

# Toward a Psycholinguistically Plausible Parser

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Child language researchers understand that a successful theory of language acquisition must be firmly rooted in linguistic theory. However, it is not clear that current competence-based grammars can be used to provide accurate characterizations of the learning process. These formalist approaches to language structure have the advantage of being carefully stated and fully generative. Their disadvantage is that they tend to force the language acquisition researcher into making a series of nativist assumptions that are seldom supported by the empirical data. The major alternative to formalist theory is functionalist theory (Dik, 1978; Foley and Van Valin, 1984; Givon, 1979). A strong point of functionalism is its emphasis upon the predictability and reasonableness of grammatical markings. However, a major weakness of current functionalist theories is the fact that they are not stated in a way that leads to concrete predictions about language processing. The goal of the present work is the formulation of a process-oriented functionally-based system that can serve as the basis for models of language comprehension, production, and acquisition. Stated more succinctly, the goal of this research is the formulation of a functionalist process model. Until such a model is fully formulated, the current controversies between nativism and empiricism and between formalism and functionalism seem largely premature. After a full process model has been fully formulated, it may well turn out that some of the issues currently being debated will be supplanted by newer more detailed issues.

The current model is called the Competition Model. Empirical work supporting the model has been reported in some 15 journal articles summarized in Bates and MacWhinney (1987). This research emphasizes cross-linguistic and cross-group comparisons. Languages studied include Chinese, Dutch, English, French, German, Hebrew, Hungarian, Italian, Japanese, Serbo-Croatian, Spanish, and Turkish. Subject groups include children of varying ages, normal adults, aphasics, second language learners, and bilinguals. The theory underlying the process model has been developed in MacWhinney (1978, 1982, 1986, 1987). The underlying linguistic representation is strongly lexicalist, using a parser that is bottom-up and cue-driven to construct a dependency graph, rather than a standard parse tree. The lexical item is the main controller of every aspect of both parsing, generation, and acquisition.

The main idea underlying the Competition Model is that mental processing is competitive in the classical Darwinian sense. In the biological world, each species becomes adapted to a particular niche or habitat. In that niche, it competes with other members of its species, while also cooperating in the competition against other species. The habitat of each species is tightly controlled by the abilities and peculiarities of competing species, of predators, and of species that serve as food sources. The mental world also demonstrates this tight, interlocking dependency. However, in language processing, the unit of competition is not the species or the individual, but the lexical item. The domain of each word is shaped both by the meanings and sounds to which it responds and by the response range of the lexical items with which it competes. When we process sentences, each lexical item sets up expectations for other lexical items. When processing is successful, these expectations interlock tightly. However, as in natural systems, there is always some variation in the system which can occasionally lead to error.

In this paper, we will first look at how lexical competition controls comprehension. When examining competition in comprehension, we will focus on 1) the initial competition between items that leads to segmentation of the speech stream, 2) competition for assignment to grammatical roles and for phrasal attachments, and 3) competitions between polysemes. Then we will turn our attention to the competition that occurs during production. There we will examine 4) competition during the packaging of semantic

intentions into lexical items, 5) morphophonological competition between allomorphs, and 6) the competition of articulatory commands for compilation during speech production. Finally, we will examine 7) how competition relates to cooperation and 8) how competition works during learning.

## 1. Comprehension: lexical competition controls segmentation

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 accumulate 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, and Cooper, 1980; Cooper and Paccia-Cooper, 1980; Wolff, 1975) 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 the major 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 "daddy is coming" which can be rendered in the UNIBET system of MacWhinney (1986) as /d&dilzkVmIN/. Let us imagine a child lexicon which includes the lexical item /d&di/ "daddy", but not /lzkVmIN/ "coming." The item /d&di/ will match segments 1 through 4. The remaining material will be tagged as not lexicalized and the child will attempt to learn its meaning to add to his lexicon. Schematically:

d	&	d	i		I	z	k	V	m	I	N
daedi											unknown

Or consider the recognition of /bVni/ "bunny". Here, the child might have the lexical items /bVrV "bun" and /ni/ "knee" and could conceivably segment /bVni/ into /bVn/ 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.

In the computational simulation of the Competition Model, each item in the lexicon is exhaustively checked against each input. The program then attempts to piece together those words which see themselves in the input into complete segmentation slates. There may be several such complete slates. In that case, the competition between the slates is left to syntactic processing. In the current simulation, segmentation is done for each utterance as a complete input. Of course, segmentation really moves across the input in a left-to-right fashion. However, the serial nature of computer hardware makes repeated exhaustive checks of the lexicon a slow process. If the hardware ran in parallel, this process would be extremely quick.

The exact fit of the lexicon to the input is often rather sloppy. In real life, the signal is often noisy. When the child cannot find an exact match between the lexicon and the input, he may settle for some close match. The sloppiness of the matching process often displays itself later, when the child uses a form that appears to have been misperceived or misanalysed. For example, instead of "screen door" the child may say "scream door." Given that mother and father stand at this door and yell out to the child on occasion, this may not be a totally unreasonable segmentation. Or, the child may say "on your market, get set, go" instead of "on your mark, get set, go." Not having the form "mark," it makes more sense to segment the new phrase with the known word "market." Many other "perceptual malapropisms" of this type are reported by Fay and Cutler (1977). Lexical

effects on segment detection have been demonstrated by Ganong (1980) and McClelland and Elman (1986). MacWhinney, Pl6h, and Bates (1985) go yet further and show that, when the auditory signal is unclear, syntactic expectations can influence lexical activation. In all of these cases, it is clear that the segmentation mechanism is tolerant of a certain sloppiness of match between the input and the lexicon.

