8 The Competition Model

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In order to learn a language, a child must have available a rich representational system and flexible ways of deciding between representations. The child's framework must be rich enough to enable him to represent the intricate set of roles, positional patterns, cues, and conditions that constitute the grammar of any possible natural language. Since the child has no idea at the outset which of the many possible natural language structures he will need to learn, his approach to language learning must be extremely flexible. The model presented in this paper, the Competition Model, uses a small set of general cognitive principles to provide the learner with the power and flexibility to support reliable and input-sensitive language learning. This article is a companion piece to the article by Bates and MacWhinney (this volume). The article by Bates and MacWhinney provides an overview of the model and discusses the cross-linguistic work conducted within the Competition Model framework. The current article provides a description of the mechanisms of the model. For a full understanding of the Competition Model approach, both articles should be read together.

A major goal of the Competition Model is the building of bridges between child language research and cognitive science in general. If this is not done, there is a real danger that many of the advances made in the area of child language research will be lost. Roger Brown (1977) articulated the worry in this way:

> Developmental psycholinguistics has enjoyed an enormous growth in research popularity . . . which, strange to say, may come to nothing. There have been greater research enthusiasms than this in psychology: Clark Hull's principles of behavior, the study of the Authoritarian personality, and, of course, Dissonance theory. And in all these cases, very little advance in knowledge took place. . . . A

> danger in great research activity which we have not yet surmounted, but which we may surmount, is that a large quantity of frequently conflicting theory and data can become cognitively ugly and so repellent as to be swiftly deserted, its issues unresolved.

Heeding Brown's warning, child language researchers have been working to avoid conceptual fragmentation. In particular, many researchers have attempted to deepen the grounding of language acquisition theory in principles of linguistic analysis (Berwick, this volume; Macken, this volume; Pinker, this volume; Roeper, this volume; Wexler & Culicover, 1980). This work has dramatically broadened our understanding of the complexity of the task of language acquisition. Unfortunately, much of this linguistically-grounded work has not made contact with central issues in psychological approaches to the study of human cognition. Some researchers working in the linguistic tradition like to think of language as special and different from other forms of human mental activity. These "modularists" (Chomsky, 1980; Fodor, 1983) see language as a special "organ of the mind" obeying its own laws and agenda, rather than that of cognition in general. One problem with this approach is that, if we try to look at language as something entirely different from cognition in general, we run the risk of ignoring insights that can be derived from other studies of cognitive processes. Language is indeed special in the sense that it, more than any other system, utilizes virtually every major aspect of higher cognition, as well as many aspects of sensory and motor systems. This pervasive utilization of other cognitive structures by the linguistic function makes it all the more likely that language processing should be governed by many of the same basic principles that govern other aspects of cognitive processing and that the acquisition of language can be explained in terms of general learning principles placed at the service of communicative intentions.

The Competition Model adopts a research strategy that relates language to general cognitive principles. In doing this, we are guided by a "minimalist" approach that avoids making assumptions whenever possible. This minimalism emphasizes the extent to which cognitive processes needed by other areas of cognitive functioning can also be involved in language processing. To be sure, any attempt to place language into the Procrustean Bed of "general cognition" must eventually fail when it runs up against aspects of language that are specific adaptations to the task of communicating between human organisms. When the minimalist approach fails, there will then be solid reason to suspect that the skills involved are specific to language.

The current chapter sketches out an account of the mechanisms underlying language processing and acquisition. The discussion deals with three major facets of the model:

1. **The representational principles** of the model emphasize the importance of the lexicon as an organizer of auditory, semantic, allomorphic, polysemic, and role-relational (i.e. syntactic) knowledge.
2. **The processing principles** of the model emphasize the ways in which lexical items compete with each other during comprehension and production. It is this competition that gives the model its name. Our research group has produced a variety of empirical studies that focus on this facet of the model (see Bates & MacWhinney, this volume), particularly in regard to the competition of nouns for grammatical roles.
3. **The learning principles** of the model work to isolate lexical items and to shape connections between items and their properties on the basis of positive instances. The system uses competition as a way of enforcing the principle of contrast or non-synonymy. Competition guarantees that the child's representations will continually come closer to adult-like lexical representations.

In this paper, the Competition Model is offered as a general theory of the acquisition of grammar. The three critical points made in this paper are that:

1. a grammar in which all knowledge is represented by connections in the lexicon can provide a descriptively adequate and theoretically productive base for child language research,
2. competition between lexical items provides a good characterization of the ways in which children and adults process sentences, and
3. using learning based on competition, the child can acquire adult-like lexical items and shape the connections of these items to auditory, semantic, articulatory, polysemic, and role-relational properties.

The sketch presented here is a preliminary to a computational implementation of the model. Although parts of the model have been implemented, the implementation will not be discussed in this paper.

REPRESENTATION IN THE COMPETITION MODEL

One of the major lessons we have learned from cognitive science is the importance of developing a clear set of representational assumptions. Taking this lesson to heart, this section will be dedicated to outlining in detail the representational structures embedded in the Competition Model.

The core representational structure in the Competition Model is the lexical item—an association between external form and internal function (Bates & MacWhinney, 1982, this volume; Saussure, 1915). The form of the lexical item

is represented as a set of auditory properties. The function of the lexical item is a set of semantic properties. In the next two sections we will look at these two sides of the lexical item—the auditory properties and the semantic properties that characterize the form and the function of the lexical item.

Auditory Properties

The auditory properties of lexical items specify their external form. In comprehension, auditory properties such as voicing onset time, formant frequencies, and noise bursts (Ladefoged, 1975, 1980) work together as cues to activate particular lexical items. It is common in phonological analysis to think of these cues as occurring in bundles as phonemes or segments (Jakobson, Fant, & Halle, 1963). For example, in the bundle of cues for a /k/, there is quiescence followed by a burst and then a high second formant transition. Although it is true that auditory properties cooccur in time, the Competition Model does not introduce a separate level of phonemic analysis to account for this cooccurrence. Rather, following Klatt (1980), the model assumes that word recognition works directly off of auditory properties.

In the Competition Model, the temporal positions of specific auditory properties are characterized by associating to each set of segmental properties a further set of positional properties. The absolute position of segments is coded as occurring within a hierarchy of four slot types: 1) position in the group of tone units, 2) position in the tone unit, 3) position in the syllable, and 4) position in the cluster. Groups contain syllables; syllables contain clusters, and clusters contain segments. Each of these four levels codes positions as "pre," "center," and "post."

In the word "springing," the positions of the seven segments can be coded in this way:

Segment	Group	Tonic	Syllable	Cluster
s	center	center	pre	pre
p	center	center	pre	center
r	center	center	pre	post
i	center	center	center	center
N	center	center	post	center
i	center	post	center	center
N	center	post	post	center

In this type of analysis, there is no single set of properties that holds for all occurrences of a segment. Rather, for the segment /s/, there is one set of properties for syllable and cluster initial quasi-randomness in fricatives such as

/s/ in "split" and "sit." There is another set of properties for syllable final but cluster initial quasi-randomness as in the /s/ of "cast." There is yet another set of properties for syllable final and cluster final quasi-randomness as in the /s/ of "bats." Each unique combination of tone group position, syllable position, cluster position, and segmental information is connected to all the words that contain it. For example the property combination [tonic, onset, beginning, /s/] that we find at the beginning of "springing" is also found at the beginning of "split," "slip," and "spill."

Articulatory form is also represented in this way. In fact, the assumption is that articulatory structure is a mapping right off of auditory structure, and that articulatory learning focuses not on the acquisition of representations, but upon the acquisition of a system for converting auditory/articulatory representations to motor commands. Child phonologists (Macken & Ferguson, 1983; Smith, 1973) believe that children possess essentially adult-like auditory representations for words. But knowing how a word sounds does not automatically tell the young child how to say that word. The child must develop a mapping from auditory forms to articulatory actions. Once this mapping is constructed, the processor uses the auditory shape of the item as a cue to its articulation. Although the actual shapes of motor commands are entirely different from the shapes of auditory properties, there is no reason to believe that the child maintains a full set of articulatory representations alongside a full set of auditory representations.

Semantic Properties and Concepts

We noted above that the basic representational structure in the Competition Model is the lexical item, which is essentially a connection between units of form and units of function. The previous section sketched out a picture of the level of lexical form in terms of auditory properties. This section examines the level of function, where lexical representations are connected to a set of semantic properties.

One of the major difficulties facing the study of lexical semantics is the fact that it is extraordinarily difficult to come up with a fixed set of semantic properties even for a single language, let alone for all human languages. Even if such a set could be devised, it would not be reasonable to imagine that the child is born with knowledge of all these many semantic properties. The problem seems to be that, although the languages of the world are sensitive to a rich array of semantic cues, there is not much evidence indicating that these cues are universally available to children at the beginning of language learning.

The Competition Model addresses this problem in two ways. First, it distinguishes semantic properties from semantic concepts. Semantic properties are basic percepts that often relate to particular experiences, individual objects, or episodes (Miller & Johnson-Laird, 1976; Medin & Smith, 1984). Concepts, on

the other hand, are constructs which derive from generalization across experiences, objects, episodes, and lexical items. As the child discovers that properties of a particular experience can be generalized to other experiences, the set of generalized properties takes on a life of its own as a concept. Consider the semantic properties underlying the operator of "plurality." Early on, the child notes that there are often several tokens of a given type. In an egg carton, he sees several eggs. In a bag of carrots, he sees several carrots. He sees that these items can be picked up separately and that each is, in most important ways, equivalent to the others. From these experiences, he develops a general concept of plurality. This concept is not yet mapped onto a lexical item, but it can nonetheless be used in the child's thinking. Similarly, when the child first encounters a balloon, it provides him with a relatively unique experience. But, when he sees more and more balloons, he comes to form a general concept of "balloon." Even proper nouns develop in this way. When the child first sees a playmate called "Bill," he has a unique experience of Bill. Later, after playing with Bill on many different occasions, he develops a more general concept of "Bill." Whenever the child can superimpose experiences and extract a common core, that common core becomes a new concept.

However, by itself, the distinction between properties and concepts is not enough to explain certain conceptual reorganizations that occur in mid-childhood. For example, Bowerman (1982) has shown how English-speaking children develop a concept of causality under the impact of certain grammatical regularities in the formation of the causative in English. It appears to be the case that the child uses grammatical regularities as a basis for abducing the semantic shapes of at least some grammatical constructs (Bowerman, 1982, Markman, 1984, Keil & Batterman, 1984; Schlesinger, 1982; Wittgenstein, 1953; Whorf, 1967).

Work based on the Competition Model has focused primarily on the acquisition of grammar. However, our functionalist account places heavy emphasis on ways in which meaning guides the child in the acquisition of grammar. Because of this, we must pay careful attention to the nature of those concepts which guide grammatical acquisition. Using a corpus of child-mother interaction collected by Jacqueline Sachs (1983) that is entered in the Child Language Data Exchange System database (MacWhinney & Snow, 1985) at Carnegie-Mellon University, Jeffrey Sokolov and I have developed a coding system to notate the basic conceptual structure of situations described in discourse. The coding system tracks concepts and roles for which there is evidence of productive use by two-year-olds. For example, we are not coding for properties such as causative or honorific, since there is no evidence that the properties in these markers have been abstracted out as concepts (as opposed to properties) until the fourth year of life or later. In coding data from older children, we will begin to add codes for concepts acquired later in the preschool period. This section presents the various concepts which we are coding.

The basic types of items. There is a fundamental conceptual distinction between words that name objects and words that name actions or processes. This conceptual distinction is recognized by all the languages of the world. It is true that languages such as Navajo and Salish often seem to blur the distinction between nominals and verbs. For example, in Navajo, a chair is "on-it-you-sit." Technically, this word looks more like a verb than a noun. However, once constructed in this way, the word for "chair" behaves as a nominal. Something similar happens in English when we take the verb "visit" and the noun "relatives" and form the complex nominal "visiting relatives." Often there is no unique morphological marker that distinguishes nouns from verbs. In English, the word "hit" can be either a noun or a verb, depending on the context. But, given the context, it is clear when "hit" is functioning as a noun and when it is functioning as a verb. Although languages provide ways of making nouns into verbs and verbs into nouns, the basic distinction between nouns and verbs is always recognized in some way. Young children appear to have access to the concepts of object, action, and process which characterize nouns and verbs. Certainly, the ability to distinguish objects from actions is fundamental to cognition. Without such an ability, we would not be able to believe in object permanence and could not understand any sort of physical causation. In practice, there are many concepts that are on the border between the nominal and the verbal. It is true that nouns such as "lightning" and "rain" really describe processes. However, by virtue of their use as nouns in role-relational frames, they come to be treated as objects.

In addition to nominals and verbals, all languages have items that modify nouns and verbs. We will call these "operators." Nouns, verbs and operators are all connected to a rich variety of specific semantic properties as well as to a much smaller set of grammaticalized concepts. In this section we focus our attention on these grammaticalized concepts.

Concepts describing nominals. Concepts which describe nominals have a very major impact on the role structure of clauses and sentences. Pronouns use concepts describing nominals as identifying cues for coreference. In a sentence such as "The cat chased the dogs because it was growling" we know that the cat was growling because "it" agrees with "the cat" in terms of the concept of number. Verbs use concepts on nominals to control verb-noun agreement. In a sentence such as "the dogs are chasing the cat," we know that the dogs did the chasing since they agree in number with the auxiliary "are." In many Indo-European languages, adjectives use markings on nominals to control adjective-noun agreement. In a Spanish sentence like "*La muchacha no quiere a los hombres pobres*" ("The girl doesn't like poor men"), one cue that helps us to know that "*pobres*" "poor" modifies "*hombres*" "men" is the fact that "*pobres*" agrees in number and gender with "*hombres*" and not "*muchacha*"

"girl." A great deal of the relational structure of clauses depends on nominal markings and the ways in which they are used as cues for placing items into particular roles.

The basic function of nominals is referential (MacWhinney, 1984a). The nominal can be either a pronoun, a common noun, a proper noun, or a dummy element (as in "It is raining"). Common nouns work by identifying a set of referents that are members of a general class of things. When we hear the word "mug," we know that the things being discussed have the properties that are activated by the word "mug." In order to further delineate the referent, common nouns can be characterized by concepts such as "singular," "plural," and "dual." They can also be characterized for "definiteness," "indefiniteness," and a variety of quantifiers. Finally, common nouns can be characterized by individuation concepts such as "mass," "count," "group," or "collection." Together, these various characterizations allow us to select out of the possible set of referents those that match the common noun to which the speaker is currently referring. In other words, when we say "this mug," the word "mug" is a cue to the consideration of all possible mugs, but the word "this" provides a further cue that rapidly narrows the possible referents down to the one currently in front of us. There are many studies indicating that, by the age of two, children understand many of the concepts expressing definiteness, number, and individuation.

