = 3x + b$," when graphed, correspond to a family of parallel lines with a slope of 3; the parameter b takes on a different value for each line, and corresponds to how high or low it is on the graph. Similarly, languages may have parameters (see the chapter by Lasnik).

For example, all languages in some sense have subjects, but there is a parameter corresponding to whether a language allows the speaker to omit the subject in a tensed sentence with an inflected verb. This "null subject" parameter (sometimes called "PRO-drop") is set to "off" in English and "on" in Spanish and Italian (Chomsky, 1981). In English, one can't say *Goes to the store*, but in Spanish, one can say the equivalent. The reason this difference is a "parameter" rather than an isolated fact is that it predicts a variety of more subtle linguistic facts. For example, in null subject languages, one can also use sentences like *Who do you think that left?* and *Ate John the apple*, which are ungrammatical in English. This is because the rules of a grammar interact tightly; if one thing changes, it will have series of cascading effects throughout the grammar. (For example, *Who do you think that left?* is ungrammatical in English because the surface subject of *left* is an inaudible "trace" left behind when the underlying subject, *who*, was moved to the front of the sentence. For reasons we need not cover here, a trace cannot appear after a word like *that*, so its presence taints the sentence. Recall that in Spanish, one can delete subjects. Therefore, one can delete the trace subject of *left*, just like any other subject (yes, one can "delete" a mental symbol even it would have made no sound to begin with). The trace is no longer there, so the principle that disallows a trace in that position is no longer violated, and the sentence sounds fine in Spanish.

On this view, the child would set parameters on the basis of a few examples from the parental input, and the full complexity of a language will ensue when those parameterized rules interact with one another and with universal principles. The parameter-setting view can help explain the universality and rapidity of the acquisition of language, despite the arcane complexity of what is and is not grammatical (e.g., the ungrammaticality of *Who do you think that left?*). When children learn one fact about a language, they can deduce that other facts are also true of it without having to learn them one by one.

This raises the question of how the child sets the parameters. One suggestion is that parameter settings are ordered, with children assuming a particular setting as the default case, moving to other settings as the input evidence forces them to (Chomsky, 1981). But how would the parameter settings be ordered? One very general rationale comes from the fact that children have no systematic access to negative evidence. Thus for every case in which parameter setting A generates a subset of the sentences generated by setting B (as in diagrams (c) and (d) of Figure 1), the child must first hypothesize A, then

abandon it for B only if a sentence generated by B but not by A was encountered in the input (Pinker, 1984; Berwick, 1985; Osherson, et al, 1985). The child would then have no need for negative evidence; he or she would never guess too large a language. (For settings that generate languages that intersect or are disjoint, as in diagrams (a) and (b) of Figure 1, either setting can be discarded if incorrect, because the child will eventually encounter a sentence that one grammar generates but the other does not).

Much interesting research in language acquisition hinges on whether children's first guess from among a set of nested possible languages really is the smallest subset. For example, some languages, like English, mandate strict word orders; others, such as Russian or Japanese, list a small set of admissible orders; still others, such as the Australian aborigine language Warlpiri, allow almost total scrambling of word order within a clause. Word order freedom thus seems to be a parameter of variation, and the setting generating the smallest language would obviously be the one dictating fixed word order. If children follow the Subset Principle, they should assume, by default, that languages have a fixed constituent order. They would back off from that prediction if and only if they hear alternative word orders, which indicate that the language does permit constituent order freedom. The alternative is that the child could assume that the default case was constituent order freedom.

If fixed-order is indeed the default, children should make few word order errors for a fixed-order language like English, and might be conservative in learning free-word order languages, sticking with a subset of the sanctioned orders (whether they in fact are conservative would depend on how much evidence of multiple orders they need before leaping to the conclusion that multiple orders are permissible, and on how frequent in parental speech the various orders are). If, on the other hand, free-order is the default, children acquiring fixed-word-order languages might go through a stage of overgenerating (saying, give doggie paper; give paper doggie, paper doggie give; doggie paper give, and so on), while children acquiring free word-order languages would immediately be able to use all the orders. In fact, as I have mentioned, children learning English never leap to the conclusion that it is a free-word order language and speak in all orders (Brown, 1973; Braine, 1976; Pinker, 1984; Bloom, Lightbown, & Hood, 1975). Logically speaking, though, that would be consistent with what they hear if they were willing to entertain the possibility that their parents were just conservative speakers of Korean, Russian or Swedish, where several orders are possible. But children learning Korean, Russian, and Swedish do sometimes (though not always) err on the side of caution, and use only one of the orders allowed in the language, pending further evidence (Brown, 1973). It looks like fixed-order is the default, just as the Subset Principle would predict.