## 2. Comprehension: Role competition controls attachment

As segmentation progresses, lexical items become activated. Once activated, each item generates expectations for other items which will link together with it in particular grammatical roles. As these links begin to form, the overall structure of the sentence begins to emerge. Just as alternative segmentations compete during processing, so alternative role attachments compete. The processor attempts to develop a relational structure that provides the best possible fit between items and roles. Semantic interpretation works upon this structure interactively, just as the development of the interpretation works interactively with segmentation.

### Roles

To begin our discussion of roles, consider a verb like "pet." This predicate expects to be linked to two arguments: a "petter" and a "pettee." These argument roles for the verb "pet" constitute its "valence description" (Tesniere, 1959; Fillmore, 1986). The primary roles are "opened up" by predicates and "filled" by arguments. 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 of 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.

Before looking at further examples of dependency structures in the Competition Model, we first need to examine the varieties of grammatical roles recognized in the model.

1. Subject: This is a central argument of the verb, it is defined functionally as in MacWhinney (1977).
2. Object: This is the second central argument of the transitive verb. It is defined functionally as the entity most involved in the activity or state of the verb.
3. Indirect: In English some verbs such as "give" have this as a third central (unmarked) argument. It is the secondary perspective or the indirect object.
4. Final: Many transitive verbs permit an optional resultative which also serves as a central (unmarked) argument in English, as "black" in "he painted the wall black."
5. Head: The head relation is actually a broad class of relations between descriptors or modifiers and the things they describe. It holds between an adjective and the noun it modifies, between a prepositional phrase and the noun to which it attaches, between a relative clause and its head, and between a noun and another noun that describes it (sometimes in an appositive relation and sometimes with a copula). Adjuncts of the verb or circumstantials also have verbs as their head. Sometimes these arguments are adverbs which simply attach to the verb. Sometimes they are prepositions which attach in two directions. First, they attach to the object of the preposition. Then, the whole preposition phrase attaches to

the verb, as if it were an adverb. A few verbs, such as "put" or "live" take obligatory locative arguments. Usually modifiers are optional and their attachment is left as a job for the preposition.

6. Complement: Various cognitive verbs and modals take allow whole clauses to serve as their objects and subjects.
7. Coordinate: The item or phrase coordinated to another item or phrase.
8. Topic: The item the sentence is "about."
9. Focus: Any contrasted element.
10. Antecedent: The item to which a "phoric" element points.

The central roles of subject, object, indirect, final, and head are further differentiated for case. Thus, the subject may be an agent, a patient, an initiator, a recipient, an executor, an actor, an experiencer, or a complement. The object may be a patient, a stimulus, a product, or a complement. The indirect may be a recipient or a beneficiary.

Each verb has a connection to a particular set of grammatical roles along with their associated case roles. For example, the verb "give" has a connection to a subject, an object, and an indirect. The cues for the subject of not just the verb "give" but of all verbs in English are preverbal position and number agreement. All the verbs of the language are connected to this role and, through it, to the correct cues. The cue for the object is postverbal position. The cue for the indirect is prepostverbal position. The case roles associated with these grammatical roles are actor, transferred, and recipient. A verb like "hit" also has a connection to an actor subject. But its second connection is to a patient object, not a transferred object.

Many of the connections from predicates to roles are semantically predictable. For example, concrete action transfer verbs such as "give," "pass," and "throw" can all take a recipient indirect. However abstract transfer verbs such as "recommend" and "donate" do not follow this same pattern. Verbs like "fill" that focus on the goal as the object generally place the material being transferred into a "with" phrase, as in "Paul filled the tub with water." On the other hand, substance movement verbs like "pour" that allow the material to serve as the object must then treat the goal in a locative phrase, as in "Paul poured the water into the tub." In some cases this predictability of features is exceptionless. In other cases, it runs up against specific lexical exceptions and preemptions from existing items. In the Competition Model, the inclusion of arguments on the basis of semantic cues is a tentative process, stimulated by connections in the lexicon (McClelland and Kawamoto, 1986). The child does not fully confirm these arguments until they are also attested in the speech of adults.

## **Role Competition**

As I mentioned earlier, the empirical work upon which the model (Bates and MacWhinney, 1987) is based has been performed in many languages. Some of our collaborators in this research include: Edith Bavin, Antonella Devescovi, Angela Friederici, Michele Kail, Kerry Kilborn, Reinhold Kliegl, Janet McDonald, Sandra McNew, Judit Osman-Sagi, Csaba Pleh, Stan Smith, Jeffrey Sokolov, and Beverly Wulfeck. This work has shown that languages differ markedly in the strengths they assign to basic grammatical cues. In English, the cue of preverbal positioning is the strongest cue to identification of the subject role. Given a sentence like "The eraser are chasing the boys," English-speaking subjects show a strong tendency to choose "the eraser" as the subject and, hence, the actor. This occurs despite the fact that the noun "boys" has the cues of verb agreement, animacy, and humanness all on its side. These three weak cues are just not enough to counterbalance the strength of the preverbal position cue in English. In Italian, however, the situation is quite different. There, the corresponding sentence is *la gomma cacciano i ragazzi* in which *la gomma* "the eraser" has support from the cue of preverbal positioning and *i ragazzi* "the boys" has support from the cues of agreement, animacy, and humanness. As Bates, MacWhinney, Caselli, Devescovi, Natale, and Venza (1984) show, agreement is a much stronger cue in Italian than it is in English. In Italian, the strongest cue is verb agreement and the second strongest cue is preverbal positioning. Thus Italians interpret this sentences as meaning "The boys are

chasing the eraser."