Some languages focus on a division of nominals into semantic classes. For example, some Navajo verbs require that the subject be classified as flat or round, straight or flexible, hard or mushy and so on. Navajo word order and morphology is also sensitive to relative position on an eight level animacy hierarchy (Perkins, 1978): human > intelligent animals > medium-sized animals > small animals > insects > natural forces > plants and inanimates > abstractions. In languages like Chinese (Chao, 1968), nouns are classified into types such as "human," "animal," and so on. Languages of the Far East often use distinctions in honorific status to code agreement marking and pronominal marking. English distinguishes between masculine and feminine animates in its pronominal system, although many languages make no such gender distinction. Of these various semantic class distinctions, the two recognized earliest in development appear to be animacy and semantic gender (Gelman, Spelke, & Meek, 1984). Although young children can make these two distinctions, other distinctions made in these systems are quite subtle and go undetected by the child for many years (Hollos, 1977; Clancy, 1986; MacWhinney, 1978). For many of these concepts, acquisition is late and occurs only under the pressure of the fact that the markings expressing the concepts are needed to control the grammar. The full control of formal gender marking of the type that occurs in German is a slow development. MacWhinney (1978) found that, for real nouns, children display nearly adult-like performance by 6. However, in terms of generalization to nonce forms, adult-like use of this system is not attained until age 12. Such

learning depends not on the extraction of a concept, but on the development of a complex set of interrelated cues which we will discuss later in the section on allomorphic processing.

Concepts describing pronominals. Pronouns provide instructions for the listener to look for referents by looking elsewhere. It is not enough to just tell the listener to look elsewhere for the referent. The listener must also be given some cues about where to look. The cues that are typically found in pronouns are much the same as the cues that are used to supplement common nouns: definiteness, indefiniteness, number, and quantifiers such as "some," "each," and "every." Pronouns also make use of person (first, second, and third) to facilitate the finding of the referent. The person cue is particularly helpful in the first and second persons, since the referent of "I" and "you" is usually quite clear.

The types of coreference that are possible include anaphoric reference (pointing to previous discourse), exophoric reference (pointing to the external situation), cataphoric reference (pointing to following discourse), and metaphoric reference (pointing to the entire speech act) (MacWhinney, 1984a). Together, these various types of reference can be called "phoric reference" and the pronouns that signal phoric reference can be called "phoric devices" or simply "phorics." To call all cases of phoric reference "anaphors" is incorrect, since many of them involve cataphora, metaphora, and exophora. This is important since, as Karmiloff-Smith (1979) and Maratsos (1976) have shown, exophoric reference is present in two-year-olds, but full anaphoric reference is not acquired until age four or later.

Pronouns can also mark certain locative concepts. The pronoun "here" can be understood as meaning "at a place close to the proximal area of reference." The pronoun "there" can be understood as meaning "at a place close to a distal area of reference." Marking locative pronouns in this way helps provide cues for the identification of the antecedent of the pronoun. Of course, what counts as proximal and distal is a relative matter and the learning of standard ways of encoding areas in relation to the speaker and the hearer is a difficult task for the child (Tanz, 1980).

Concepts describing verbals. The main impact of verbal properties is not upon agreement or coreference, but upon the selection of adverbial elements relating to the verb itself. For the noun, high frequency concepts include elements such as number and definiteness. Low frequency nominal concepts are usually coded as adjectives. For the verb, high frequency concepts include tense, aspect, and the modals. Low frequency verbal concepts are usually coded as adverbs.

Bybee (1985) has conducted a cross-linguistic analysis of the ways in which languages express mood, aspect, and tense. Her results show that aspect and

mood are less free, in morphological terms, than tense. In languages such as Polish that make aspectual distinctions fundamental, there is evidence that children can use aspect early on (Weist, Wysocka, Witkowska-Stadnik, Buczowska, & Konieczna, 1984). The Polish evidence and that of Antinucci and Miller (1976) show that children use aspect as a property, but not that they have extracted it as an concept. The grouping of verbs into aspectual types is made difficult by the fact that the exact interpretation of aspect or verb type varies from verb to verb. Markings for verb class such as the causative are even less productive. When such markings are expressed morphologically, they are usually derivational rather than inflectional and lower in morphological productivity (Bybee, 1985). This is not to say that the properties underlying "causative" cannot eventually be wrapped up into a causative concept. But, as Maratsos et al. (this volume) show, the extraction of the causative concept is a late, weak, and variable process.

Another major group of verbal concepts is the group of modality markers. These markers are often expressed as affixes or auxiliaries on the verb. Some of these concepts express the speaker's belief status vis a vis the clause (certain, conditional, counterfactual, desiderative, dubitative, inferential, necessary, negative, potential, possible). Others express the illocutionary force (declarative, emphatic, imperative, intentional, interrogative, obligatory, prohibitive, presumptive) of the clause. Of these several modality concepts, the ones which are most clearly available to the two-year-old are negative (Choi, 1986), interrogative, and imperative (Ervin-Tripp, 1977). However, many of the other modality concepts begin to emerge during the third and fourth years of life. Kuczaj (1981) documents the acquisition of the conditional concept. However, other concepts such as the reportative and dubitative seem to come in much later. In languages which express non-basic concepts by affixes on the verb, there is a pressure to acquire the morpheme even before its function is clearly understood. Thus, in Turkish (Aksu & Slobin, 1986), there is a single affix *mis-mas* expressing the reportative/evidential. For some time, this concept is used in a not clearly reportative fashion. In Lhasa Tibetan (DeLancey, 1985), there are four evidentials which differ in respect to the part of the action (initiator, product, activity, report) being used to make the inference. Unfortunately, data on the acquisition of the Tibetan system are not yet available.

Eventually, all normal children acquire means of expressing all of these modals, although not necessarily as single morphemes. For example, English uses phrases such as "I heard tell that . . ." to express the meaning of the reportative in Turkish. English uses phrases such as "I see you had eggs for breakfast" when what is meant is "I infer from the result which is unfortunately spread all over your shirt that you had eggs for breakfast." Given the low functional frequency of such concepts, it is not surprising to find that they are acquired rather late.

Connectives. Connectives play a very specific role by joining together items and groups of items. Connectives may either come in pairs (if-then, both-and, either-or, although-nonetheless) or singles (and, or, but, but not). In the coding of the Sachs data, the set of possible connectives is essentially the set of logical connectives.

Concepts describing other concepts. Finally, we should note that there are a few important operators that describe other operators. For example, in the word "happier," the comparative operator depends on the adjective "happy" which is itself an operator. Apart from the comparative and superlative, operators such as "more" and "very" also behave in this way. Of course, adverbs may modify adjectives, as in "slightly dizzy" or "entirely finished." However, these kinds of constructions are quite rare in the speech addressed to two-year-olds and have few consequences for relational structure. When they occur in the Sachs data, they are coded by using the full adverb as an operator.

Summary of codings. In summary, the discussion in this section has indicated early availability of the following concepts:

1. Major item type: nominal, verbal, operator, and connective.
2. Nominal status: common, proper, pronoun, and dummy.
3. Number: singular, plural, and dual.
4. Person: first, second, third, and fourth (nominals are always third).
5. Quantification: definite, indefinite, some, each, every, and all.
6. Individuation: mass, count, group, and collection.
7. Location: proximal, medial, and distal.
8. Nominal class: masculine, feminine, neuter, animate, and inanimate.
9. Tense: present, past, future, generic, and nonpast.
10. Aspect: inchoative, terminative, continuative, iterative, punctual, and durative.
11. Modality: negative, imperative, and interrogative.

Grammatical Roles

We have now completed our brief examination of the auditory and semantic systems. The discussion of the semantic system focused on those concepts which play a role in grammatical processing. These two systems provide a basic skeleton for language. However, by themselves, lexical items are not enough to express complex meanings. There must be a way of showing how meanings

relate to one another. Without a way of indicating these relations, our verbalizations would be an unstructured set of unrelated words. To solve this problem, language has developed a system of grammatical roles that use cues to place lexical items into relation with one another (Tesniere, 1959). Like the form-function relations expressed in lexical items, grammatical roles are also form-function relations. In relational structure, the forms are the surface word order patterns and morphological markings that cue particular relations; the functions are the underlying meaningful relations without which semantic interpretation could not proceed. If we were just to utter lexical items one after another, we would have only a vague notion of how to fit these words together into ideas. Grammatical roles provide us with a way of knowing what goes with what. This is their function. In the work of the transformational school (Chomsky, 1980), syntax is taken as a purely formal object. In the Competition Model, as in other work in the functionalist school (Dik, 1978; Givon, 1979), role-relational structure (i.e. syntax) is viewed as a way of expressing relational functions.

Relational structure connects lexical items to each other by means of grammatical roles. Roles are "opened up" by predicates (verbs and operators) and "filled" by arguments (nominals). We can schematize the opening up of a role in this way:

predicate ---- role ----> argument

For example, the opening up of a role for a subject by the verb "goes" can be diagrammed as:

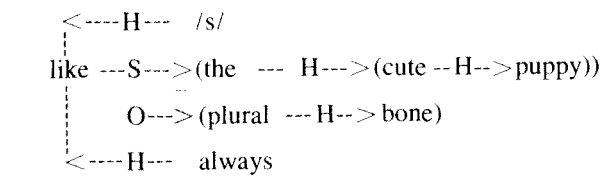
goes --- S ---> argument

Here the "S" stands for "subject" which is the role played by the argument vis a vis the predicate. In this way, the sentence "John goes" can be diagrammed as:

goes---S---> John

Often predicates can take several arguments, but in such cases each argument is bound to the central predicate by its own relation.

In order to understand how roles work to build up dependency structure in Competition Model terms, it may be helpful to first take a look at an simple example of a dependency structure. Consider the sentence "The cute puppy always likes bones" which has the following structure:



S = subject
O = object
H = head

In this structure, The phrase "the cute puppy" is bound to the subject role; "bones" is bound to the object role; "always" is bound as an adjunct with the verb as its head. The items "the" and "cute" are bound as operators to their head "puppy." This section will explain the meanings of these various roles and how they are assigned.

Verbs have connections to one, two, or three central argument roles. The central argument roles to which verbs may be connected are: subject, object, indirect, oblique, and result. These roles are not formal objects, rather each entails a specific functionalist interpretation. If there is only one argument to a verb, it is the subject. If there are two, they are the subject and the object. If there are three arguments, they must be subject, object, and result ("John put the lamp on the table") or subject, object, and indirect ("John gave Bill the lamp").

MacWhinney (1977) argued that, from a functionalist perspective, the role of subject is that of the argument from whose point-of-view the sentence is interpreted. He called this the role of the "perspective." Although the word "perspective" is a better description of this role, there is no reason to discard the term "subject," as long as the reader understands that it is being used here to refer to the functionalist concept of perspective. Similarly, from a functionalist perspective, the role of the object is that of the argument which is maximally involved in or changed by the action of the verb. Descriptively, it would be better to call this the role of the "affected." However, to avoid terminological unfamiliarity, the term "object" is used to refer to the element most affected by the activity of the verb.[1] The role of indirect (Ertel, 1977) is that of the secondary perspective—the participant that by virtue of being a beneficiary or recipient engages in a secondary action. The role of result is that of end result or goal. It appears with verbs like "paint" as in "Bill painted the wall red." The role of oblique occurs with transfer verbs such as "put" as in "Bill put the lamp on the table."

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[1]It is important for the reader to that the following traditional terms have theory-dependent definitions within the Competition Model: subject, object, head, predicate, noun, verb, role, concept, cue, cue validity, reliability, availability, and competition. Words coined expressly for the current paper are: "exohead," "relhead," and "phoric."

Verbs can take up to three central arguments. For example, the verb "put" takes a subject, an object, and an oblique, as in "John put the lamp on the table." Sometimes English verbs come in homophonous pairs, one member of the pair takes one argument and one takes two arguments. For example, the same auditory form is used for the two different verbs in "the door closed" and "John closed the door."

Of the four central roles, only that of the subject is fully obligatory. In some languages, there are subjectless verbs like "rain" and "be hot." In English, such verbs take dummy subjects. On the other hand, there are no verbs for which the indirect is obligatory. We can say "John gave the present" or "Mary sent the letter" without using the indirect, but it is harder to omit required objects and finals. Under some fairly strange set of circumstances, one might say "The speaker addressed until his breath gave out" or "John put the plate." But such omissions are highly marked and prompt a search for the missing argument.

For each argument role that it activates, the verb also activates one or more case roles. For example, the verb "hit" takes either an agential subject, as in the sentence "John hit the ball" or an instrumental subject, as in the sentence "The ball hit the window." In such cases, the alternative case roles are in competition with one another. There are only four central argument roles, but there are dozens of possible case roles and some speakers may actually make finer case role distinctions than others.

In addition to the five central argument role slots for verbs, there are nine additional roles in the Competition Model account:

1. **Head:** Operators open up slots for heads. Modality elements, logical operators, articles, and adjectives serve as predicates that modify a single argument which is their head. The arguments of these operators can be verbals, nominals, or other operators. What makes the head role particularly powerful is the fact that the head may itself be a complex structure. For example, adverbial operators can take clusters of other operators as their head, as in "a not so very bright light" which has the structure (a ((not (so (very (bright)))) (light))). Adjectives may nest in the same way. The phrase "my red wooden hammer" has the structure: (my (red (wooden (hammer)))). Nominal adjuncts may also attach to other nominals through the head relation as in "the cat on the table," where the adjunct "on the table" attaches to "the cat." Prepositions can also take complex clusters as their heads as in the phrase: (with (my (red (wagon)))).

2. **Exohead:** Prepositions take two arguments. One argument is the head of the prepositional phrase. This argument is called the "head." The other argument is the verb or noun which the whole prepositional phrase modifies. This second argument is called the "exohead." When the prepositional phrase is an adjunct of the verb, the verb is the exohead. When the prepositional phrase modifies a noun, the noun is the exohead. In a sentence such as "they

discussed the dogs on the beach," the exohead of "on the beach" could be either "the dogs" or "discussed."

3. **Coordinate:** Like prepositions, coordinate conjunctions take two arguments. One argument is the "coordinate" and the other is the "head." Verbals, nominals, or operators can all serve as coordinates. In the English phrase "Mary and John," "Mary" is the head and "John" is the coordinate. The whole phrase plays the role played by the head. Since verbs are the centers of clauses, there is no difference between verbal coordination and clausal coordination. In strings of coordinates such as "the duck, the turkey, and the goose" each of the nouns is bound to the head as a coordinate. Coordinates can also come in pairs, as in "both John and Mary" or "if you like butter, then you will love these cookies." In pairs such as "both-and" or "if-then," the material preceding the conjunction is its head and the other conjunction is the coordinate.

