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Linguistic structure: A plausible theory

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Abstract. This paper is concerned with discovering the system that lies behind linguistic productions and is responsible for them. To be considered realistic, a theory of this system has to meet certain requirements of plausibility: (1) It must be able to be put into operation, for (i) speaking and otherwise producing linguistic texts and (ii) comprehending (to a greater or lesser extent) the linguistic productions of others; (2) it must be able to develop during childhood and to continue changing in later years; (3) it has to be compatible with what is known about brain structure, since that system resides in the brains of humans. Such a theory, while based on linguistic evidence, turns out to be not only compatible with what is known from neuroscience about the brain, it also contributes new understanding about how the brain operates in processing information.

Keywords: meaning, semantics, cognitive neuroscience, relational network, conceptual categories, prototypes, learning, brain, cerebral cortex, cortical column

1. Aims

Nowadays it is easier than ever to appreciate that there are many ways to study aspects of language, driven by different curiosities and having differing aims. The inquiry sketched here is just one of these pursuits, with its own aims and its own methods. It is concerned with linguistic structure considered as a real scientific object. It differs from most current enterprises in linguistic theory in that, although they often use the term 'linguistic structure', they are concerned mainly with the structures of *sentences and/or other linguistic productions* rather than with the structure of *the system that lies behind these and is responsible for them.* To have one's primary interest in sentences and other linguistic productions is natural for people interested in language and is nothing to be ashamed of or shy about; so to say that they are more interested in linguistic productions than in the system responsible for them is in no way intended as critical of these other theories. They have been providing useful and

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interesting information over the years, which satisfies various well-motivated curiosities about words and sentences and other linguistic structures.

To mention just one such descriptive theory, Systemic Functional Linguistics (SFL) aims to understand the structures of sentences and other texts by characterizing the set of choices available to a speaker in forming them (Halliday 2013, Fontaine, Bartlett, and O'Grady 2013, Webster 2015, and many other publications). The values of this approach are shown, for example, in Fontaine, Bartlett and O'Grady (2013) and in Halliday (2015). While the aims of SFL are not the same as those of the present investigation, they are compatible (cf. Gil 2013, Lamb 2013), and SFL therefore provides valuable data for use in devising a theory of *the system that lies behind* the texts and provides those choices to speakers. Similar things can be said, *mutatis mutandis*, in relation to various other descriptive linguistic theories.

In his *Prolegomena to a Theory of Language* (1943/61), Hjelmslev wrote, "A [linguistic production] is unimaginable—because it would be in an absolute and irrevocable sense inexplicable—without a system lying behind it". That system is unobservable in itself, but we know that it has to exist. The investigation described in this paper operates on the presumption that careful analysis of linguistic productions will reveal properties of the system that produced them. When we observe words in linguistic productions, we accept that there has to be a system that has produced them. Our task is to posit what must be present in the linguistic system to account for them. In Hjelmslev's terminology, this is a process of *CATALYSIS*. Catalysis begins with analysis of *observed* phenomena (texts and portions of texts), and proceeds to build an abstract structure consisting of elements *that are not observed.*

Most of linguistics, even that which claims to be studying 'linguistic structure', engages in *analysis and description* rather than in catalysis; it is occupied with analysing and describing and classifying linguistic productions. Again, to make this observation is in no way a criticism of analytical/descriptive approaches. Actually, most people, both ordinary people and linguistic scholars, have a greater interest in the outputs of the linguistic system than in the structure responsible for them. An account of 'linguistic structure' that contains rules or words or parts of words (prefixes, suffixes, stems, and the like), however interesting and valuable, cannot be an account of the underlying system, since that system could not *consist of* rules or words or parts of words. To claim otherwise would be akin to claiming that the human information system is a type of vending machine, in that what comes out of a speaking human is stuff that was inside. Rules too are linguistic productions, however formalized, but the system that produces them must have an altogether different form. It is that different form that we seek to encatalyze through the examination of words and parts of words and syntactic constructions and other linguistic productions.