## How competition works during processing

The parser for the Competition Model is designed to take the cue strengths estimated in these empirical studies and use them to control the operation of the parser. The parser moves through the utterance from beginning to end, activating lexical items as it goes. As soon as an item reaches a threshold for activation, its arguments also become activated and the parser begins to search for candidates to fill the argument roles. The cues supporting this filling include word order, grammatical markings, prosodic cues, and lexical class information. Non-configurational languages like Warlpiri and variable word order languages like Hungarian receive a straightforward treatment in the Competition Model, since assignment of arguments to roles in these languages is primarily based on cues provided by grammatical markings, which are on an equal footing with word order cues.

The parser is basically driven by the attempt to instantiate the arguments of each predicate. A sentence parses successfully if all expectations are instantiated and no argument is left unattached. In a sentence such as "\*John gave Bill the key Frank," the word "Frank" is extra material that does not attach to any other argument. In a sentence such as "\*John put the plate," there is a missing argument, since it is not clear where John is putting the plate. Following Fillmore (1986), the parser allows arguments to be instantiated in five different ways.

1. Direct Instantiation: Arguments may be instantiated directly in the clause currently being processed.
2. Coinstantiation: Arguments may be coinstantiated as arguments of higher clauses in complement constructions.
3. Extraposition: Arguments may be instantiated through extraposition.
4. Distant Instantiation: Arguments may be instantiated at a distance through "raising."
5. Null Anaphora: Finally, some arguments may be ellipsed under specified conditions for anaphoric identification.

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:

```
-8 IH I (a <-H-> (young -H-> soldier)) <-O-> like <-  
S-> Mary  
  
I  
IH  
reall  
Y
```

The labels S, O, and H on the nodes represent the subject, object, and the head, respectively. Double headed arrows indicate covalent bonds and single headed arrows indicate ionic bonds. In this structure, "Mary" plays the subject role and the phrase "a young soldier" plays the object role. These two arguments are bound to the verb covalently, since nominals expect to be the arguments of verbs and the verb "like" is looking for two arguments. "Really" takes the verb as its head. "Young" takes "soldier" as its head and the phrase "young soldier" is the head for the operator "the." The noun "soldier," like all common nouns, generates an expectation for a determiner such as "the" or "a" and this expectation is taken over by the phrase "young soldier" in accord with the principle of inheritance from head to phrase. When "the" attaches to "young soldier," a covalent bond is formed from the expectation of "the" for a nominal and the expectation of the nominal phrase for a determiner.

Now let us look at how this structure is pieced together during processing. First the child lexicalizes "Mary." Since "Mary" is a proper noun, it does not expect any modifiers, but it does expect to fill some role vis a vis a verb. At this point, "Mary" with its unfulfilled

expectation constitutes the "fragment pool" of activated items that are not yet bound to verbs. "Mary" is the only item in that pool. Next, segmentation moves on to lexicalize "likes." This verb expects a subject in pre position and an object in post position. Whenever a new item is lexicalized, all of the currently unattached items in the fragment pool become possible candidates for the roles expected by that item. Since "Mary" is a noun in pre position, and since it expects to be the argument of a verb, a covalent subject role bond is formed between "Mary" and "likes." There is no competition for this role, so the binding is fairly strong. Next segmentation lexicalizes the determiner "a" and the adjective "young" which both expect a following noun. Until "soldier" is lexicalized, these two items remain unbound in the "fragment pool." 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 roles are filled and all items are attached. The trace for this processing is as follows:

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

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

The symbols Arg' and H' in this trace indicate that an item expects to be the argument of a verb or the head of some determiner.

As a further example of how parsing works in the Competition Model, let us consider the processing of a sentence with a center-embedded relative clause such as "the dog the cat chased ate the bone." First, the unattached units "the dog" and "the cat" are built. The next item is "chased" which opens up argument roles 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 "ate" which opens up subject and object roles. There is no simple item in preverbal position, so the "clustering" procedure works to take all the material in preverbal position as a unit. To do this, "the dog" is taken as the head of relative clause (RH) which places it in the role of the "described" and which inserts it as the object of "chase." 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	
dog	Arg'.H'	-	the<-H-->dog
the	Head	post.N	
cat	Arg'.H'	-	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) <--D- (the cat <--S--> chased <--O-> =RH)) <--S--> ate			
the	Head	post.H	
bone	Arg'.H'	Arg'.H'	the <--H--> bone
Final: ((the <--> dog) <-D- ((the <--> cat) <--> chased <--> =RH)) <--> ate <--> (the <--> bone)			

## Prepositional phrase attachment

A particularly well-studied type of role competition is for the role of the head of the

prepositional phrase. Consider a sentence such as "The women discussed the dogs on the beach." We can interpret this sentence as saying that the dogs are on the beach or as saying that the women engaged in a discussion on the beach. In the former case, the head of the prepositional phrase is the nominal. In the latter case, it is the verb.