4. **Topic:** In many languages, clause-initial nominals are treated as topics by default. The topic is like the adjunct in that it can be a "free" argument to the verb. When no cues indicate any further role for the nominal, it simply retains its role of topic. This is frequent in languages such as Chinese that encourage the placement of unmarked nominals in clause initial position. Depending on the nature of the grammar, nominals may either preserve or lose their topic role when they take on a central role (subject, object, indirect, final). The most common central role for the topic is that of subject (MacWhinney, 1977). A common cue to topic assignment is the presence of an intonational break before or after the nominal. The topic is related to the rest of the clause by the topic-comment relation.

5. **Focus:** The counterweight to the role of topic is the role of focus (MacWhinney, 1977, 1982, 1985). The focal argument is the one which conveys some sort of contrastive presupposition. Like the topic, the focus is an optional argument of the verb. Like the topic role, the focus role can combine with any of the central roles. However, association of focus with the object is the default (Bates and MacWhinney, 1982).

6. **Antecedent:** Phoric forms (pronouns, definite NP's, "too," "so") open up slots for antecedents. The antecedent serves as an argument and the phoric form is the predicate.

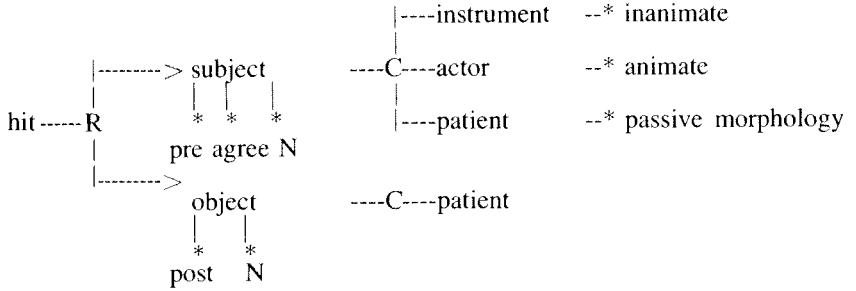
7. **Relhead:** The most complex grammatical role is that of the head of a relative clause. For brevity, we will call the head of a relative clause the "relhead." The relhead plays a role both in the main clause and in the relative clause. In the main clause, the relhead serves as an argument of the verb or an adjunct of the verb. In the lower clause, the relhead also serves as an argument of the verb. It does this by filling what would otherwise be a "gap" in the argument structure of the verb. For example, in the sentence "the man I saw chased Bill," the "man" is the subject of "chased" in the main clause

and the object of "saw" in the relative clause. The relhead also serves as the "head" in the modification relation which holds between it and the relative clause as a whole. This analysis also assumes that verb complements are actually arguments of the verb with dummy heads. Thus, the logical structure underlying "John said he wanted to go" is "John said it that he wanted to go."

8. **Description:** The role of predicate adjectives and nominals.
9. **Appositive:** The role of the appositive phrase.

Together with the five central argument roles, these nine roles constitute the basic set of grammatical roles.

Examples of items. Let us now take a look at the role and case connections for a few example lexical items. First consider the argument and case role connections for the verb "hit."

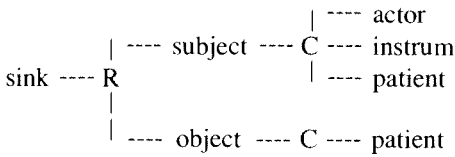


The letter "R" indicates the set of connections to the major grammatical roles (subject and object). The letter "C" represents connections to competing case role assignments. The connections ending in asterisks indicate cues for roles and cases. For this verb there are two arguments—the subject and the object. The agreement and preverbal positioning cues support the candidacy of a noun as the subject. The postverbal positioning cue supports the candidacy of a noun as the object. Following the two major roles, are the possible case role interpretations of each argument. When the verb is in the active mood, the subject can have either an actor or an instrument case role interpretation. The actor interpretation is favored when the N is animate and the instrument interpretation is favored when the N is inanimate. When the verb is in the passive mood, the subject plays the case role of patient. The cues to this case role selection are the inflectional cues for passive morphology on the verb.

The set of connections characterizing the subject of "hit" together with all of its case role interpretations is a very common set of connections. Verbs like "strike," "break," and "crack" have an identical subject structure. Rather than forming a set of connections for these additional verbs, it is possible to have them activate the same set of connections used by "hit." During development,

the child comes to control such recurring patterns of connections between roles and cues by separate nodes connected to lexical items. Such nodes or "grammogens" can take on a certain life of their own. For example, Bock (1986a, 1986b) has shown that, in adults, role types can be primed by previous sentences.

Verbs like "sink" that have both transitive/causative and intransitive readings can be represented by two competing lexical entries. Omitting the notations for the cues we have already discussed, the lexical role representation for transitive "sink" is:



The role clusters found in "hit" also occur here with the same cues.
The lexical role representation for intransitive "sink" is:

sink ---- R ---- subject ---- C ---- patient

Maratsos (this volume) shows how the transitive and intransitive forms differ along a variety of dimensions besides their causality. These differences indicate that it is indeed correct to analyse these verbs in terms of two separate lexical entries. This is not to say that some relations between the transitive and intransitive entries of this type cannot be detected. Rather, these relations arise as a secondary fact with the lexical entries themselves being primary. Competitive processing must resolve the choice between these two forms of "sink." The presence of nominals to fill both of the slots specified by the transitive "sink" will make that form win out in its competition with the intransitive "sink" for lexical activation.

Unlike verbs, adjectives take a single argument. They are operators that open up a slot for a head. An adjective such as "big" has this role structure:

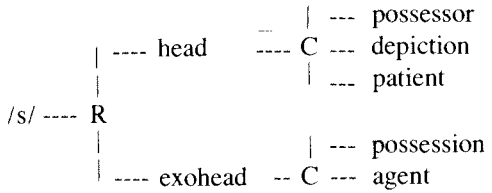
big --- R --- head --- C --- modified

In English, nouns can fill the head role slot if they occur in a position after the operator. In languages such as French or Spanish, modifiers occur in both pre and post position, but there is also often a semantic difference between the two positions and a morphological difference between the words in the two slots.

So far we have discussed two types of items: 1) verbs which take several nominal arguments and 2) operators which take only one argument. Prepositions work in a somewhat different way. In regard to their heads, they work like operators. For example, in a phrase like "into the box," the preposition "into"

attaches to its head "box." At the same time, the preposition "into" also opens up a slot for a head to which the whole phrase "into the box" can attach. This is the preposition's exohead. The exohead to which the prepositional phrase attaches may be a nominal exohead or a verbal exohead and these two attachments are in competition. In a sentence such as "she moved the clothes on the rack" there is a competition between the attachment of "on the rack" to the verb "move" and the attachment of the prepositional phrase to the noun "clothes."

The possessive marker also takes a head and an exohead. In English, the possessive can be marked either by the preposition "of" or by the suffix /s/. In either case, the head of the preposition is the possessor and the exohead is the possession. The entry for the suffix is:



The exact semantic role of the head of the possessive is often ambiguous. In a phrase such as "the statue of Venus," it could be that Venus is depicted by the statue or that she owns the statue. When there are additional cues on the exohead, the head may also take on the role of a patient. For example, Roeper (this volume) notes that we can speak of *the robber of the bank* and *the cooking of the stew*, but not *the thief of the bank* and *the cook of stew*. Roeper argues that the affixes *-er* and *-ing* provide a trigger for thematic inheritance. In the language of the Competition Model, we would say that these morphemes serve as cues supporting a patient role interpretation for the head of the preposition "of."

The *-er* on "robber" in the phrase "the robber of the bank" is an example of an item that has its effect on the interpretation of both its head and the phrase of which its head is the exohead (i.e. "of the bank"). The third person singular present tense affix on the verb in English (i.e. -/s/) works in much the same way. It marks the tense of its head verb. It also signals that any noun which is attempting to be a subject of its verb must be singular.

The nature-nurture issue and grammatical roles. The developmental psychologist will be quick to ask whether one must assume that these eleven grammatical roles are learned or innate. Schlesinger (1982) gives a thorough analysis of three plausible answers to this query. One approach is to say that the roles are learned during the period preceding the onset of multi-word utterances on the basis of exposure to perceptual regularities. For example, it is reasonable to imagine that the relation of coordination is learned early on when the infant

scans his visual environment and discovers pairings of similar objects that move in a common trajectory or which share a common fate (Bower, 1978; Haith, 1980). There are probably also early antecedents of the topic and head relations in the figure-ground organization of infant perception. Perception may not be the only basis for the development of these relations in infancy. In action, the infant also works with recurrence, focusing, and modification. Thus, both perception and action may provide recursors to grammatical relational structure.

A second approach holds that at least some aspects of these roles are acquired during the period of language learning, possibly under the impact of language learning itself. For example, the three-year-old understands how to use agents and even instruments as subjects. However, taking the perspective of the patient in a transitive verb is more difficult. Perhaps it is the case that children only consider taking such a strange perspective when they find a linguistic device (the passive) that encourages them to see a patient as a subject.

A third approach to this issue is to claim that all of the roles are part of the biological inheritance of the human species. One version of this approach sees this inheritance as specifically linguistic. Another version sees it as generally cognitive. Although there is some *prima facie* evidence for such a nativist position, the untestability of such a position makes it one that we should accept only as a last resort. On the other hand, the two learning accounts have the advantage of forcing us to make detailed accounts that can be tested empirically. Because of this, we must favor the learning accounts over the nativist account.

Competition and phrase-structure. How does the Competition Model account of grammatical structure relate to traditional phrase structure analysis? In the work of child language researchers such as Brown (1973), Bloom (1970), and Pinker (1984), phrase structure plays a role as the central organizer of all of syntactic development. Accounts that focus more on the patterns governing relations between individual items have been offerred by Braine (1976), MacWhinney (1975b), and Schlesinger (1977).

The most powerful argument supporting the analyses of those who believe in the early presence of full phrase-structure competence is that, since adult performance is controlled by phrase-structure rules, children must eventually acquire these rules in full form and that it is better to have the child start off on this task early on. To start the child off on the path of language learning with lexically-based formulas, according to this view, is to start him off with an incorrect hypothesis from which he must eventually retreat. The Competition Model approach we are offerring here undercuts this argument. In the Competition Model, the connections between lexical items and roles learned by the child are the same connections used by the adult. Because children are learning the same types of things they will need as adults, they are not exploring a dead end along the route to learning the language. Rather, they are moving incrementally and monoto-

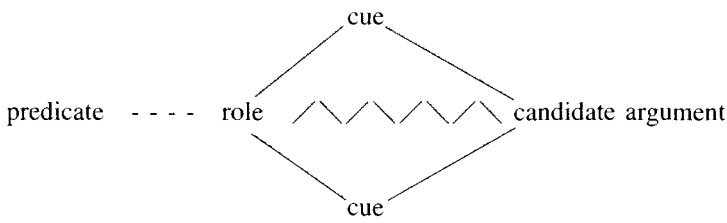
nically toward the adult state. Given this, one cannot argue that the learning of the role-relational structure of particular lexical items is a grammatical cocoon that must later be sloughed off by the language learner.

Models that require that the child acquire phrase structure right at the beginning of language learning must deal with a number of tough problems. In such accounts the acquisition of languages with VSO word order is problematic, since this order breaks up the "verb phrase." In the Competition Model this is not a problem, since the model does not group the object and verb into a separate phrase. All that is necessary for processing of VSO order is use of either morphological or positional cues that clearly mark the object. The fact that children have no trouble learning VSO languages like Welsh supports the Competition Model analysis and calls the standard phrase-structure analysis into question. The acquisition of non-configurational languages such as Warlpiri (Bavin, in press) and Hungarian (MacWhinney, 1986) would also appear to be a problem for phrase-structure analyses. Such languages differ from configurational languages only in that the morphological cues are so well developed that they need not be supplemented by positional cues. The cue-based processor of the Competition Model is ideally suited for dealing with non-configurational cue processing, since it allows affixes on stems to directly cue the roles of those stems.

Pinker (1984) presents a number of further problems that phrase-structure analyses must address. For each of these issues, Pinker proposes a series of strategies that can acquire the necessary competence. However, in few cases is there independent evidence for these strategies. Rather, we need to believe in Pinker's principles P1, P2, P3, P4, P5, P6, and L1 largely because, if we do not believe in them, it is not clear how phrase structure could be learned. In the Competition Model, on the other hand, phrase structures are epiphenomena, with the core of the grammar being composed of the arguments entered on particular predicates. By relating arguments to predicates, the listener builds up something that looks like a parse tree, but this construction is from the bottom up and is promoted by competition between alternative attachments. There is no top-down parsing of the type proposed by Marcus (1980) or Wanner and Maratsos (1978). In this way, there is no need for a separate encoding of phrase-structure rules, since the correct patterns emerge from the operation of predicate-argument relations.

Connectionism and Roles. The Competition Model shares much with current "connectionist" proposals in cognitive psychology. The various connectionist models differ in their assumptions, but there is one way in which the Competition Model deviates from any current connectionist account. This is in its treatment of grammatical roles. In the Competition Model, each predicate is connected to roles which are in turn connected to cues that support the correct assignment of lexical items to those roles. However, the cues themselves are

connected only to the roles, not to the items that fill those roles. We can think of the situation in terms of the following diagram:



Up to the point of the zig-zagged line, the account of roles is much like that given in the interactive activation model of McClelland and Rumelhart, 1981. However, in the Competition Model, the connection between the role and the candidate argument is not hard-wired in the lexicon, but is formed dynamically during processing. This dynamic connection is indicated by the /\/\/\/\/\ connection. The assignment of arguments to roles could conceivably be handled in a standard connectionist fashion by linking every word in the lexicon to every possible role (Cottrell, 1985; Dell, 1985). This is the "binding nodes" solution. There are serious problems with the binding nodes solution. In a sentence such as "The big dog and the little dog both ate the ham," there would have to be two bindings of the item "dog" to the subject role node. This would require that there be connections not only from "dog" to the subject role but to a second copy of the subject role. There is no limit in principle on the number of similar nouns that can be coordinated. Thus, there would be no limit on the number of additional binding nodes that would have to be added to such a system. Another connectionist solution to this problem might be the "programmable blackboard" of McClelland (1985). In this solution, units need not be dedicated to particular positions, since they can be programmed during processing. Perhaps this approach could be extended to the problem of role assignments, but it is not immediately clear how this extension would work.