Apparently there are some who believe that Chomskian Biolinguistics is a theory that shares the aims of the investigation described here. The erroneous thinking that has led to this belief has been described in detail by Adolfo García (2010).

It should be fairly obvious from the outset that whatever the linguistic system consists of, it does not *consist of* words or phonemes, and certainly not of written symbols. When a person speaks a word, he is not simply putting out an object that was in him, as a vending machine does. Rather, he has an internal system that activates, in proper sequence and combination, muscles of the mouth, tongue, larynx, and other parts of the speech-producing mechanism, including the lungs, so that the word *is produced on the spot*, an object that has not previously existed (see also Lamb 1999: 1–2, 6–7). The structure that produces words need not resemble them at all. Therefore, we can be sure right away that any theory that describes structures consisting of words or other symbolic material is *not* a theory of *linguistic structure* in the sense of that term used in this paper.

2. Evidence and plausibility

There are five easily identifiable areas of observation, relating to four kinds of real-world phenomena that are relevant to language and which therefore provide evidence for linguistic structure (see also Lamb 1999: 8–10).

The first type of evidence is easy and obvious. It relates to what Hjelmslev called *EXPRESSION SUBSTANCE* (1943/61). We have abundant knowledge from biology about the organs of speech production, which provide grounding for articulatory phonetics. So whatever a theory of linguistic structure has to say about phonology must be consistent with well-known facts of articulatory phonetics. Biology likewise provides knowledge of the inner ear and other structures related to hearing, which give solid ground to auditory phonetics. And acoustic phonetics is grounded by knowledge available from physics relating to frequencies and formants and so forth. Similarly we have plenty of scientific knowledge about the physical aspects of writing and reading and other kinds of expression substance.

The second body of evidence is the linguistic productions of people, the things they say and write, which are generally also things that people can comprehend (to varying degrees). For any such production I use the term *TEXT*, applying it to both spoken and written discourse. The term covers productions longer than sentences, and productions that under some criteria would not be considered well-formed, such as spoonerisms and other slips of the tongue, unintentional puns, and utterances of foreigners with their lexical, grammatical, and phonological infelicities. Such productions provide valuable evidence about the nature of linguistic systems (e.g., Dell 1980, Reich 1985, Lamb 1999: 190–193).

Third, as is obvious from cursory observation relating to the second body of evidence, people are indeed able to speak and write, and to comprehend texts (if often imperfectly). This obvious fact assures us that linguistic systems *are able to operate for producing and comprehending texts*. Therefore, a model of 'linguistic structure' cannot be considered realistic if it cannot be *put into operation* in a realistic way. This principle, the requirement of *OPERATIONAL PLAUSIBILITY*, has also been mentioned by Ray Jackendoff (2002).

Fourth, and also clear from cursory observation, real-life linguistic systems undergo changes, often on a day-to-day basis. Such changes are most obvious in children, whose linguistic systems undergo rapid development during the first few years, from essentially nothing at all at birth to huge capacity and fluent operation by age five. But adults also acquire new lexical items from time to time, in some cases quite often, as when they undertake learning some new body of knowledge. They also sometimes acquire new syntactic constructions. And so a model of linguistic structure, to be considered realistic, must incorporate the ability to develop and to acquire new capabilities of production and comprehension. This criterion may be called the requirement of *DEVELOPMENTAL PLAUSIBILITY*. It provides another easy way to distinguish a theory of linguistic structure from a theory of the outputs of linguistic structure. Valuable as they are for their own purposes, theories of the outputs, are in such a form that there is no plausible avenue that could lead to their development. This statement applies also to some network theories, such as the well-known connectionist theory of Rummelhart and McClellan (1986).

Finally, since we are attempting to be realistic, we cannot treat a linguistic structure as just some kind of abstract mathematical object. In keeping with the preceding paragraphs, we have to recognize that linguistic structures exist in the real world and that their loci are the brains of people. And so a theory of linguistic structure needs to be consistent with what is known about the structure and operation of the brain. This is the requirement of *NEUROLOGICAL PLAUSIBILITY*.