The psycholinguistic literature investigating such sentences is fairly large. Frazier and Fodor (1978) have used subjects' supposed preference for attachment of prepositional phrases to the verb as support for the Sausage Machine model of sentence processing. Oden (1978) has pointed out that a resolution of the competition between alternative parses requires use of the full real-world context described by the sentence. Ford, Bresnan, and Kaplan (1982) have shown how an LFG parser can handle attachment by following principles of local attachment and thematic control. The Competition Model approach to attachment is most similar to the approach of Ford, Bresnan, and Kaplan. It differs from that approach primarily in the importance it assigns to the preposition as an independent source of activation and in the emphasis it places on competition.

In the Competition Model, prepositions first attach to their heads yielding prepositional phrases. These phrases then attach to an external head which may be either a verbal or a nominal phrase. In cases of "local" attachment the prepositional phrase attaches to the preceding nominal. In "distant" or "minimal" attachment the prepositional phrase attaches to the verb as a verbal adjunct or "circumstantial" specifying the location, time or manner of the verb. The interpretation of the prepositional phrase as a circumstantial is supported by the presence of an expectation from the verb for a certain type of circumstantial. For example, the verb "put" has a very strong expectation for a locative goal; the verb "position" has a somewhat weaker expectation; and the verb "break" has a yet weaker expectation. Thus, in the following three sentences, attachment of the prepositional phrase to the verb is increasingly less likely:

1. The woman put the vase on the table.
2. The woman positioned the vase on the table.
3. The woman broke the vase on the table.

However, as in Bock (1986a, 1986b), the expectation for a verbal attachment can be primed by being used in a previous utterance, as in "The man picked up the pitcher and broke it onto the table. Then the woman broke the vase on the table."

Relative pronouns also such as "who" or "which" also behave in this way. Relativizers first play a role in their own clause, serving as an argument of the verb. Then the whole relative clause can attach either to a noun, a verb or an adjective. The head may be a nominal as in "Bill waved to Frank, who was walking toward him." It may be an adjective as in "Tim was depressed, which is not a good thing to be." Or, the head may be a whole clause, as in "Mary criticized John, which surprised me."

## A few additional structures

By way of illustration, let us examine a few additional structures. For coordinate structures, the model postulates fully parallel structures. Material that is ellipsed in the surface structure, but which can be restored to the dependency structure is followed by an asterisk. Here is the structure for "Mary petted and John kissed the dog."

```
Mary <-S-> petted <-O-> (the <-H-> dog)*
      I
      an
      d
      I John <-S-> kissed <-O-
      > (the <-H-> dog)
```

Before looking at a rather more complex coordination, let us first look at how Fillmore (1986) treats auxiliary verbs. Fillmore treats a verb sequence such as "can go" as a verb chain. The first verb in the chain takes a subject which it then passes on to the next verb in the chain. The copula is also treated as a chaining verb. However, it passes on its subject not to a following verb, but to the predicate nominal, predicate adjective, or

predicate prepositional phrase. The subject then plays the role of Described vis a vis the predicate. Thus, the structure of "John is happy" is: John <-S- is -C-> (happy <-D->S ) Here the S at the end of an arrow represents a coinstantiation with the subject of the higher clause. The structure of "my dog can be mean" is: (my dog) <-S- can -C-> (S<-S- be -C-> (mean -D->S)).

To take a somewhat more complex example, consider "My dog can be as mean as any of your dogs."

(my dog) <-S- can -C-> (S<-S- be -C-> (mean -D->S))  
 I Has I C(arsy of your dogs)<-S- can\* -C-> (S<-S- be\* -C-> (mean\* -D->S))

An extraposition such as "it is easy for John to like Mary" has the following structure:

it <-S-> is-C->easy-C->(for->(John<-S->(to like)<-O->Mary))  
 I I  
 I \_\_\_\_\_ A \_\_\_\_\_ |

Here, the phrase "for John to like Mary" is in the appositive role vis a vis "it." Following Fillmore (1986), "easy" is given two competitive valence descriptions-one for extraposed constructions and one for "raisings." In its extraposed valence, "easy" takes a generic null subject (GNS), as in "It is easy to like Mary." In its "raised" valence, "easy" has an object of the complement clause that is identical with the subject of the main clause. Thus, the structure of "Mary is easy to like" is:

Mary <-S- is -C-> easy -C-> ( GNS <-S- (to like) -O->S )

For verbs such as "expect," there is raising to object position. In this case the subject in the lower clause coinstantiates the object of the earlier clause, as in "Tom expected Bill to come."

Tom <-S- expected -O-> Bill  
 I C ((to  
 come) -S-X)

Control verbs such as "try" and "persuade" are treated in a similar way.

As a final example, consider "Mary's promise to Phil to leave the party early caused an uproar" which has this structure:

|—1-> Phil I—early  
 I I  
 Mary's (SOS- promise- C - ( S<-S- (to leave) -O-> the party)))  
 I  
 S I cause -O-> (quite an  
 uproar)

### 3. Comprehension: polysemes compete

So far, we have discussed how alternative segmentations compete during lexicalization and how role slots activate competing attachments. The third type of competition that occurs during comprehension is between different polysemic readings of a given lexical item. This is the problem of lexical ambiguity. In general, the activation of a lexical item leads to the activation of each of its polysemes. These polysemes are then placed into competition. The polyseme which is supported by the strongest cues wins. Polysemy within the same part of speech cannot be resolved by syntactic cues alone. The word "needle" can refer to a pine needle, a sewing needle or a phonograph needle. Consider a sequence such as 'The gardener had finished raking up the pine cones, when



he found some needles stuck in a pin cushion." At first, "needles" appear to be pine needles, but the words "stuck" and "pin cushion" quickly block that reading and leave us with the reading of "sewing needle." In Lashley's famous garden-path sentence "Rapid righting with his uninjured left hand saved from destruction the contents of the capsized canoe" readers often mistake "righting" for "writing" because of the association between "writing" and "hand." The effect is very strong when the sentence is read aloud, thereby removing the orthographic cues. In general, non-syntactic polysemy is resolved in favor of the polyseme which has the most associations through spreading activation to other items in the sentence.