In the architecture of the standard digital computer, the linking of the candidate to the role is not a problem at all. The whole matter is simply handled by pointers and addresses. However, a pointers-and-addresses architecture is not appropriate as a model of the fundamentally parallel neuronal hardware of the brain. The problem of passing variables in parallel hardware is fairly severe in the general case, but it would be a mistake to think that the brain has no way of implementing variable binding for a small set of grammatical roles. In the long run, researchers must be able to devise a way in which connectionist hardware can be wired up to compute a dynamic relation between the role and the item filling the role.

Polysemy

The lexical item is basically a way of mapping functions onto forms. However, as Bates and MacWhinney (this volume) point out, language is more than just a set of mappings from function to form. Language also involves patterns or correlations within the domain of function and patterns within the domain of form. Within the domain of function, patterns between items are important in resolving polysemy.

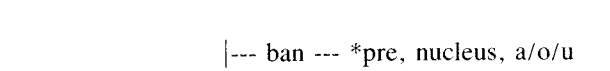
To resolve polysemy, items specify cues that help choose between alternative readings. If we hear that "the needle pricked her finger" we assume that the needle in question is a sewing needle and not the needle of a pine tree. The semantic features of sharpness and penetration which are contained in "prick" are cues to the activation of the proper polyseme of "needle." These connections are indeed the same ones that would be postulated in many theories of semantic memory (Anderson, 1983). By activating words related to a target polysemic item, we spread activation to that item and help it win out over its competitors (Cottrell, 1985). MacWhinney (1984a) provides a more detailed discussion of the exact cues used to choose between the various interpretations of devices such as the definite article and personal pronouns.

Allomorphy

Within the domain of form, the speaker must be able to resolve allomorphic competitions such as the conflict between "drove" and "*drived." Often these conflicts are between an irregular form that must be learned by rote and a regular form that can be produced by combination (MacWhinney, 1978). In order to resolve such conflicts, the speaker must rely on a series of cues. Sometimes these cues are properties of the morpheme itself; sometimes the cues are other morphemes. Every item that undergoes allomorphic variation must have connections both to the competing allomorphs and to those cues whose activation helps choose between these allomorphs. Schematically, the connections are of this form:

```
                |--- allomorph ---* cue
item ---A
                |--- allomorph ---* cue
```

In this diagram, the letter "A" indicates connections to competing allomorphs. The problem that arises in relational structure of binding items to roles does not arise in allomorphy. Each allomorph is "hard-wired" to its parent item. And each cue is also wired to the allomorph it supports. For example, the inessive suffix in Hungarian uses the allomorph /-ban/ when the stem has a back vowel. When the stem has a front vowel, the allomorph is /-ben/. These connections can be diagrammed as follows:



In German, the choice of feminine allomorph *die* of the nominative definite article is influenced by many cues. One particularly strong cue is the presence of a final -e on the stem. Whole affixes may also serve as cues in these competitions. For example, the derivational suffixes *-keit* and *-lein* are cues to the selection of the article in German.

PROCESSING IN THE COMPETITION MODEL

This section will examine the way in which competition works during sentence processing. First, we will consider the general principles governing competition and then we will look at how competition operates in terms of audition, articulation, role assignment, polysemy, and allomorphy.

Basic Assumptions

The model assumes that lexical elements and the components to which they are connected can vary in their degree of activation. Activation is passed along connections between nodes. During processing, items are in competition with one another. In auditory processing, the competition is between candidate lexical items that are attempting to match input data. In allomorphic processing, the competition is between candidate allomorphs. In the processing of role relations, the competition is between candidate items for bindings to argument slots. In polysemy, the competition is between candidate readings of polysemous or homophonous items. In each of these competitions, the item that wins out in a given competition is the one with the greatest activation. An item must dominate over its competitors sufficiently strongly and for a sufficiently long period to emerge as a winner. When two items continue to have a closely matched activation, no clear winner can be discerned and ambiguity results. However, the competition system is designed to minimize such instances of close competition. There are four ways in which the activation of an item can be raised or lowered: cue support, completeness, domination, and previous activation.

1. **Cue Support:** The connection between cues and the items or roles they support vary in *strength*. When a cue is strongly activated and when it has a strong connection to a role, then that role is also strongly activated. For example when a noun is clearly in preverbal position in English, it is a strong candidate for the subject role, because the connection from preverbal positioning to the subject role is strong. The more cues that a given candidacy

receives, the stronger it becomes. Cue support is assumed to be additive. In lexicalization, support is also assumed to favor "specificity" in that one large item receiving support from several cues will dominate over two items that depend on the same set of cues even though the combined strength of the opponents equals that of the large form. This occurs because the strong single item is opposed to each competitor separately in a "divide-and-conquer" fashion. Thus, "party" dominates over "par tee" when the input cues are /parti/. Similarly, *cat* is better than *at* when the input cues are /kaet/, since *cat* receives support from three bundles of cues and *at* only receives support from two. Similarly, *bunny* is better than *bun* and *knee* when the input is /buni/. When receiving activation from connections to semantic cues, portmanteau forms are superior to their analytic counterparts. In French, both *du* and *de* + *le* compete for the masculine partitive. However, because *du* has more matches than *de* or *le* separately, it gets more activation. It is generally the case that rote forms and combined forms dominate over analytical forms (MacWhinney, 1978, 1986). In role processing, a candidate for subject that receives support from both agreement and animacy cues is superior to one that receives support from only animacy. However, if there is a single cue that is particularly strong, the item it supports may dominate over an item supported by two weak cues.

2. **Completeness:** Most competitions can be resolved simply through using cues to support items. However, sometimes the winning "slate" of candidates does not provide as good an overall match as does some alternative slate whose individual members narrowly lost out in their respective competitions. For example, if the items "tension" and "Ulster" were lexicalized out of an input which was actually "attentional stir" the lexicalization would be incomplete, since the initial vowel of "attentional" would not be recognized. When the failure is noticed, the failure decrements the candidacy of the winning items. This lets the losers gain enough collective activation to eventually win out and hence provide a more complete solution.

3. **Previous Activation:** Frequent items have a higher resting activation than less frequent items. However, when an item is activated by the current context (Warren and Warren, 1976), by previous mention (Bock, 1986a) or by other lexical items (Bock, 1986b), it receives still further activation. For example, it is unlikely that we would lexicalize the input /parti/ as "par tee" unless we were talking about golf or had already primed the words "tee" and "par." However, once "par" and "tee" have attained some pre-activation, they can compete successfully with the more specific form "party" for lexicalization.

4. **Resolution:** The competitive processor attempts to select a single candidate for each competition, although sometimes the resolution of the competition is not completed in time. In auditory processing, this means that the processor attempts to have each segment participate in one winning lexical item. However, sometimes a single segment may end up as a component of two winning items (Stemberger and MacWhinney, 1986). In articulatory

processing, the processor attempts to have only one word controlling a given output syllable, although occasionally blends arise (Stemberger, 1982). In semantics, the processor tries to have only one reading for a given lexical item, although sometimes ambiguities remain. In role assignment, the processor strives to have only one argument bound to each argument slot, although sometimes attachments remain ambiguous (Kurtzman, 1985; Sokolov, 1983). In order to maximize the resolution of competitions, the processor uses a winner-take-all strategy which makes "the rich get richer and the poor get poorer" in that good guesses are supported and poor guesses are eliminated (McClelland and Rumelhart, 1981) through excitatory and inhibitory feedback. The actual decision to go with one competitor over another is based on the extent to which that competitor dominates over the other competitors. As one candidate begins to emerge as clearly stronger than the others, it also starts to have dominant effects on processing throughout the system.

The four factors we have discussed operate at different points in the competition. The previous activation of an item is determined before the current stimulus is excited. Auditory cues begin to work as soon as they are detected. Cues for roles begin to work as soon as the lexical items controlling them are recognized. However, cues for role assignments cannot have their effect until the candidate for the role is also recognized. Completeness only comes into play when some assignment has not been successful. Resolution works throughout the period of competition with the goal of deriving a single result for each competition.

The Control of Processing

The goal of language processing is the extraction of meaning in comprehension and the communication of meaning in production. However, in order to achieve these goals, processing must focus on the activation of lexical items and the establishment of relations between these items. In comprehension, competition begins on the auditory side. As a lexical item starts to win out in the auditory competition, its lexical strength increases. If the item is a predicate, as its strength grows, it generates expectations for arguments. As an item has its arguments satisfied, this gives it further support in its competition with homophonous forms. For example, when we hear the word "saw," we activate both the verb and the noun, but when the slots of the verb "saw" turn out to be correctly filled by nominals, the nominal reading of "saw" is suppressed and the verbal reading begins to dominate.

Auditory Competition

Competition in auditory processing is between alternative possible lexicalizations of stretches of auditory information. The lexicon is, in effect, the major controller of the segmentation of the speech stream. When enough cues accumu-

late to support a given item, that item effectively segments off a part of the speech stream as "known." Many approaches to the segmentation problem (Cole, Jakimik, & Cooper, 1980; Cooper & Paccia-Cooper, 1980; Morgan, 1986; Wolff, 1983) in child language focus on the issue of the availability of juncture cues to perceptual segmentation. Although these cues can certainly assist in segmentation, it would be a mistake to think that there are enough juncture cues in the input to achieve a full segmentation of speech. Where juncture cues fail, the lexicon itself steps in as a powerful controller of segmentation. As cues for a given item accumulate, that item crosses over threshold and begins to dominate over its competitors. The item then sends information back to its cues telling them that they have already succeeded in finding a lexical match and that there is no need for them to further activate items. This "commits" the cues to the winning item. However, those cues that are not matched continue to send out activation in search of lexical matches.

Consider the segmentation of the phrase /ɨzdaedikʌmiŋ/ "is daddy coming?" Let us imagine a child lexicon which includes the lexical items /ɨz/ "is" and /daedi/ "daddy", but not /kʌmiŋ/ "coming." The item /iz/ will match segments 1 and 2. The item /daedi/ will match correctly and without competition for segments 3 to 6. The remaining material will be tagged as not lexicalized and the child will attempt to learn its meaning to add to his lexicon. Schematically:

ɨ	z	d	ae	d	i	k	ʌ	m	i	ŋ
iz			daedi			unknown				

A more difficult example might be recognition of /bʌni/ "bunny". Here, the child might have the lexical items /bʌn/ "bun" and /ni/ "knee" and could conceivably segment /bʌni/into /bʌn/ and /ni/. However, because "bunny" derives activation from all the cues that support both "bun" and "knee," it is stronger than any single competitor and can therefore defeat the competition.

As a final, much more complex example, consider an adult's segmentation of the input phrase /malnerbEr/. In this case, there is activation of "mine," "Minor," "miner," "herb," "herbal," and "beer." "minor" and "miner" will be in competition with "mine" since they are all candidate items for the same syllable. "Herbal" is in competition with "beer." "Herbal" has segments that do not match the input and is penalized for these mismatches and is defeated by "beer." "Minor" and "miner" defeat "mine" because they score more matches. The combined use of "mine" and "herb" fails to provide a match for the final /-er/ and is defeated by "minor" or "miner" and "beer." The competition between "minor" and "miner" is not resolved in auditory processing, but is left for polysemic competition. Studies of lexical priming (Seidenberg, Tanenhaus, Leiman, & Bienkowski, 1982) show that items such as "herbal" and "mine" that lose in this competition are indeed forced below their normal activation levels for a short refractory period.

Because the system is being dominated by the attempt to detect full lexical items, it is fairly robust against noise. It will hear a stimulus such as /tuθpeIst/ as "toothpaste" even though there is a misarticulation of the last consonant of "tooth." If form /tuθpeIst/ is placed into a context in which "toothpaste" is also semantically primed, it will be even more quickly perceived as "toothpaste." This is because there is no competing word "toofpaste." However, where two words compete closely, such as "present" and "pleasant," the role of context will be relatively weaker and the competition will be based more exclusively on the actual auditory input.

Articulatory Competition

In production, grammatical roles open up slots for groups of syllables in the articulatory buffer. The exact shape of these slots is not determined until particular items try to fill them. Transposition and stranding errors (Garrett, 1975; Stemberger, 1982; MacWhinney & Anderson, 1986) occur when items are sent to the wrong role slots.

Once a lexical item is activated, it begins to open up a set of syllable slots within the group slot opened up by relational structure. If an item is a head, it opens up its own set of syllable slots. If an item is an operator, it can open up slots in relation to the slots of the head. Suppose the child wants to say "a hippopotamus." When the item "hippopotamus" is activated, it opens up two groups of syllables—one for "hippo" and one for "potamus." The item "a" does not open up its own syllable group, but attaches before the first group of the head. If the item "a" is lexicalized before the noun is lexicalized, it cannot open up a syllable slot, since it only opens up a slot once a center has been established. Once that center is established, it then opens up a position that is "pre" in the group "a hippo." When the articulatory compiler is ready to output speech it simply reads off these activations syllable by syllable. Rumelhart and Norman (1982) have suggested one way in which such read-off can occur. This is to set up each syllable position as having a level of activation and then reading off actions by their activation levels.

Sometimes two forms that are both targeted for the same articulatory slots are so close in activation that neither has won by the time it is necessary to send information to the articulatory buffer. Blends such as *flavor* + *taste* = *flaste* arise from such head-on competition. Other competitions are not so direct. For example, in English, there is a competition between the three allomorphs of the plural /s/, /z/, and /ɨz/. However, thihs competition is not equal between the three forms. In errors such as "dogses" the /z/ allomorph wins out in the competition for final position in the final cluster of the head. The allomorph /ɨz/, on the other hand, is competing for a position which is post-head. So there is no direct conflict between these two sets of articulatory actions. The Competition Model can provide a good account for many of the most important types of

speech errors. For details on how this account is constructed, consult MacWhinney and Anderson (1986), Menn and MacWhinney (1984), and Stemberger (1982).

Role Competition

Role competition begins with the activation of a predicate. As the predicate becomes activated, it awakens expectations for items to fill its role slots. For example, the verb "chase" specifies a slot for subject and object. Once these slots are opened, nominals begin to compete for these roles. In doing this, they use cues of the type analysed by Bates and MacWhinney (this volume). These cues include word order, agreement, case-marking, and grammatical prosody. In a sentence such as "the dogs are chasing the cat" the cues supporting "the dogs" as subject are preverbal positioning and agreement. There are no cues supporting "the cat" as subject and its postverbal positioning makes it a good candidate for the object slot.

Clustering. A major problem facing role competition is the fact that argument slots can be filled either by simple arguments or by complex arguments. A simple argument is a single lexical item. A complex argument is composed of several lexical items. In the sentence "Mary likes Bill" the object of "likes" is the simple argument "Bill." In the sentence "Mary likes a young soldier" the object of "likes" is the complex argument "a young soldier." The term "clustering" will be used to refer to the process which links two items such as "a" and "young soldier" into a cluster which can then be assigned as a unit to a role.