Wexler & Manzini (1987) present a particularly nice example concerning the difference between "anaphors" like herself and "pronouns" like her. An anaphor has to have its antecedent lie a small distance away (measured in terms of phrase size, of course, not number of words); the antecedent is said to be inside the anaphor's "governing category." That is why the sentence John liked himself is fine, but John thought that Mary liked himself is ungrammatical: himself needs an antecedent (like John) within the same clause as itself, which it has in the first example but not the second. Different languages permit different-size governing categories for the equivalents of anaphors like himself; in some languages, the translations of both sentences are grammatical. The Subset Principle predicts that children should start off assuming that their language requires the tiniest possible governing category for anaphors, and then to expand the possibilities outward as they hear the telltale sentences. Interestingly, for pronouns like "her," the ordering is predicted to be the opposite. Pronouns may not have an antecedent within their governing categories: John liked him (meaning John liked himself) is ungrammatical, because the antecedent of him is too close, but John thought that Mary liked him is fine. Sets of languages with bigger and bigger governing categories for pronouns allow fewer and fewer grammatical possibilities, because they define larger ranges in which a pronoun prohibits its antecedent from appearing -- an effect of category size on language size that is in the opposite direction to what happens for anaphors. Wexler and Manzini thus predict that for pronouns, children should start off assuming that their language

requires the largest possible governing category, and then to shrink the possibilities inward as they hear the telltale sentences. They review experiments and spontaneous speech studies that provide some support for this subtle pattern of predictions.

10 Conclusion

The topic of language acquisition implicate the most profound questions about our understanding of the human mind, and its subject matter, the speech of children, is endlessly fascinating. But the attempt to understand it scientifically is guaranteed to bring on a certain degree of frustration. Languages are complex combinations of elegant principles and historical accidents. We cannot design new ones with independent properties; we are stuck with the confounded ones entrenched in communities. Children, too, were not designed for the benefit of psychologists: their cognitive, social, perceptual, and motor skills are all developing at the same time as their linguistic systems are maturing and their knowledge of a particular language is increasing, and none of their behavior reflects one of these components acting in isolation.

Given these problems, it may be surprising that we have learned anything about language acquisition at all, but we have. When we have, I believe, it is only because a diverse set of conceptual and methodological tools has been used to trap the elusive answers to our questions: neurobiology, ethology, linguistic theory, naturalistic and experimental child psychology, cognitive psychology, philosophy of induction, theoretical and applied computer science. Language acquisition, then, is one of the best examples of the indispensability of the multidisciplinary approach called cognitive science.

11 Further Reading

A general introduction to language can be found in my book *The Language Instinct* (Pinker, 1994), from which several portions of this chapter were adapted. There is a chapter on language acquisition, and chapters on syntactic structure, word structure, universals and change, prescriptive grammar, neurology and genetics, and other topics.

The logical problem of language acquisition is discussed in detail by Wexler and Culicover (1980), Pinker (1979, 1984, 1987, 1989), Osherson, Stob, & Weinstein (1985), Berwick (1985), and Morgan (1986). Pinker (1979) is a nontechnical introduction. The study of learnability within theoretical computer science has recently taken on interesting new turns, reviewed in Kearns & Vazirani (1994), though with little discussion of the special case we are interested in, language acquisition. Brent (1995) contains state-of-the-art work on computer models of language acquisition.

The most comprehensive recent textbook on language development is Ingram (1989). Among other recent textbooks, Gleason (1993) has a focus on children's and mothers' behavior, whereas Atkinson (1992), Goodluck (1991), and Crain and Lillo-Martin (in press), have more of a focus on linguistic theory. Bloom (1993) is an excellent collection of reprinted articles, organized around the acquisition of words and grammar. Hoekstra and Schwartz (1994) is a collection of recent papers more closely tied to theories of generative grammar. Fletcher & MacWhinney's *The Handbook of Child Language* (1995), has many useful survey chapters; see also the surveys by Paul Bloom in Gernsbacher's *Handbook of Psycholinguistics* (1994) and by Michael Maratsos in Mussen's *Carmichael's Manual of Child Psychology* (4th edition 1983; 5th edition in preparation at the time of this writing).

Earlier collections of important articles include Krasnegor, et al., (1991), MacWhinney (1987), Roeper & Williams (1987), Wanner & Gleitman (1982), Baker & McCarthy (1981), Fletcher and Garman

(1979), Ferguson & Slobin (1973), Hayes (1970), Brown & Bellugi (1964), and Lenneberg (1964). Slobin (1985a/1993) is a large collection of major reviews on the acquisition of particular languages.

The most ambitious attempts to synthesize large amounts of data on language development into a cohesive framework are Brown (1973), Pinker (1984), and Slobin (1985b). Clark (1993) reviews the acquisition of words. Locke (1993) covers the earliest stages of acquisition, with a focus on speech input and output. Morgan & Demuth (in press) contains papers on children's perception of input speech and its interaction with their language development.