Polysemy between parts of speech is resolved by more deterministic cues. For example, the sound /tU/ is ambiguous between the locative preposition "to," the infinitive "to," the numeral "two," and the modifier "too." In a sentence such as "I went to the store," all four polysemes are viable candidates up to the beginning of the article. When the article is lexicalized, only locative polyseme remains viable. The infinitival reading would have required a following verb. The other two readings would have required either a following adjective or a following noun.

By allowing each polyseme to be activated and by then allowing cues to determine the competition between rivals, a great number of problems in parsing can be handled quite directly. Consider a sentence such as "I know that cats are playful." Up to the plural marker on "cat," there is a competition for the word "that" between a reading as a complementizer and a reading as a deictic determiner. The cue for the determiner reading is the presence of a following singular noun. The cues for the complementizer reading are the presence of a verb that takes a complement and the presence of a well-formed complement clause following. Here, the determiner reading loses because the following noun is plural. A similar competition occurs with a pair of sentences such as

1. What soldiers did it?
2. What soldiers did is what he films.

Another important type of polysemic competition is between adjectives and their corresponding zero-derivation nominals. Consider a sentence such as "The old can get in for half price." Here, the adjectival reading of "old" requires that the following word be interpreted as a noun. The word "can" is itself ambiguous between a nominal and a verbal reading. However, the nominal reading is blocked by the fact that the verb "get" requires a plural subject. As Milne (1986) shows, agreement cues are often important in resolving such competitions. This leaves the much weaker nominal polyseme of "old" as the remaining competitor. As the nominal reading gains activation, it allows the verbal reading of "can" to gain activation, and finally the correct reading of the sentence surfaces. In a sentence such as "have the students take the exam" the main verb and auxiliary verb readings of "have" compete up to the end of the verb "take." At that point, the auxiliary reading would require a participle, as in "Have the students taken the exam?"

A very similar chain of events occurs when interpreting "The communist farmers hated died." When "farmers" appears after "communist," the adjectival polyseme dominates strongly. However, when this reading fails to provide a subject for the verb "died," relative clustering is attempted. In order to have clustering work, "farmers died" needs a head and the nominal reading of "communist" provides this. However, the adjectival reading has dominated so strongly by this point that it is difficult to recover the nominal reading.

In a sentence such as "the trash can hit the table" both the adjectival and nominal readings of "trash" continue in competition. Then the nominal and auxiliary verb readings of "can" also compete. Since the adjectival reading of "trash" goes with the nominal reading of "can" and the nominal reading of "trash" goes with the auxiliary reading of "can," both interpretations continue competing and the sentence remains ambiguous. Similarly, in the sentence "I took her waffles" both the possessive and the indirect readings of "her" yield possible interpretations and the sentence is ambiguous.

Even grammatical markers can be polysemous. Consider the suffix -s which

marks not only the plural of the noun, but also the singular and plural possessive of the noun, and the third person singular present on the verb. Part of speech of the stem is not enough to decide this competition, since many English nouns can also be verbs. However, the items preceding the stem generally tip the scale in the right direction. If the stem is a proper noun, it cannot be a verb. If it is a common noun, it will be preceded by a determiner. Since determiners cannot precede verbs, this is a very strong cue for the possessive polyseme. The selection between the verbal suffix and the nominal suffix is usually fairly clear, since nouns are often The possessive is itself polysemous. Consider the phrase "Reagan's defeat" which could be either, say, a defeat of the hecklers by Reagan or a defeat of Reagan by the hecklers.

Probably the most extensive competitive processing of polysemy is that needed to resolve anaphora. Following MacWhinney (1985) we can divide anaphora into five major types: exophora, clause external anaphora, clause internal anaphora, cataphora, and metaphora. Cues such as parallel function, gender, number, implicit causality, and action readiness all operate to favor one type of phoric reading over the other. Within each phoric type, there may be any number of possible candidate referents. However, the actual number of strong candidates is usually confined to the elements that are currently in the discourse foreground. For an example of how this competition works, consider these sentences:

1. When it was copied, my file disappeared.
2. It disappeared, when my file was copied.

In the first sentence, the presence of the subordinating conjunction licenses a possible cataphoric reading for "it." This is not the only possible reading, however, since an exophoric reading would also be reasonable. In the second sentence, on the other hand, the referent must be either exophoric or clause external anaphoric, since it must be fully referential at the time of mention.

In general, the Competition Model allows each polysemic reading of each word it encounters to continue as long as its competitors have not yet received overwhelming support. In many cases, competitors soon do receive overwhelming support and the weak reading quickly loses out.