In order to see how this works, let us work through a trace of the processing of "Mary likes a young soldier."

Item	**Roles**	**Cues**	**Links**
Mary	—	—	—
likes	Subject	Pre,N,Anim,Sg	Mary <--S-- likes
	Object	Post,N	
a	Head	Post,N,Sg	
young	Head	Post,N	
soldier	—	—	young --H--> soldier
			a --H--> (young --> soldier)

Final: Mary --S--> likes --O--> (a --H--> (young --H--> soldier)))

Traces of this type are designed to reflect the major decisions made by the processor as it works on-line to accept incoming auditory material. Since these traces are designed to illustrate role competition, they do not reflect details of

auditory competition. Let us walk through this trace. First the child lexicalizes "Mary." Since "Mary" is a noun and since nouns have no arguments, no links are built and no roles are expected. Then the child lexicalizes "likes." This verb expects a subject in pre position and an object in post position. Since "Mary" is a noun in pre position, it is bound as the subject of "likes." There is no competition for this role, so the binding is fairly strong. Next the child lexicalizes "a" which expects a following noun. Since the form which follows ("young") is not a noun, no binding can occur. After lexicalizing "soldier," however, all the unfulfilled expectations can be fulfilled. First "young" binds to "soldier," because it is in pre position. Then the nominal cluster "young soldier" binds to "a." Finally, the nominal cluster "a young soldier" fills the post verbal slot for an object. At this point, all the slots are filled and all items are attached.

When a cluster such as "young soldier" is formed from the combination of "young" and "soldier," it inherits the nominal properties of the head. A similar inheritance occurs within strings of operators. In a phrase such as "a not very clearly described pathway," the initial operators are clustered on the operator "described" and the resultant product also serves as an operator. This principle of inheritance from nominal heads is a basic notion of traditional linguistic analysis which has been recently reflected in the X-bar principle of Jackendoff (1977).

Clusters are established when simple structures fail to make proper assignments during sentence processing. There are three ways in which clustering can be triggered:

1. **Unfulfilled expectation:** If a predicate specifies that an argument should appear in a positional slot and the item in that slot does not match the cue expectations for a head, no role assignment is made. In the case of "Mary likes a soldier" the item following "likes" is "a." However, by itself "a" cannot be the object of "likes," since it is not a noun. This unfulfilled expectation leads the processor to hold off on attachment of "a" to any role. By holding off on attachment, the processor provides an opportunity for "a" to attach to "soldier" as a cluster. Then the whole cluster "a soldier" becomes a complex noun which then can serve as the object of the verb "likes."
2. **Unassigned item:** Sometimes the item in the head slot matches the cue expectations for a head, but assigning it as head will leave some other nominal unassigned. Consider a sentence such as "Bill has a toy dog," Initially, "toy" is a good candidate for the role of the head of "a." However, this reading fails to assign "dog" to any role. The alternative, and usually weaker, polysemic reading of "toy" is as an adjective. In order for the adjectival polyseme of "toy" to dominate, the nominal polyseme must be decremented by the failure of "dog" to receive any attachment.

3. **Cluster occupies slot:** In left-branching constructions, a cluster may already have been formed by the time the operator is lexicalized. Consider a phrase such as "the former Queen of England's hat." In this phrase, the possessive suffix /s/ is an operator which takes a head to its left. However, /s/ cannot take "England" as its head, since "England" is already a part of the cluster "the former Queen of England." The head cluster may be a phrase of arbitrary complexity. We could have "the former Queen of England's butler's hat" or "the former Queen of England's butler's dog's hat." In each of these cases, the attachments of elements within the head cluster are largely complete by the time that the operator is lexicalized. This makes it so that the only reasonable candidate for the head is the cluster itself.

The principles of clustering outlined for the head role also operate for the other roles. A subject may be a cluster, as may a topic. In a sentence such as "The dog the cat chased ate the meat," the whole structure "the dog the cat chased" functions as the subject of the verb "ate."

Flat structures and rebracketing. Adults tend to impose a hierarchical structure on phrases more than do children. The literature on adjective ordering (Martin & Molfese, 1971, 1972; Richards, 1979, Scheffelin, 1971; Schwenk & Danks, 1974) shows that children do not have clear ideas of the logical relations encoded by variations in adjective ordering. Hill (1983) argues that children initially compose relations such as "a big cat" from flat structures rather than hierarchical structures. In other words, children may code "a big cat" as the flat structure:

$$a \text{ -H-}> \text{ cat } <\text{-H- big}$$

rather than as the hierarchical structure:

$$a \text{ -H-}> (\text{big -H-}> \text{cat})$$

Adult may also make occasional use of flat structures, but it is clear that children must eventually learn to hierarchicalize clusters.

If hierarchical clustering is imposed, the exact bracketing of clusters can be a matter for competition. When clustering "a young soldier," no competition between attachments occurs, since "a" cannot attach to anything until the cluster "young soldier" is constructed. However, the corresponding phrase in Spanish cannot be processed without rebracketing. In Spanish, the adjective follows the noun, although the article precedes it. The phrase "un soldado joven" reads, word for word, as "a soldier young." If assignments are made from left to right, "soldado" will first be put in the role of the head of "un." This cluster would

then serve as a head for "joven" and the final structure would be ((a soldier) young) or ((un soldado) joven). This is not correct, since the structure should be (un (soldado joven)). The rebracketing procedure takes an element that follows a cluster and attaches it closer to the head than the competitors.

Anticipation. In our discussion of clustering, we noted that sentences like "Mary likes a soldier" involve an unfulfilled expectation. The expectation is that the object of "likes" should follow it immediately. This anticipation is not immediately fulfilled. At the same time, the operator "a" anticipates that a nominal should follow it. Such anticipations establish weak attachments to items even before they are actually detected. Such links are particularly important in structures with strings of prepositions or prefixed adpositions. For example, English verbs can be preceded by long strings of auxiliaries and adverbs such as "might not have always been." English nouns can be preceded by strings of adjectives as in "my two big square red blocks." In Navajo, up to 12 prefixes may precede the verb stem. In such situations, the information-processing load can be decreased by allowing these preposed operators to all attach to the anticipated head that will follow them. This anticipated element is set up as an abstract unit in relational structure to which the other items attach. When it is finally lexicalized, its attachments to operators are already activated.

Gaps and relative clause clustering. In relative clauses in English, the head of the relative clause, or "relhead," is used in two ways. On the one hand, it is the item which the relative clause modifies. The whole relative clause is treated as a single cluster which follows the noun which it modifies. On the other hand, the relhead also works as a "filler" for the "gap" that occurs within the relative clause.[2]

During processing, the listener must decide when a noun should be judged to be a relhead. In English, this can be done in two ways. When a relativizer ("that") follows a noun, the noun is taken to be a relhead. A noun can also be judged to be a relhead when rebracketing is forced by the verb that follows the relative clause. Once a noun has become a candidate for the role of relhead, it also becomes a candidate for some role within the clause that modifies the relhead. If there is a missing argument or "gap" within that clause, the relhead fills the gap.

Let us consider the processing of a center-embedded relative clause such as "the dog the cat chased ate the bone." First, the units "the dog" and "the cat" are built. The next item is "chased" which opens up argument slots for a subject and an object. The only real candidate for the subject role is "cat" which is in preverbal position and gets bound to this role. Then the processor encounters

[2]In languages with resumptive pronouns in the relative clause, the processor has to compute the antecedent role, but does not have to use the relhead to fill a gap.

"ate" which opens up slots for a subject and an object. There is no simple item in preverbal position, so clustering works to take all the material in preverbal position as a unit. To do this, "the dog" is taken as relhead. Finally, the item "bone" receives support from the postverbal positioning cue and wins out with no competition for the role of object of the verb "ate." The trace for "the dog the cat chased ate the bone" is as follows:

Item	Roles	Cues	Links
the	Head	post,N	the --H--> X
dog	—	—	the --H--> dog
the	Head	post,N	the --H--> X
cat	—	—	the --H--> cat
chased	Subject	pre,N,Sg,Anim	(the --> cat) --S--> chased
	Object	post,N	
ate	Subject	pre,N,Sg,Anim	relative clustering
	Object	Post,N	
Clustering: ((the --> dog) <--RH-- (the cat <--S-- chased --O-->RH)) <--S-- ate			
the	Head	post,H	the --H--> X
bone	—	—	the --H--> bone
Final: ((the --> dog) <-- ((the --> cat) <--chased--> RH)) <-- ate --> (the --> bone)			

Alternative attachments. The process of attachment of elements to other elements or clusters is often ambiguous. Given a series of items A, B, and C, we could have the structures (A (B C)) or ((A B) (C)). The study of alternative attachments of prepositional phrases and reduced relative clauses has been a major topic in psycholinguistics in the last ten years (Clifton, Frazier, & Connine, 1984, Ford, Bresnan, & Kaplan, 1982; Frazier, 1985; Frazier & Fodor, 1978). Consider a sentence such as "The women discussed the dogs on the beach." The cluster "on the beach" can attach itself either to the cluster "the dogs" or to the main verb. In the Competition Model framework, the cluster "on the beach" can have either a verb (discussed) or a noun (dogs) as its head. Both relations are being opened by the same item, so they must be in competition with one another. The one with the most cue support will be the winner.

Alternative attachments are in competition in the sentence "I have a list of 300 people who are Communists that I can send to you." The head of "that I can send to you" could be either 1) "300 people who are Communists," or 2) "a list of 300 people who are Communists." Usually, a relative will attach to a single

noun. In this particular case, however, we realize after awhile that it is unlikely that the speaker is really proposing to send 300 Communists and that the head of "that I can send to you" must be "list."

Many studies have looked at the processing of reduced relative clauses such as in "the horse raced past the barn fell." From the viewpoint of the Competition Model, the processing of these sentences involves a competition rather than the full retracing implied by the term "garden-pathing". It is clear that the major interpretation of "the horse raced" is the one which assigns "horse" as the subject of "raced." However, in an experiment rich with reduced relatives, adult subjects might also be able to establish a possible modification relation between "raced" and "horse." They can maintain this competition for some time, until encountering information later in the sentence that leads to the victory of one of these interpretations over the other (Clifton et al, 1984; Kurtzman, 1985). The Competition Model provides the following trace for "the horse raced past the barn fell."

Item	**Roles**	**Cues**	**Links**
the	Head	Post,N	the --H--> X
horse	—	—	the --H--> horse
raced-1	Subject	Pre,N	(the --> horse) <--S-- raced
raced-2	Subject	Pre,N	(the --> horse) <--S-- raced
	Object	Post,NonHuman	
past	Head	post,N	
	Exohead	pre,V or N	(the-->horse) <--raced <--E-- past
the	Head	Post,N	the --H--> X
barn	-	-	(the --H--> barn)
fell	Subject	Pre,N	relative clustering

Final: ((the --> horse) <--RH-- (X <--S-- raced <--E-- past --H--> (the barn))) <--S-- fell

The relative clustering process here begins in the same way as the relative clustering that occurs in "the dog the cat chased fell." The phrase "the horse" is taken as the head of a relative clause in which it will play the role of object. This means that "raced-2", the transitive polyseme of "raced," must be chosen, since the head has to play the role of the object of the verb of the relative clause. What is tricky here is that the relative has an ellipsed subject. This requires yet another filling—this time by a general subject X.

Visitors. Some of the most complex grammatical patterns that the child has to learn involve the role assignment of raised elements. These raised elements will be called "visitors." Visitors are elements which are related not to elements in

the "foreign" clause where they appear but to elements in a "home" clause. Visitors take up temporary roles in the foreign environment, but their candidacy for further roles is maintained by "helper" cues along the way, until they can eventually be attached to a role in their home clause.

Let us consider a sentence such as "What did John say you ate?" The interrogative auxiliary "did" serves as a cue to the fact that the element following it is the subject. When the verb "say" is lexicalized, it opens up a slot for a subject and an object. The word "John" wins out as the candidate for subject since it is in preverbal and postauxiliary position. The interrogative "what" serves temporarily as the object of "say," but both the presence of a nominal after "say" and the fact that "say" is a cognitive verb serve as cues to maintain the candidacy of "what" as a visitor in search of a role as an object back home. The next item ("you") is in preverbal position *vis a vis* "ate" and wins the competition for the subject of "ate." However, "ate" also opens up a slot for an object and there is no word in postverbal position to fill that slot. But since the candidacy of "what" has been maintained by the verb "say", it can now fill that slot. Then, the cluser of "you ate" plus the visitor falls into postverbal position and serves as the object of "say." With this, each nominal is bound to a slot, every slot is filled, and the role competition is completed.

Competition Model analyses can be constructed for the most important types of raisings. Unfortunately, space is limited here and presentation of analyses of the various types of raisings and the cues that support each must wait for another occasion.

What determines how complex the competition gets?. One possible approach to the parsing problem would be to imagine that all possible parses of a sentence get built in parallel all the time (Kurtzmann, 1985). The Competition Model takes a different approach to this problem by focusing on the bottom-up construction of fragments of parses. There are two ways in which alternative parses can be generated. The most important source of competing parses is lexical polysemy. Consider a sentence like "He bought her waffles." The item "her" could be either the possessive or the indirect pronoun. The two competing parses of this sentence are both controlled off of this polysemic competition. The other major source of alternative parses is the competition between local and non-local attachment. The default attachment for heads, exoheads, and relheads are the items in the "standard" position. In English, the default head of an adjective is in post position; the default exohead of a preposition is in immediate pre position; and the default relhead of a relative clause is in pre position. However, when such attachments seem incorrect because of other cues, non-local attachments become strong competitors. Together these principles of polysemic control and failure of local attachment are the determiners of the generation of alternative parses.

Role competition in production. So far, our discussion of role competition has focused on comprehension. However, roles are also important in terms of controlling the order of items in production. When a verb or preposition becomes activated in production, it opens up a slot in the articulatory buffer for itself. It then also opens up slots for each of the nominal arguments related to it. When the nominal slot is opened up, it is then possible for the operators on the noun to open up further slots vis a vis the nominal head. Transpositions such as "closets in his skeleton" can be understood as nominals moving to the wrong slot around the preposition. In such errors, the operators are targeted separately and often end up at their correct targets, even though the heads have been transposed. For a further discussion of these various error types, see MacWhinney and Anderson (1986).