12 Problems

1. "Negative evidence" is reliable information available to a language learner about which strings of words are ungrammatical in the language to be acquired. Which of the following would, and would not, count as negative evidence. Justify your answers.
 - a. Mother expresses disapproval every time Junior speaks ungrammatically.
 - b. Father often rewards Junior when he speaks grammatically, and often punishes him when he speaks ungrammatically.
 - c. Mother wrinkles her nose every time Junior speaks ungrammatically, and never wrinkles her nose any other time.
 - d. Father repeats all of Junior's grammatical sentences verbatim, and converts all of his ungrammatical sentences into grammatical ones.
 - e. Mother blathers incessantly, uttering all the grammatical sentences of English in order of length -- all the two word sentences, then all the three-word sentences, and so on.
 - f. Father corrects Junior whenever he produces an overregularization like *breaked*, but never corrects him when he produces a correct past tense form like *broke*.
 - g. Whenever Junior speaks ungrammatically, Mother responds by correcting the sentence to the grammatical version. When he speaks grammatically, Mother responds with a follow-up that merely recasts the sentence in different words.
 - h. Whenever Junior speaks ungrammatically, Father changes the subject.
 - i. Mother never repeats Junior's ungrammatical sentences verbatim, but sometimes repeats his grammatical sentences verbatim.
 - j. Father blathers incessantly, producing all possible strings of English words, furrowing his brows after every ungrammatical string and pursing his lips after every grammatical sentence.
2. Consider three languages. Language A is English, in which sentence must contain a grammatical subject: *He ate the apple is good*; *Ate the apple is ungrammatical*. In Language B, the subject is optional, but the verb always has a suffix which agrees with the subject (whether it is present or absent) in person, number, and gender. Thus *He ate-3MS the apple is good* (assume that "3MS" is a suffix, like -o or -ik, that is used only when the subject is 3rd person masculine

singular), as is Ate-3MS the apple. (Those of you who speak Spanish or Italian will see that this hypothetical language is similar to them.) Language C has no inflection on the verb, but allows the subject to be omitted: He ate the apple and Ate the apple are both good. Assuming a child has no access to negative evidence, but knows that the language to be learned is one of these three. Does the child have to entertain these hypotheses in any fixed order? If so, what is it? What learning strategy would guarantee that the child would arrive at the correct language? Show why.

3. Imagine a verb pilk that means "to have both of one's elbows grabbed by someone else," so John pilked Bill meant that Bill grabbed John's elbows.
 - a. Why is this verb unlikely to occur in English?
 - b. If children use semantic context and semantic-syntax linking rules to bootstrap their way into a language, what would a languageless child infer about English upon hearing "This is pilking" and seeing Bill grab John's elbows?
 - c. If children use semantic context and semantics-syntax linking rules to bootstrap their way into a language, what would a languageless child infer about English upon hearing "John pilked Bill" and seeing Bill grab John's elbows?
 - d. If children use semantic context and semantics-syntax linking rules to bootstrap their way into a language, what would a child have to experience in order to learn English syntax and the correct use of the word pilk?

13 Answers to Problems

1.
 - a. No. Presumably Mother also expresses disapproval for other reasons, such as Junior uttering a rude or false -- but grammatical -- sentence. If Junior were to assume that disapproved-of sentences were ungrammatical, he would spuriously eliminate many grammatical sentences from his language.
 - b. No, because Father may also reward him when he speaks ungrammatically and punish him when he speaks grammatically.
 - c. Yes, because Junior can deduce that any nose-wrinkle-eliciting sentence is grammatical.
 - d. Yes, because Junior can deduce that any sentence that is not repeated verbatim is ungrammatical.
 - e. Yes, because for any sentence that Junior is unsure about, he can keep listening to mother until she begins to utter sentences longer than that one. If, by that time, Mother has uttered his sentence, it is grammatical; if she hasn't, it's ungrammatical.
 - f. No, because we don't know what Father does for the rest of the language.
 - g. No, because while we know whether the changeover in Junior's sentence is a "correction" or a "recasting," because we know what's ungrammatical (hence corrected) or grammatical (hence recast), Junior has no way of knowing that from his point of view, Mother just changes everything he says into different words.

- h. No, because presumably Father changes the subject on some occasions when Junior's sentence was grammatical but Father was just getting bored with the topic.
- i. No, because many of his grammatical sentences might never be repeated verbatim, either.
- j. Yes, because sooner or later Father will utter Junior's last word string, and Junior can see whether Father's brow was furrowed.
2. English (Language A) has to be hypothesized before Language C, and rejected only if a subjectless and suffixless sentence turns up in the input. That is because Language C is a superset of English; if the learner tries C first, nothing in the input will ever tell him he's wrong. Language B can be hypothesized at any point, and confirmed whenever the child hears a sentence with an agreement in it or disconfirmed when the child hears a sentence without agreement.
3. a. In English (and almost every other language), the agent of the action is the subject of an active sentence, and the entity affected by the action is the object.
- b. He would infer, incorrectly, that pilk means "to hold someone's elbows."
- c. He would infer, incorrectly, that English word order was Object-Verb
- Subject. That would cause him subsequently to apply universals about subjects to objects, and vice-versa.
- d. He would have to have heard enough ordinary English verbs (with agents as subjects and affected entities as objects) to have inferred that the subject comes before the verb, which in turn comes before the object. Then he would have to hear John pilked Bill and see Bill grab John's elbows, and use the verb's syntax to infer its unusual semantics.

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Figure Caption

Four situations that a child could be in while learning a language. Each circle represents the set of sentences constituting a language. "H" stands for "hypothesized language"; "T" stands for "target language." "+" indicates a grammatical sentence in the language; "-" indicates an ungrammatical sentence.