#### **4. Production: Competition for lexical packaging**

In production, "ideas and intentions are converted into lexical items. The conversion of ideas into items involves a competition between items. This competition is based not upon perceptual cues, but upon the cues that represent the properties of ideas. These cues are motives-things the speaker wants to express. There are many possible ways in which a given set of ideas could be packaged into a set of lexical items. The speaker generally tries to select a packaging that 1) makes it clear to the listener what the referents are and 2) conveys interesting new information about these referents. There is an important trade-off between new information and conveying old information and every sentence strikes its own balance in this regard. In addition, each sentence must use a central verb that places the various referents into the correct roles.

Perhaps the most basic commitment that a speaker makes when producing a sentence is the choice of a speech act-type. The choice between declarative, imperative, and interrogative forms is fundamental and influences much of the further selection of material in the sentence. This choice involves a competition between alternative speech acts. Usually, the illocutionary force of a speech act matches its perlocutionary force. However, sometimes this natural coalition breaks down and sentences exhibit certain indirect speech act properties. The relation of speech acts to sentence form has been widely discussed in the literature and we cannot review that literature here.

The choice of a speech act type, a sentence topic, and a main verb are all commitments that have their impact on the overall packaging of the sentence. In this sense, we can think of these various decisions as centers of lexical commitment. Once the speech act type is selected, the next center of commitment in the clause is the

topic. The topic is frequently a noun that has already been lexicalized in previous discourse. The selection of a topic is an important matter, since there are often several topics that have been kept active in previous discourse, and one speaker's set of topics may not match the other speaker's set of topics. In addition, either speaker may wish to introduce totally new topics at any given point in the discourse. All of these possible topic candidates are in competition at any given point in the discourse. The candidacy of a particular topic is promoted by its recent mention by both speaker's and by its centrality in the conversation. However, these givenness cues are not enough to fully determine the competition. The most important cue in favor of a given topic is whether or not it is a part of some message that the speaker crucially wants to discuss. The competition between continuing old shared topics and introducing new not-shared topics is a tough one. Sometimes we find that we can never bring a conversation around to the topic we wanted to discuss because of the other speaker's insistence on pursuing a different agenda.

In English, making a commitment to a topic noun then further commits the speaker to selecting a verb that places the topic in the subject or perspective role (MacWhinney, 1977). If the verb is intransitive, no further major commitments are entailed. However, if the verb is transitive, an object must be selected and sometimes a third obligatory argument must also be selected. Often there is a competition between alternative verbs or sets of verbs. For example, verbs like "buy" and "sell" are in direct competition. Other competitions are between two-clause and one-clause packagings by verbs. For example, the verb "knocked over" often competes with a verb siren as "went over to and bumped into and thereby pushed over." The earlier verb conflates a series of verbs that each might require its own clause. The sentence planning mechanism need not have all of the nominal arguments fully selected when lexicalizing the verb. However, it commits itself to lexicalizing them eventually. A particularly extensive sort of commitment is incurred by verbs that take complement clauses, since complementation can be recursive.

The other major commitments made in sentence packaging are more optional. The inclusion of further specifications of the nouns can involve relative clauses and appositive phrases which involve further recursion. There can also be temporal, locative, benefactive, and other circumstantial descriptions of the activity of the clause. Sometimes these circumstantials involve the lexicalization of prepositions. Prepositions work as independent centers by promoting lexicalization of the object of the preposition and by searching for attachment to a verb or a noun head.

In order for lexicalization to terminate, several conditions must be fulfilled:

1. the verb must be lexicalized and each of its arguments must be filled
2. there should be no activated prepositions that are not attached to verbs
3. there should be no active attempts to further characterize any noun

Of course, it is possible to begin articulation of the subject of the verb even while working on the specification of further arguments.

## 5. Production: Allomorphic competition

In some cases, the activation of a particular lexical item involves allomorphic competition. For example, activation of the plural suffix in English actually activates three competing allomorphic alternatives: -s, -z and -Iz. This competition is resolved by cues that are activated by the stem. In English, the presence of a final sibilant is a cue that boosts the strength of the -Iz suffix. The presence of a non-sibilant with final voicing boosts the strength of the -s suffix. Or, to take another example, consider vowel harmony in Hungarian. For a suffix like the inessive, the allomorph -ban competes with the allomorph -ben, relying on the shape of the final vowel of the stem.