Ill-formedness and error. The Competition Model accounts for ill-formedness or ungrammaticality in terms of unassigned material. If a string of auditory cues goes unrecognized, the processor signals that there is an error. Children are accustomed to such errors and often treat them as ways of learning new words. Adults are more confident about their abilities and assume that it is the signal and not their grammar that is at fault. Ill-formedness can also be detected on the level of relational structure. If an item is lexicalized, but not attached to any other items through a role relation, there is an error. This can occur when an item expects another item and fails to find it. For example, the string "Bill had a big" is ill-formed because "big" expects a head and no head is available. Ill-formedness can also arise when there is simply an extra unattached noun, as in "John gave Fred the package Bill." This way of characterizing ill-formedness is very different from the systems of filters and constraints used in transformational grammar. Sometimes there may be both a missing expectation and an extra element. The speaker might think that the listener could somehow match up the extra element with the unfilled slot. However, there may be no cues to activate the match. For example, At the age of 5 years and 3 months, my son Mark was sitting in the kitchen eating a peanut sandwich. Out of the blue, he remarked, "Dad, next time when it's Indian Guides and my birthday, what do you think a picture of should be on my cake?" Some listeners have trouble processing such sentences. When they encounter a "what" before an auxiliary, they treat it as a "visitor" and search for its home environment. the major cue to that environment is the presence of a verb that takes an object and which is not a cognitive or communication verb such as "believe" or "say." In Mark's sentence, this cue is missing and it is hard to bind the visitor to a role slot. A somewhat better sentence would be "What do you think we should have a picture of on my cake?" Here the visitor fills a slot in the cluster which serves as the object. What makes this situation better is that the cue of the transitive verb keeps the slot active while the cluster with "picture of" is being formed and then the visitor fits

into this cluster. When "picture of" is in subject position, the visitor is not activated to look for a home while the cluster is being formed.

Immediacy of processing. Note that this system is designed to handle grammatical information as it enters into the auditory buffer. In this sense, the system implements the principle of "immediacy of processing" espoused by Thibadeau, Just, and Carpenter (1982) and Marslen-Wilson and Tyler (1981). For example, each noun in a clause is a possible candidate for assignment to the role of subject. Cues serve to strengthen or weaken the candidacy of each noun for this role. For example, when parsing a sentence such as "the dogs are chasing the cat," the assignment of "dogs" as the subject is first promoted by its appearance as the initial noun. Then the fact that "are chasing" agrees with "dogs" in number further supports this assignment. Finally, when "cat" appears post-verbally, its candidacy as the object further supports the candidacy of "dogs" as the subject. Thus, at each point in the processing of the sentence the strength of the candidacy of "dogs" is updated. Because the language designs the cues to permit ongoing updating, the need for backtracking is minimized.

Allomorphic Competition

Competition also arises between allomorphs of a given item. In order to resolve allomorphic competition, the system uses a series of auditory and semantic cues. Unlike the model for inflectional processing presented by Rumelhart and McClelland (this volume), the Competition Model allows for a great deal of rote lexicalization. As in the accounts of Bybee (1985), Jackendoff (1975), MacWhinney (1975, 1978, 1982, 1986), Menn and MacWhinney (1985), Stemberger and MacWhinney (1985), and Vennemann (1972), many inflected forms are stored as whole lexical items. All irregular forms are stored in this way. So, "went," "geese," and "has" are all stored as complete items. In addition, high frequency regular forms such as "jumped," "wants," and "cats" are also stored as single lexical items.

Although the model of MacWhinney (1975, 1978, 1982, 1986) allowed for *rote* lexical storage, it also recognized the importance of *analogic processes* in forming inflected words, particularly forms using novel stems. Rumelhart and McClelland (this volume) provide an excellent characterization of the way this underlying analogic processing could occur in connectionist hardware. In the Rumelhart and McClelland "verb learning" model, the child uses the "Wickelfeatures" in the stem of the present tense as cues to the activation of phonological markings for the past tense. For example, the use of /a/ in syllable center position is cued by the presence of a final velar nasal, as in "sing-sang" and "ring-rang." The presence of a final /t/ is a weak cue to use of no inflection at all, as in "cut-cut" or "put-put." However, if none of these cues are activated strongly enough, the formation of the past by "-ed" wins out. In the

Competition Model, the underlying analogic (Brooks, 1978), property-based computation of the Rumelhart and McClelland model runs in parallel with rote lexical access. When rote access is weak, the underlying process wins out. Thus, a child may, at first, use the underlying analogic process to produce "*breaked" as the past tense of "break." While producing "*breaked," he is also learning the rote form "broke" and strengthening its representation. As "broke" grows in strength, the child finds it increasingly easier to retrieve. However, the analogic form does not disappear and continues to place some pressure on the system. Finally, in order to solidify the retrieval of the correct form, the child strengthens a specific inhibition of "*breaked" by "broke."

Gender and case marking languages such as German provide interesting examples of allomorphic competitions. In German, "der," "die," and "das" are all entered under the nominative singular definite article. For well-learned nouns, there are direct connections to the correct definite article. However, as with the English past tense, there is an underlying analogic cue-based process which selects the correct allomorph when rote retrieval fails. Final /e/, final fricative plus /t/, and a variety of other terminations are cues to activation of the various "feminine" markers including: "die (nominative, accusative)," "der (dative, genitive)," "-e (adjectival)," "ihr" (dative, genitive)," and "sie (nominative, accusative)." There are also full morphemes such as *-keit, -heit,* and *-in* which serve as cues to activation of the feminine markers. Finally, the feminine markers also receive activation from a series of semantic cues. Names for trees and ships are usually feminine as are names for humans and domestic animals of feminine biological gender. Köpcke and Zubin (1983) have explored the determination of gender in German through both phonological and semantic cues and shown that a cue integration model correctly accounts both for assignment of real nouns to gender in the language and for subjects assignments of nonce nouns to gender class in experiments. Just as high frequency past tense forms such as "went" and "had" resist the regular pattern in English, so high frequency nouns such as "Knie" and "Bier" are exceptions to the cue patterns worked out by Köpcke and Zubin. Such forms have direct connections to articles to yield "das Knie" and "das Bier."

In languages such as Hungarian, the underlying analogic process is a very accurate determiner of inflected forms and few forms need to be stored by rote. The choice between either /ban/ or /ben/ as the inessive suffix on the noun depends on whether the noun stem has either a back vowel such as /a/, /o/, or /u/ or a front vowel such as /e/, /i/, or /o''/ in its last syllable. If the stem is /ablak/ the final vowel is /a/ and the inessive is /ablakban/. If the stem is /keret/ the final vowel is /e/ and the inessive is /keretben/. Connections lead from each of the possible auditory cues to activation of the corresponding articulatory forms in the output.

An interesting problem in Hungarian is whether the variation between forms is handled on the level of whole morphemes, i.e. a selection between /ban/ and

/ben/, or whether there is a more local competition between just /a/ and /e/. The generality of the pattern supports the solution that focuses on the competition between /a/ and /e/. However, the fact that the child does not automatically extend the pattern to all suffixes equally (MacWhinney, 1978) indicates that the morphemes also play a controlling role. We can understand these two effects by assuming that the child must acquire the competition set (e.g. /ban/ vs. /ben/) separately for each suffix. However, once acquired, the competition is between /a/ and /e/. All the cues that are relevant to the competition between /a/ and /e/ for one suffix are automatically relevant to the competition between these segments for other suffixes, once the allomorphs of those other suffixes are learned.

Polysemic Competition

In order to resolve polysemy, the processor must look at two types of cues. One type of cue derives from differences in patterns of role attachment. In a sentence such as "the boy got fat fried" the causative polyseme of "got" wins out because of the failure of the non-causative to provide for attachment of "fried." However, most competitions between polysemes are resolved not on the basis of parsing cues, but on the basis of the priming of meanings by other meanings. Much recent work has focused on the extent to which contextual effects prime one polyseme over its competitors. Many studies have shown facilitative effects of context on word recognition. For example, Tulving, Mandler, and Baumal (1964) find that context can facilitate identification of an impoverished stimulus. More recently, studies by Seidenberg, Tanenhaus, Leiman, and Bienkowski (1982), Swinney (1979), and Tanenhaus, Leiman, and Seidenberg (1979) have failed to find significant priming of the contextually appropriate polyseme. However, detailed examination of these results indicates that in seven of the eight experiments involved in these three reports, there are effects in the direction of facilitation of contextually appropriate forms. In one experiment in Seidenberg et al. the effect was significant. From this we can conclude that, whereas contextual priming is real and available right at the beginning of lexicalization, it is a fairly weak effect. It makes sense, after all, that priming should be weak and have little impact at first, since otherwise the listener would run the danger of mishearing words entirely. However, this research provides little evidence in support of the view that the lexicon is somehow encapsulated in a way that prevents it from making use of contextual or relational information.

LEARNING IN THE COMPETITION MODEL

According to the account of sentence processing sketched out above, the language-learning child must acquire four types of representational structures:

1. The child must be able to code data in terms of the specific semantic and auditory cues and grammatical roles utilized by lexical items.
2. The child must acquire associations between auditory cues, semantic cues, and lexical items.
3. For verbs and operators, the child must add information about the roles they specify and the cues that promote the candidacy of items for those roles.
4. The child must also represent competitions between allomorphs and polysemes and the cues that decide these competitions.

This section examines the ways in which children acquire these structures. Learning of forms moves through four stages. First, the child develops a function to express. We will call this *functional acquisition.* Then the child makes a first stab at a way of mapping the function onto a form. We will call this *jumping in.* Then a period of *competition* ensues during which the range of the form is narrowed or widened. Finally, for some forms, a period of *conflict learning* works to block residual erroneous uses of the form.

Functional Acquisition

Before the child acquires language, he develops a set of things he wants to talk about. These are the functions that underly the forms of language. Lexical acquisition is initially driven by the child's interest in expressing some meaning. As Brown (1973) and MacWhinney (1975, 1978, 1984, 1986) have argued, the child usually develops an interest in the concept expressed by a word before actually acquiring that word. Bates and MacWhinney (this volume) refer to such pre-digestion of the semantics of lexical items as *functional readiness.* In connectionist terms, the acquisition of the function underlying a potential lexical item is achieved by strengthening the links between a set of semantic cues and a central concept node. Later, when the child strengthens the connections of this node to auditory cues, the node that was at the center of the earlier function becomes the central node of the lexical item.

There are a variety of ways in which the child can develop functional readiness for an item. The one-year-old child may have developed a concept of "dog" from repeated encounters with dogs. The child may find that being able to categorize a new animal as a dog is useful in that it helps predict a variety of actions that animals may take, such as barking, jumping, licking, and sniffing. Some months later, the same child may have learned enough language to be able to use terms such as "want" and "gimme." He sees a small stuffed dog among a collection of other stuffed animals and says "gimme." The parent is not sure which animal he wants and says "doggie?" while handing him the stuffed dog. The child is elated. At the same time, he learns to associate the sound "doggie"

with the concept of "dog" that he has used for some months. Or the three-year-old child may be playing the game of naming colors and have just been presented a new color for which he will soon learn a new name. In this case, the gap between the acquisition of the form and the acquisition of the function is much shorter.

In both of these cases, the function is ready before the form is acquired. Seeing a concept realized in the current situation and hearing a sound being produced in association with that concept, the child then associates that sound to that concept. It is important to realize that the child is not searching blindly for forms to express the already-prepared function. He only needs to pay attention to forms when he understands that the adult is focusing on a function for which he does not yet have a name. In the case of the "doggie" example, the child recognized that the stuffed dog was present and that the parent was looking at the dog. If the parent had instead given the child the stuffed alligator he would not have attempted to associate the word /dawg/ to the concept "alligator." The child appears to be assuming that language is constructed so that it provides forms for the ideas that children have in their heads. Clark (this volume) calls this the principle of "conventionality" and holds that the child realizes that "for certain meanings, there is a conventional word or word-formation device that should be used in the language community." Mervis (1984) talks of such meanings as "child-based concepts" and holds that they are often major determinants of the scopes of the meanings of early words. She also shows that such first guesses at word meanings are often too broad. Fortunately, it is not necessary that the ideas in the child's mind exactly match the concepts sanctioned by the adult community. As long as the function is mapped onto a form that is of the right general type, competition will eventually force each concept into its adult-like shape. If the child mistakenly associates the concept "dog" to the form /alligalter/, this association will simply die out altogether and be replaced by the association of "dog" to /dawg/.

Jumping-In

As Carey (1982) has argued, the process of item acquisition is remarkably quick at first. These rough-and-ready "fast mappings" may be inaccurate in many ways, but by "jumping in" to a lexical domain the child is able to make a reasonable first guess that can be fixed up by later learning. The acquisition of a lexical item is the acquisition of a set of connections between auditory cues and semantic cues to a single lexical node. Since every item begins as an auditory-semantic association, the question becomes: How does the child know which auditory features to associate with which semantic features?

Quine (1960, 1977) views this problem as the fundamental problem in language acquisition. If a language learner hears a hunter say "gavagai" while aiming at a rabbit, what is the learner to infer? Should the sound /gavagai/ be

associated with the concept "rabbit" or could it refer to the act of shooting? Might it refer only to a part of the rabbit or the hunter's dismay in not having been able to aim soon enough to have hit the rabbit? How does the child solve this problem? There is no single solution to the problem, but that a variety of factors work together to guide the child toward accurate learning. These factors include: 1) functional readiness on the part of the child, 2) the use of known items as a way of discovering the shape of new unknown items, and 3) the use of competitive learning to weed out incorrect hypotheses. If the child agonized about Quine's problem too much, he might never venture to make lexical associations at all. However, by "jumping in" he establishes a beachhead in unfamiliar territory which can be widened and strengthened by competition.

Finding the unknown within the known. The basic technique that the child uses to make an initial fast mapping of sound to meaning is to attempt to isolate out a part of the incoming signal that is unknown. The child can never be sure that the item he is learning rerers to exactly the referent that he has in mind. Nor does he know in advance exactly how much of the input should be matched to the item he is trying to form. In the worst case, the child must simply connect a whole audition with a complex meaning. For example, given the string *Mommy is coming* or /mamiyɨzkʌmiŋ/ as the first input to the simulation and the propositional structure: (present - -H- -> come - -S- -> Mommy), the child will associate the sound to the meaning and pick up the following lexical item:

Phonology: /mamiyɨzkʌmiŋ/
Semantics: (present - -H- -> come - -S- -> Mommy)

Such early amalgams blur the distinction between the word and the sentence. This is precisely what should happen, since the child has no idea at the outset whether he is trying to learn English with its emphasis on combinations of items into sentences or Greenlandic Eskimo with its emphasis on combinations of items into words.

Because the child does not know how much of the input corresponds to the item he is trying to acquire, the mapping of sound to meaning can be not only fast, but also quite sloppy. As MacWhinney (1975, 1978, 1982, 1986) and Peters (1983) have shown, early forms are full of superfluities, contradictions, and redundancies that come from connecting too much auditory material to a given meaning.