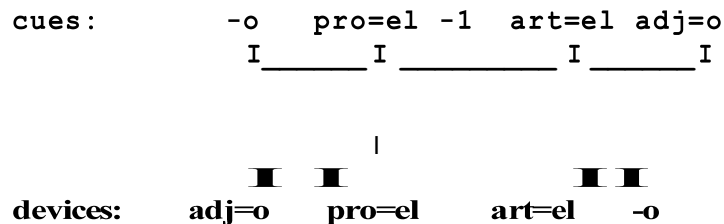
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                                I --ban  ----{pre, nucleus, a/o/u}
"inessive"  ---A
                                I --ben  ----{pre, nucleus, e/i/u"/o"}

```

In these examples from English and Hungarian, the competition is based entirely on phonological cues. In more abstract systems, additional stem cues are used. These additional cues include semantic properties of the stem and operators with which the stem is associated. Systems like gender in Indo-European are of this type. These systems are pieced together bit-by-bit on the basis of concrete cues (MacWhinney, 1978). For example, in learning Spanish, the child first uses stem final -o as a cue to use of the masculine article *el*. In other words, he learns that words like *hijo* and *perro* appear as *el hijo* and *el perro*. Then, he learns that forms that take the article *el* are referred to with the pronoun *el*. And, conversely, forms that are referred to with the pronoun *el* also take the article *el*.

At first, each of these cue-device relations are encoded separately. However, as the child learns to traverse each path bidirectionally, he sets up an overall cue-device system of the following shape:



This structure corresponds to a formal class such as "masculine." However, it is actually composed entirely of cue-device relations. Several writers have attempted to emphasize the importance of the contrast between formal and functional approaches to language acquisition, particularly in the area of morphophonology. However, this analysis indicates that what is important is not formalism or functionalism, but the ways in which children map cues onto the competition between devices.

## 6. Production: Competition in articulation

Speech errors constitute the most obvious external manifestations of competition. Elsewhere Joseph Stemberger and I (MacWhinney and Anderson, 1986; Menn and MacWhinney, 1984; Stemberger, 1982; Stemberger and MacWhinney, 1986a, 1986b) have applied Competition Model constructs to account for the basic types of speech errors that have been reported in the literature. The basic phenomenon here is that of "response competition" which is pretty much an old chestnut in psychology. The arena of this competition is the articulatory buffer from which the articulation is read out in a serial manner. In order to provide for parallel addressing for this buffer, 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."

For example, 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

Given this arrangement, we can see how a blend such as "flaste" arises from the

merger of "flavor" and "taste." The form "flavor" wins out in activating the syllable initial cluster and nucleus. However, it does not succeed in opening a second syllable. The form "taste" wins out in the competition for syllable "post" or coda position.

## 7. Cooperation

This can be no competition without cooperation. Every meaning that the child wishes to express represents a coalition of motives (Bates and MacWhinney, 1982). This is particularly easy to see in the area of lexical selection. When we choose to call an animal a "bird," we are expressing not just one lone intention, but a whole range of correlated attributes. The animal not only has feathers, a beak, and wings, but probably lays eggs, flaps its wings to fly, and has a song or call. These attributes live together peacefully in nature, happily correlated with each other. When it comes time to choose between calling the animal a "bird" or a "dog," the strength of this peaceful coalition works in its favor to defeat all competitors. However, in most such cases, none of the competitors are too sorely disappointed, since few of their features were activated anyway. In this sense, a well-oiled competition is cooperative in that it maximizes the chances in the long run for any given meaning to properly express itself lexically, while cutting to a minimum the amount of improper lexicalization.

Cooperation works in a similar way for those devices that express grammatical roles. For example, the subject-expressing devices of preverbal positioning and verb agreement work together to express a variety of naturally correlated role motives, including agency, causality, topicality, givenness, and perspective (MacWhinney, 1977). Text studies (Givon, 1979) show that, for a number of reasons, these motives are indeed highly correlated. But sometimes this natural coalition breaks down. In the passive, the element that is given, topical, and perspectival turns out to be non-agential. In such cases the agent may receive a "consolation prize" which places it in a by-clause.

## 8. What has to be learned? How is it learned?

The real pay-off from a Competition Model analysis of language is the way it can clarify our understanding of language acquisition. As long as child language researchers worked with standard adult-based descriptions of competence they were forced to imagine the children came to the language learning task complete with a fairly elaborate set of hypotheses whose only major purpose was to work out facts of language structure. However, the child proceeds in a much more bottom-up fashion, acquiring the language system brick by brick.

What are the basic structures that the child must learn. First, he must extract O:t from experience as set of concepts which will later serve as the meanings expressed in words. Second, he must acquire a set of lexical items that map sounds onto concepts. Third, he must learn how to fill the role relations required by these lexical items. Fourth, he must acquire cues to resolve allomorphy and polysemy. Let us look at each of these four types of learning.

Concepts must be clearly formed before children can acquire lexical items. In acquiring and structuring concepts, the child must rely heavily on the fact that, in nature, attributes are often intercorrelated. It is not the case that conceptual development always precedes lexical acquisition. Sometimes children learn words or usages of words for which they have not yet learned the corresponding concepts. In such cases, language acquisition can serve as a goad to conceptual acquisition.

Lexical items are learned by associating a sound to a meaning. There are three major stages in this learning. First, the child detects an unknown phonological string. This occurs during the process of segmentation which we discussed earlier. Second, the child makes a fast mapping of some current referent to the new phonological string. This is the process of jumping-in. If this initial mapping is incorrect, it will be weeded out by

the competition. If child thinks the sound "alligator" means "dog," competition will simply weed out this bad guess. Third, the item undergoes a period of generalization. Generalization involves a continual determination of the union of the current features or concepts of the item with the features in subsequent clear presentations. This determination is an inherently conservative process, since it does not generalize the representation unless a generalization is clearly attested in the adult input. This learning is essentially exemplar-based and the full union of features is stored, at least in the short run. If a feature appears in each new exemplar, then it is high in overall cue validity and its cue strength is also kept high. If a feature only occurs in a few exemplars, its cue strength will begin to fall and eventually it will fall out of the lexical item. This core of experienced exemplars is the "confirmed core" which serves as the child's surest guide to the usage of the lexical item.