Often the child can use lexical forms he has already acquired to perform a fairly complete analysis of the sentence and thereby make a close guess at the length of the auditory form of a lexical item. If the child has already learned the word "Mommy," then he will directly acquire the item "is coming" from "Mommy is coming." The principle is simple. Because the lexical item "Mommy" rapidly reaches full activation with no competing forms, it is able to

"commit" the auditory cues that led to its activation. The lexical item also commits the semantic cues corresponding to "Mommy." The remaining auditory cues are /yɨzkʌmiŋ/ and the remaining semantic cues are: (come <- -H- - present)). If the child is sufficiently interested in the semantic remainder, he associates it with the auditory remainder and acquires a new lexical item.

Note that, when associating auditory material with a new item, the child will assign ambiguous material to both the known lexical item and the new. For example, in Hungarian, there is a linking vowel that joins the stem to the suffix. In a form such as /ablakot/ the stem /ablak/ "window" can also have a final /o/ attached as in /ablako/. This does not preclude also attaching the /o/ to the final /t/ "accusative" to form /ot/. As Braine (this volume) argues, children appear to maximize the size of the stem in order to gain a maximum ability to predict allomorphic variation. They maximize not only the stem, but also the suffix. This is to say that material between a stem and a suffix is treated as ambimorphemic. The tendency of the perceptual system to treat one auditory group as part of two components is discussed in Menn and MacWhinney (1984) and Stemberger (1982).

Parents can make use of the child's ability to pick up the new within the frame of the old. If the child has learned a few simple sentence frames such as "that's a X" and "look, the man is X-ing that", the parent can rely on this knowledge to present new forms within the context of old. Because the child already understands the old forms, all he has to do is associate the new part of the semantics of the message with the new auditory forms. The more well-learned the frame, the smoother this process. However, it is generally true that the child can use familiar context to delimit the scope of the material for a new item.

Of course, adults can also help the child out by presenting forms in isolation. In such cases, the task of isolating the new is facilitated. If the child only wants to learn the word for "dog" and the parent knows this, an efficacious way of teaching the new form is to present it in isolation as /dawg/. Such a mode of presentation is not necessarily the best. When a form is presented in a frame such as "That's a X," the child can see quite clearly that the new form is a nominal and that it is a common noun. As Katz, Baker, and Macnamara (1974) have shown, children are quite sensitive to the cooccurrence specifications that operate in such frames.

What happens with incompletely analysed forms such as /mamiyɨzkʌmiŋ/ or /yɨzkʌmiŋ/? As MacWhinney (1978, 1986) has argued, such forms will be maintained only if they are useful in terms of lexical processing. Non-analytic or combined forms have a certain advantage over analytic forms in that they are more specific and match more cues than their analytic competitors. However, if they occur too rarely, their connections to cues will be so low that the specificity advantage will not be great enough for them to dominate over their analytic competitors. This means that learners retain rote patterns whenever they are used

frequently enough. This is exactly what Stemberger and MacWhinney (1986) have shown for experimental tasks and speech error analyses with adults.

Competition in Learning

In the section on processing, we saw how competition works to choose lexical items with strong cue support over lexical items with weaker cue support. The same principle of competition also applies to the long-term development of strength in the connections between cues and lexical items. Connections which activate items that win in competitions become stronger and connections to items that lose in competitions become weaker. Connections that are pivotal in determining the correct output are the ones that are favored most by competitive learning.

Competition and Contrast. The Principle of Competition provides us with a powerful way of understanding the control of lexical acquisition. Much like Clark's (this volume) Principle of Contrast or Pinker's (this volume) Uniqueness principle, the Principle of Competition guarantees that the language will not tolerate a situation in which two different forms express exactly the same meaning. Because of competition, full synonymy is not possible. This relation between form and meaning was first proposed by Bolinger (1965) who noted that "when I say two different things I mean two different things by them." Clark (this volume) presents a wide array of evidence showing that children work within the context of this principle of contrast. Clark's analysis seems fundamentally sound. However, there are many times when forms appear to be in free variation in some environments. The competition principle predicts that some variation will occur at the boundaries between forms and in those areas where the cues governing the competition have not yet been discovered. The Competition Model analysis differs from Clark's mainly in the way it allows for predictable deviations from the principle of contrast. Clark views contrast as a constraint on language acquisition, but she does not attempt to explain how this constraint could be implemented in processing terms. In this sense, the Competition Model supplements Clark's analysis by allowing us to understand the processing mechanisms that support the Principle of Contrast.

The Uniqueness Principle and the Principle of Contrast are reflections of a more general principle—the Principle of Competition. Consider a multidimensional grid in which the points in the grid represent a particular combination of values on the semantic cues of the system. For example, one set of cues such as "utensil," "for drinking," "handle," and "cylindrical" might activate the item "mug" in the adult language. If the child codes this intersect of cues with the form "cup," he will place the incorrect form "cup" into competition with the correct form "mug." The correct extension of "mug" will be reinforced

during comprehension. Eventually, after repeated presentation and occasional use in conflict cases, "mug" will come to dominate over the use of "cup" for this particular conjunction of cues. For other areas in the semantic cue space, it is "cup" that will come to dominate over "mug." A similar competition will lead to the elimination of errors in role assignment. The part of semantic space that is used to activate the form "*goed" is also used to activate the form "went." Since the latter form receives more reinforcement in the input, it will eventually come to dominate over the erroneous form "*goed."

The situation is much like that in population genetics. If two species of birds are competing for exactly the same ecological niche, one of the two species will win out and the other species will move into another niche or die out altogether. The niche of the losing species may overlap partly with that of the winning species, but it cannot be an exact overlap. Why must this be true? Because the two species are genetically different, they must also differ in one or more phenotypic characteristics. Each difference has some level of impact on the survivability of the species in each microenvironment of its niche. In some cases the impact will be small, in others it will be large. Each impact will be felt in terms of the ability of the species to compete in a given microenvironment. To the degree the species loses out in many major microenvironments, its overall survival can be threatened. Or, while losing out against its original competitor, it may shift over to competing against new competitors and its entire niche will change significantly. If one species has a thicker beak, it will be able to eat seeds with a tougher shell or husk, perhaps coming to dominate in areas around certain species of trees. However, this thickness of the beak may be a disadvantage in catching small insects and the other species will dominate in areas around ponds and meadows where insects abound.

A similar situation arises in language. Consider two possible past tenses of the verb "weave." We say that the Navajo mother "wove" a blanket for her child. But we say that the basketball player "weaved" his way down the court. The competition between "weaved" and "wove" is paralleled throughout the irregular past tenses. In such situations, allomorphic patterns give rise to competing formations. As Butler and MacWhinney (1983) and Stemberger and MacWhinney (1985) have shown, there is a good chance that even erroneous forms like "keeped" will be stored as lexical items along with forms like "kept." Once they are stored, competition places pressure upon these forms to differentiate semantically.

Competition and cue strength. The initial acquisition of a new lexical item is often just a preliminary first guess at the shape of that item. Both the auditory and semantic connections to that item may be inaccurate in various ways. The child may have only a vague idea about the way the word sounds and what it means. Over time, the child must prune from and graft onto these representations in order to reach forms that emulate the performance of the adult target (Witt-

genstein, 1956). In the Competition Model, the gradual tuning of the connections to lexical items is a fundamental aspect of the developmental process. Unlike models such as those proposed by Anderson (1975) and Pinker (1984), which can learn major sections of the grammar on the basis of only a few examples, learning in the competition model proceeds by small increments, as it does in the child. If the item's shape is basically correct, any remaining inaccuracies can be shaped by competition. If the child finds that "raccoon" competes successfully for referents that he would have called "cat," he learns to restrict the range of "cat" by strengthening connections to "raccoon." Competition serves to strengthen those connections between cues and items that lead to successful usage. As these connections are strengthened, their competitors become weakened by comparison. If the form of an item has been so badly characterized that the item cannot be recognized auditorily or cannot be accessed semantically, then that item will fall into disuse because of the growth of other items.

Cue validity and cue strength. From the viewpoint of developmental psychology and learning theory, the most important claim of the Competition Model is that the primary determinants of cue strength are cue validity and task frequency (MacWhinney, Pleh, and Bates, 1985). Following Brunswik (1956), the Competition Model argues that human beings possess psychological mechanisms that bring them in tune with the validity of cues in their ecology. Cue validity is assessed within a given task domain. For example, the validity of a cue to assignment to the object role is assessed within the domain of sentences that require a decision regarding who did what to whom. This is the domain of transitive sentences. Note that some tasks are very frequent tasks and others are very infrequent. The task of deciding which of two sides of a balance scale has more weight is an infrequent task. The task of deciding who was the actor in a transitive sentence is a much more frequent task. Cue strength will be a function of both task frequency and cue validity in that cues for highly infrequent tasks will be learned later. However, within a given task domain, the major determinant of order of acquisition and eventual cue strength should be cue validity.

MacWhinney (1978) and MacWhinney et al. (1984) analyze cue validity into two components: cue availability and cue reliability. If a cue is there whenever you need it, it is maximally high in availability. McDonald (1984) notes that availability can be expressed numerically as the ratio of the cases in which the cue is available over the total cases in the task domain. If a cue always leads you to the correct conclusion when you rely on it, it is maximally high in reliability. Reliability can be expressed numerically as the ratio of the cases in which the cue is reliable (leads to correct assignments) over the cases in which it is available. Validity can then be defined as the product of reliability times availability. Following McDonald, the Competition Model represents cases where the cue is not available as A, cases where the cue is available but not reliable as B, and cases where the cue is available and reliable as C. Then availability is the ratio of

B + C divided by A + B + C. Reliability is the ratio of C divided by B + C. Validity is then defined as the product of availability times reliability. Since the B + C term cancels out when multiplying reliability times validity, validity becomes the ratio of C divided by A + B + C. This is precisely the way one wants to define validity, since this is the ratio of cases that are available and reliable over the total cases.

These notions can be illustrated by looking at how validity works for the cue of preverbal positioning in English. This cue is an excellent guide to assignment of a noun phrase as the subject. The cue is present in almost all sentences and almost always correct (except in structures like the passive). The cue of agreement with the verb is not so highly valid. It is only available when there is a competition between two nouns and when those two nouns differ in number, as in "The dogs are chasing the cat". As MacWhinney (1978), MacWhinney et al. (1984), Sokolov (1986), and McDonald (1984) demonstrate, both availability and reliability can be calculated from studies of the input of the language learner.

Learning on conflict. So far, we have painted a picture of a child who focuses only on what is right, hoping thereby that errors will be choked out by correct forms. For the young child, this picture is generally accurate. However, as learning progress, it is clear that the child pays more and more attention to the conflicts between clues. Both McDonald (1986) and Sokolov (1986) find that, for young children, cue validity is an excellent predictor of cue strength. However, this prediction is best during the initial stages of cue learning. As learning progresses, the best predictor of learning becomes what McDonald (1984) has called conflict validity, rather than simple cue validity. Conflict validity is the validity of the cue in those particular instances where it conflicts with other cues to the same role. For example, case-marking conflicts with word order in a sentence such as "the dogs saw she." In English, this conflict is resolved in favor of word order and the sentence is given an SVO interpretation, but in Dutch the corresponding sentence is resolved in favor of case-marking and is given an OVS interpretation. Such conflicts between case-marking and word order are rare even in Dutch. Because they are so rare, it is difficult to estimate their frequency from text counts. Because children have not yet been exposed to many such conflicts, the strength of cues in their system is more determined by overall cue validity than by conflict validity. Indeed, Sokolov (1986) has shown that the intial strength of cues to identification of the object in Hebrew correlates at .96 with overall cue validity but that the strength of these cues in adults and older children correlates better with conflict validity.

Let us distinguish two basic types of learning: *positive learning* and *conflict learning*. Positive learning simply involves the strengthening of individual forms. If, by their nature, strong forms come to dominate over weaker forms, this is simply a by-product of positive learning. For example, in a garden one can plant ivy and nasturiums. Because the ivy grows so vigorously, it will eventually choke off sunlight to the nasturiums. In this way it will come to dominate without

there being any direct "blocking" relation between the two plants. In conflict learning, on the other hand, there child learns a specific link between two forms such that, when form A occurs, the use of form B is specifically blocked. This occurs because activation is siphoned off from form B to form A. For example, if the child has learned a blocking relation between "*breaked" and "broke", then when underlying analogic system for past tense formation produces "*breaked," the specific connection between "*breaked" and "broke" siphons activation off from "*breaked" to "broke." In this way, the child does not have to rely solely on the strength of "broke" as a way of preventing usage of "*breaked."

Alternatives to conflict. When the child is faced with competition between two forms, he must either set up a way of blocking one of the forms or try to find a use for it. When the child first hears the word "animal" used to refer to a dog, he initially senses a conflict between the words "animal" and "dog." In the Competition Model, this conflict leads to a period of free variation. During this period, the child is receptive to any data that can distinguish the two forms. In this particular case, the child will also hear "animal" being used to refer to cats, mice, and horses. During this period, the word "animal" is competing with a variety of forms. However, it is also gaining strength from those features with are shared by cats, mice, dogs, and horses. This then leads to the formation of a concept which expresses the shared features, but which loses out when the child wishes to express more detailed features. In this way, the child uses competition to acquire superordinates (Callanan, 1982; Rosch, 1977).

Conflict can also arise between a subordinate term such as "dachshund" and a basic-level term such as "dog." Again, the child allows the forms to coexist for some time as variants. During this period of probation, the form "dachshund" gains support from features such as "short" and "long-eared." This allows the form to carve out a niche *vis a vis* "dog," so that when the child sees a dog that is clearly a dachshund and wishes to emphasize its exact identity, he uses "dachshund" rather than "dog." However, if the child is talking to a friend, and the friend has only one dog, he asks, "What's your doggie's name?" rather than "What's your dachshund's name?"

Teaching and competition. Competition is at the heart of the didactic interactions that occur between children and their parents. Recent work by Bohannon, Stanowicz, Ness, and Warren-Leubecker (1986), Hirsh-Pasek, Trieman, and Schneiderman (1983), Demetras and Snow (1986), and Ninio (1986) indicates that parents are indeed quite sensitive to the well-formedness of their children's speech. Ill-formed utterances are more likely to elicit recasts and repetitions of a variety of types. The exact shape of the recasting depends upon the nature of the error in the ill-formed utterance. It appears that the parent's didactic method is based on the application of the Principle of Contrast. When

the child makes a phonological error, the parent can usually retrieve the meaning of the utterance. The parent can then repeat the utterance in the correct shape. This reinforces the correct pronunciation of the form and, by competition, decrements all alternative pronunciations. When a referent is named by the wrong nominal, the parent again often knows what the real referent is and can simply rename it with the correct term. In the competition framework, by providing one positive instance for the correct form-function mapping, the parent implicitly provides many negative instances.