A new item may have a semantic range that overlaps that of the confirmed core of a current item. For example, the child may have learned something about the word "pine" and then see a tree that looks like a pine, but which is called a "spruce." The child does not ignore this new word, but assumes as does Clark (1984) that words have conventional meanings that contrast. At first, the child does not understand the basis of this contrast. However, he allows "spruce" to coexist with "pine" by shielding it for some time from the competition. Each time he hears "spruce" he attempts to gather cues that may eventually serve to separate it out from "pine." A similar period of free variation is allowed for superordinates. When the child first learns the word "animal" it does not contrast with "dog," "cat," or "goat." However, over time, it acquires generic mention features that allow it to win out in the competition when the more specific features of the basic level categories are not so important.

In addition to the conservative techniques for acquiring the "confirmed core," the child can also use less conservative techniques to temporarily generalize the item. He may simply use the item to refer to something outside its domain. Often the child must do this because he has no other way of naming the item. Although the child may wish to produce such overgeneralizations, but he must be careful to not add them to the "confirmed core" until they are also confirmed in comprehension. Thus, the child may call a tiger a "kitty," but realize that this is not actually correct. Only if the adult cooperates with this error will the child acquire the incorrect domain for the item "kitty." Nor will a child acquire a new lexical formation unless it is produced by an adult. Thus a form such as "unsqueeze" will never be entered into the lexicon unless it is produced by an adult.

Roles and Cues to Roles are also learned by depending on a conservative "confirmed core" with features whose cue strength depends on their cue validity. An important consequence of the lexically-based nature of grammatical roles in the Competition Model is that the child only needs word pairs to acquire roles. For example, when the child hears a sentence like "The smart little boy gave the dog a bone," he notices that there is "giving" in the situation and that the "dog" is a recipient. This teaches him that "give" takes a recipient in postverbal position with no other marking. In other accounts, such as those of Anderson (1977), Siklossy (1975), Wexler and Culicover (1980), Berwick (1986), and Pinker (1984), one must believe that the child receives complete situation representations of the meanings underlying every utterance he hears. If this were true, why would the child pay attention to language, since everything would be clear in the situation. Surely, this assumption is much too strong. The Competition Model replaces this indefensible assumption with a more defensible assumption based on encoding of pair-wise relations.

Information regarding what kinds of items can fill roles is recorded in role slots on predicates. Every time the child hears a new item in a role slot, he must record about each argument: 1) its major lexical semantic features, 2) its position vis a vis the predicate (pre, post, postpost), 3) its stress properties, 4) the lexical items attached to it phonologically, and 5) the lexical items phonologically attached to the predicate.

The first time that a child records a new argument for a predicate, only the information on the particular item that filled that slot is recorded. As new items are encountered in that slot, their cues are merged with the cues currently in the slot. Cues that are common across exemplars grow in strength. Cues that are not common

drop out. In connectionist terms, the connections between items and cues develop on the basis of repeated presentations of exemplars. If an argument is only occasionally attested in the data, it will not grow much in strength. So, if we occasionally hear an indirect object with verbs like "report," we will still be uncertain about whether such arguments are possible. Since the packaging "Bill reported Tom the event" is in competition with the packaging "Bill reported the event to Tom," the weakness of the indirect role on the former will lead to the victory of the latter form in the competition.

In regard to the acquisition of **polysemy** and **allomorphy**, the situation is pretty much the same. The major problem the child must face in entering polysemes is to judge when a new meaning for a word is sufficiently different from an existing meaning to indicate that polysemy is involved. Suppose that the child knows the word "needle" as a way of referring to sewing needles. He then hears someone refer to a needle on a pine tree as a "needle." Some of the cues in his confirmed core for "needle" match correctly. The pine needle is long and has a sharp point. But many other cues do not match. The pine needle bends, is not made from metal, is not about an inch long and so on. If the child tries to merge the new "needle" with the old, he would have to decrement the cue validity of most of his existing cues. However, the child acts more conservatively. Whenever a new exemplar differs from the current confirmed core in several ways, the child sets up a new polyseme. If this polyseme does not grow its own conceptual core over time, it eventually merges back into the more basic core for the word.

When establishing new allomorphs, the child uses as cues the semantic and phonological properties of the stem or head, along with the lexical identity of items attached to the head. Each allomorph develops connections to the cues that aid in its selection. As argued by Braine (1987), the child attempts to maximize the features of each allomorph which involves maximizing their size in segments. Here again, there is a conservative "confirmed core" which delineates what the child really knows. However, the child may be forced to go beyond this confirmed core when no alternatives are available.

From this analysis, we can draw a fairly clear set of implications for language instruction. In general, our analysis suggests that the clearer the input, the clearer the learning. There is no need in the Competition Model to imagine that the child must learn on the basis of negative instances. Rather, what is crucial is that the parent present clear exemplars of lexical items and grammatical role frames. If the parent encounters a child error, then he should only recast that utterance if he can be sure that he knows what it was that the child was trying to say. If the parent recasts the wrong meaning, he will teach the child the wrong form. Since all forms are always in competition, by continually reinforcing correct meanings, the parent is always indirectly weakening wrong forms. This interpretation of parental feedback to children is strongly supported in recent work by Warren-Leubecker, Bohannon, Stanowicz, and Ness (1986) and Hirsh-Pasek, Trieman, and Schneiderman (1984).

This account of the Competition Model has indicated the ways in which the fundamental concepts of competition and cooperation can be applied to a wide range of phenomena in language processing and acquisition. We began our examination of the language system asking whether it was necessary to follow the formalist approach of viewing language as a unique module separate from the rest of cognition. We conclude with an approach that emphasizes the relation between not only language and cognition, but also between cognition and nature in general.

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