The parent's problem is somewhat more serious when the child makes a complex error or when he makes several errors in one sentence. In such cases, the parent may not be able to retrieve the child's meaning at all. Without retrieving the meaning, it would be risky to recast the child's form, since that might amount to teaching the child the wrong form-function mapping. In practice, when there are several errors or when there is a complex error, adults do not recast the child's sentence, but instead use clarification attempts in order to make sure what it was that the child meant to say (Bohannon et al., 1986).

Problems for competition. Bowerman (this volume) points out several possible problems for a Competition Model account of language learning. First, Bowerman wonders how the Competition Model can account for the emergence of the understanding that a form such as "*breaked" is incorrect and that the correct form is "broke." Perhaps Bowerman is suggesting that the child does not simply beef up the strength of "broke" on the basis of positive instances, but also actively suppresses "*breaked." In fact, the Competition Model recognizes the importance of learning based on conflict, particularly in the later stages of the acquisition of precise distinctions between forms and meanings. As MacWhinney (1978) and McDonald (1986) point out, at least some aspects of learning must be driven on the basis of the detection of error. However, young children's intuitions regarding the correctness of competitors such as "*breaked" and "broke" are often very vague. From the age of 3 until the age of 6, my son Mark could not reliably distinguish correct from incorrect past tense forms of irregular verbs and made many errors in past tense usage in spontaneous speech. After age 6, he continued to make some errors, but his ability to judge a particular form as correct was close to the adult level. As Bowerman suggests, it may be experience with conflicts between the forms that leads to the firming up of judgments of acceptability. Such conflicts are recognized by the Competition Model as fundamental for learning (MacWhinney, 1978).

Bowerman also cites some erroneous forms for which she believes there are no real competitors. She claims there is no well-formed competitor to "*Who did John overhear the statement that Mary kicked?" Although there may be some debate on this matter, many speakers would use the sentence "John overheard the statement that Mary kicked WHO?" to express this meaning. Perhaps the problem here is that it is hard to imagine when one would ever want to say

anything like this. But, if people did start saying things like this, listeners would simply have to learn to treat "overhear" in the same way they treat "believe" and "say," i.e. as cues to the continuation of the search of a "visitor" for a role in its home clause.

Along a similar line, Bowerman wonders how children ever decide to stop using "disappear" as a causative, since she believes that the conventional way of saying this ("make disappear") is not in direct competition with causative "disappear." Here, the problem is that, in fact, the semantic range of a periphrastic form such as "make stand up" actually includes that of a lexical causative such as "stand up." Whenever we say that we "stand the doll up" we can also say that we "make the doll stand up." The reverse is not the case. For a lexical causative to dominate over the periphrastic causative, it must be continually reinforced by being heard in the input. If it is not, the periphrastic will simply take over, much as grass will take over an untended flower bed. Bowerman claims that "*unsqueeze" has no direct competitor, although forms like "release" and "ease up" overlap on its semantic domain. Again, here is a situation where the range of the competitors is so wide (particularly that of "release") that, without reinforcement from the input, the erroneous form "*unsqueeze" will simply die out. The problem of "unlearning" errors in Dative Movement is basically the same as the other problems Bowerman raises. The child may say "I said her no" or "I'll brush him his hair." But, for these forms to survive the child must record the indirect as a central argument of the verb. In fact, the input does not support this addition to the lexical items "say" and "brush" and the child's innovation will die out like a flower that is not watered. Bowerman is correct in pointing out that a full suppression of these errors may require more than simply positive instances. Whenever a child makes an error that is not supported in the input, he does so on the basis of some regularities that he perceives in the lexicon. These underlying pressures will always be there and they may well lead to a continuing attempt to produce the overgeneralization. When other forms compete less directly, it may be necessary for the child to go to some extra work to block production of these overgeneralizations, as suggested by MacWhinney (1978) and McDonald (1986). The crucial point is that the child's initial approach is to rely on overall cue validity as a way of organizing language. But, the Competition Model emphasizes that in some areas, the child will eventually have to rely on conflict validity rather than overall cue validity.

The Acquisition of Role Structure

In order to acquire the role structure of predicates, the child must establish and strengthen (1) the connections between predicates and the roles they specify, (2) the connections between predicates and specific case relations, and (3) the connections between cues and the roles and cases they support. The first two types of

learning are "role acquisition" and the third type of learning is "cue acquisition."

Role acquisition. Consider the verb "give." The child must establish and strengthen a connection between "give" and the subject, object, and indirect roles. He must also learn connections from "give" to specific case roles such as "giver," "transferred," and "recipient." For the passive and the dative passive, the subject role takes the case role of "transferred" or "recipient." When the child hears "Bill gave a tomato," he sees Bill giving a tomato to Hank and assumes that "Bill" is the subject and that "tomato" is the object. He also judges "Bill" to be the "giver" and the "tomato" to be the "transferred." In the Competition Model framework, the acquisition of roles is not a particularly difficult matter. The child uses situational cues to guess at the role for each nominal. The first few such guesses set up a connection from the predicate to its arguments. The acquisition of case roles occurs in a similar fashion.

Psycholinguistics has paid a great deal of attention to the acquisition and use of the passive. In the Competition Model account, the child faces two problems in learning the passive. One is that of isolating a discontinuous morpheme with two parts that both show extreme allomorphic variation. The second problem is that of associating the use of this cue with the correct case role or set of case roles for the noun that precedes the auxiliary. When learning the passive, the child has to learn a case interpretation that always competes directly with the standard actor interpretation of the subject. He must connect the passive morphemes to this alternative case role interpretation to insure that it can win in the competition. In the dative passive ("John was given a flower by Fred."), the child must learn that the subject can also be a recipient. These additional case roles for the subject must be entered one-by-one into each lexical form. The conservativeness of the generalization of verb frame patterns process in language acquisition is well-documented (Fodor and Crain, this volume; Maratsos, this volume; Roeper, this volume; Mazurkewich and White, 1984). Thus, it appears reasonable to suppose that these case role options are connected to each verb one-by-one. At the same time, it is clear that verbs form semantic groups in terms of the argument types they take. In our current account, these semantic groups exert an underlying pressure on the system which tends to keep individual verbs in line with the overall pattern. However, the child is also careful to note the grammatical and case role combinations for each verb individually. If a particular argument has not yet been encountered, the child could comprehend its use by reference to the underlying semantically-based system. But, in production, he would be guided chiefly by information stored on the verb itself.

Like Wexler and Culicover (1980) and Pinker (1984), The Competition Model assumes that the child has some representation of the meaning of the sentence that guides him in acquiring grammar. However, these other authors must assume that the child has complete trees of phrase-structure representations

of the entire base or deep structure for each input sentence. This strong assumption is probably not defendable. Although the child may well construct some semantic assignments on the basis of his understanding of the situation, it is not clear that he continually builds complete dependency trees or that the representations he does build look much like deep structure. The Competition Model account makes fewer assumptions about such unobserved processes going on in the child. It only assumes that the child can at least occasionally assign arguments to roles. The assignment of a single argument to a role does not require the building of a complete tree for the entire clause. It only requires a link between the argument and its predicate.

Cue acquisition. The acquisition of connections between cues and roles is a more difficult task. The problem with cues is that the child does not know initially what should count as a cue. Potentially, anything in the clause could be a cue. Indeed, there could be cues that would involve all sorts of bizarre combinations such as "the nucleus of the second syllable on the word three before the candidate word if there is a /p/ at the end of the word at the end of the clause." In fact languages never make use of such bizarre cues. If the language did make use of such a cue, the child might not be able to learn it. In other words, the system for cue learning is structured so that only certain types of cues can be learned. As suggested by MacWhinney (1978a, b), cue acquisition occurs through the sifting out of commonalities that is the hallmark of competition. In other words, whenever the child encounters a competition that needs to be predicted by cues, he records the cue environment of each positive instance. Those cues which are repeatedly encountered across instances are the ones which survive the competition and become strong.

The recording of the cue environment of each positive instance is the computational bottleneck of the cue acquisition process. To streamline movement through this bottleneck, the child classes cues into four types:

1. **Positional Cues:** The child records the position of the argument vis a vis the head.
2. **Auditory Cues:** The child records the segmental and suprasegmental phonological properties of the argument.
3. **Semantic Cues:** The child records the semantic concepts that describe the argument (as discussed earlier).
4. **Lexical cues:** The child records the lexical identity of all the operators on the argument as well as all the operators on any predicate to which the argument is bound.

The child is trying to figure out how to identify a given argument and he is tracking cues that can be used to identify that argument. For example, the child is

learning that stressed words are likely to take the focus role or that animate nouns are strong candidates for the subject role. Only in the case of lexical cues is the child tracking not just information about the argument itself, but also information attached to the predicate to which the argument attaches. If the child were not tracking such secondary lexical information, he could not acquire agreement cues.

Allomorphic Acquisition

The child must also acquire competing allomorphs and the cues for selection between allomorphs. When the child finds that a single meaning takes on two articulatory forms, he associates each articulatory form to the meaning. Each phonological variant that appears in the surface is stored in its full surface form. Just as in syntactic learning, the cue acquisitionl mechanisms must acquire cues to determine the choice of one allomorph over the other. These cues can be:

1. **Auditory cues:** The mechanism records the auditory cues of the item and of its head. For example, the presence of a final /e/ on a stem in German activates choice of feminine markers.
2. **Semantic cues:** The mechanism records the semantic cues of the item and of its head. For example, the presence of the semantic feature or cue "tree" on a stem activates choice of feminine markers.
3. **Lexical cues:** The mechanism records the lexical items attached to the head. For example, when the suffix "-keit" is attached to the head, this activates feminine articles, pronouns and suffixes in German.

As in the learning of cues to roles, the learning of cues to allomorph selection requires that the child be keeping track of these three basic types of predictors. The only difference between articulatory cue tracking and role cue tracking is that there is no need to track the shape of arguments of the head for allomorphic decisions.

Underlying Pressure

Both the selection between allomorphs and the use of particular arguments on the verb can be influenced by underlying pressures in the lexicon. Even if the speaker has never used an indirect argument with the verb "tap," he could say "LeMieux tapped Johnson the puck" when describing a hockey game. Similarly, after we have learned a new verb such as "obfuscate," we can immediately produce a past tense form such as "obfuscated" without having firmed up a direct connection between "obfsucate" and "-ed." This kind of role and allomorphic productivity is based upon an underlying system of connections of the type described by Rumelhart and McClelland (this volume) for allomorphy and McClelland and Kawamoto (1986) for roles.

Form-Driven Learning

In general, functional learning precedes formal learning. However, this is not always the case. As the child's vocabulary grows, he starts to comprehend more and more of the speech he hears. As this known material grows, the size of the unknown begins to shrink. This means that unknown material begins to stand out more clearly. When a small stretch of auditory is clearly unknown, the child may then provisionally think of that auditory material as a lexical item to which he has not yet connected a set of semantic cues.

Having decided entered this new lexical item, the child can then proceed directly to attempt to figure out what the item means and what arguments it takes. To do this, he looks at the role frames for the item in the current clause. For example, given a sentence such as "The man niffed the plate at the fence," coocurrence learning can abduce facts about the arguments of "niff" and some of its semantics. The child does this by attending to the underlying system of connections between semantics and verb frames described by McClelland and Kawamoto (1986). This system tells us that "niff" takes a subject and an object and that the action of the subject on the object is like that in "hit" and "slam."

The importance of a mechanism of this type has been stressed by MacWhinney (1978), Maratsos and Chalkley (1980), Bowerman (1982), and Schlesinger (1977). Bates and MacWhinney (1982) stressed the importance of functional characterizations of role-relational classes. There is evidence that even very young children are able to infer the class of a word from cooccurrence data. For example, Katz, Baker, and Macnamara (1976) found that, beginning around 17 months, girls who were given a proper name for a doll learned this name better than girls who were given a common noun. In the proper noun frame, girls were told that the doll was called "Zav"; in the common noun frame they were told that the doll was "a zav." Thus, even at this early age, children seem to realize that names with articles are common nouns and names without articles are proper nouns. This ability to infer the semantics of words on the basis of cooccurrence continues to develop. By age 8, Werner and Kaplan (1950) were able to show in their classic "corplum" experiment that children could acquire many aspects of the semantics of abstract nouns from highly abstract sentence contexts.

This chapter has shown how the Competition Model provides an account of the acquisition of the grammar and the lexicon. The account has focused on the ways in which cues interact to determine competitions between lexical items in auditory, semantic, relational, articulatory, allomorphic, and polysemic processing. The key constructs in the model have been *competition* and *cues*. The notion of grammar presented by the model is a not the standard account of generative transformational theory. However, from the viewpoint of psycholinguistics and cognitive psychology, the account is fairly orthodox. It would be a mistake to think of the Competition Model as a "performance model" distinct from some other, more formal "competence model." Rather, we should think of the Competition Model as a "processing model"—one which focuses on the psychological status of sentence processing.

We have attempted to keep the model consistent with the facts of both linguistic analysis and psychological experimentation. If we are correct in claiming that the processes used in language acquisition and language processing are not unique to language, then it should be possible to extend the Competition Model to other areas of cognitive development. This would be the major pay-off of our attempt to achieve cognitive generality. In fact, the developmental and cognitive literature is rich with competition-like models and accounts. The strategy-choice analyses of Siegler (Siegler 1986, Siegler & Shrager, 1984) and the information-integration approach of N. Anderson (Anderson & Cuneo, 1978) can be seen as applications of competition-type models to non-linguistic domains. Competition accounts are fundamental in much of the research on prototypes and fuzzy categories (Rosch & Mervis, 1975; 1976). One can find competition in infant search behavior (Sophian, 1984), visual-auditory cross-modal processing (Massaro, 1985) phonological processing (Massaro and Cohen, 1983, Menn & MacWhinney, 1984; Scott & Cutler, 1984), and competition can provide a useful characterization of data from studies of concept identification (Palermo & Eberhart, 1968). Well-articulated understandings of competition or both stimuli and responses can be found throughout the perceptual literature and the conditioning literature. The phenomenon of response competition is common to many associationist accounts such as those of Hull (1943) and Hebb (1949). Early cognitive Competition Models can be found in Herbart (1816) and Freud (1898). It is clear that the Competition Model has firm roots in psychological theory.

Although we see many parallels to the Competition Model elsewhere in cognitive development and psychology as a whole, few of these models use exactly the same constructs presented in the current paper. In extending the model to these new domains, there are particular questions to ask. How can we construct a task analysis of these other domains that properly reveals the types of cues the child uses in learning and decision-making? Can one construct competition-based accounts for highly "serial" skills such as computer programming or long division? Will the Competition Model be able to provide ways of dealing with strategy selection and hypothesis testing? By extending the model in these ways we will learn much about these new tasks and we will learn a great deal about the model itself.

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