To summarize, our aim is to construct (encatalyze) a realistic theory of linguistic structure, recognizing that to be realistic means accounting for the fact that real linguistic systems (1) are able to produce texts and to understand them (however imperfectly), (2) are able to develop and the change themselves, and (3) have structures that are compatible with what is known about the brain.

3. Basic observations

The development of the theory sketched here has followed a crooked path over the past half-century, building on earlier work including that of Jan Baudouin de Courtenay, Adolf Noreen, Ferdinand de Saussure, Louis Hjelmslev, Benjamin Lee Whorf, Charles Hockett, and H.A. Gleason, Jr., with numerous cul-de-sacs along the way (cf. Lamb 1971). For this presentation the path is smoothed out. The earlier sections of this paper set forth in a straightened path the developments up to about the turn of the 21st century, most of which has previously been mentioned in scattered publications that appeared along the crooked path (including Lamb 1999, Lamb 2004a, 2004b, Lamb 2005; see also García 2012). Later sections concentrate on neurological plausibility, which I take as a central concern for a realistic theory of linguistic structure, and propose several findings that have not previously appeared in print, including some that are offered as contributions to cognitive neuroscience.

Since we can't do everything at once the path takes up one thing at a time, as with any exploratory enterprise. It best begins with easy stuff. Easy things are not only easier to work with in initial stages, they are likely to be basic and therefore to lay the foundation for further exploration. In focusing on the more obvious and easier to handle, we are not ignoring additional complications, just deferring their consideration until we have a basis for further investigation.

Perhaps the most obvious thing about linguistic productions is that they are combinations of various kinds: combinations of words, combinations of speech sounds, combinations of sentences, …

Another basic finding well known from the early days of language study is that which led to the distinction between *SUBSTANCE* and *FORM*. Speech sounds are endlessly variable, yet behind the variety is a much simpler structure. So for speech we have a set of *PHONEMES*, elements of *EXPRESSION FORM*, each of which is realized by any of a large variety of similar articulations and resulting sounds, belonging to *EXPRESSION SUBSTANCE*. For example, the phoneme /k/ of English is recognized as one and the same phoneme regardless of the exact location where the back of the tongue touches the palate and regardless of how much aspiration occurs at its release. Similar organization can be applied to marks on a surface visà-vis *GRAPHEMES*—consider the letter (*GRAPHEME*) 'k' and its many typographic variants, and with even greater variability in the case of handwriting. The key consideration is that the variability among different manifestations of a phoneme or grapheme is generally treated by language users as non-significant, and the non-significant variation is often outside the awareness of language users.

At the same time, we have to recognize that this distinction (between form and substance) cannot be taken as absolute. As pointed out by Lucas Van Buuren (in press), it applies mainly to what Halliday calls the ideational function of language, much less to other functions. For example, phonetic features that would be considered non-significant from the ideational point of view may be quite important from an interpersonal point of view, and, as Hjelmslev himself pointed out (1943/61), they may provide information about where the speaker grew up.

Another readily observed fact about language is that linguistic expressions generally have meanings or other functions. Here too we can use terms of Hjelmslev, and say that language relates meanings and other functions—*CONTENT*—to speech or other means of *EXPRESSION*. Typically, a given word or phrase can be interpreted differently by different comprehenders or in different contexts. Similarly, such meaning can usually be represented in a variety of different wordings.

Further, following Hjelmslev's usage, we need the distinction between *CONTENT FORM* and *CONTENT SUBSTANCE*. For example, a unit of content form like CUP, is represented in content substance by many different actual cups out there in the world, of different shapes and colors and made of different materials. For both content and expression we find more or less haphazard variability of actual *SUBSTANCE* and the much simpler structure of *FORM*. So for *CONTENT SUBSTANCE* we have the world, existing as what B. L. Whorf (1956) called a *kaleidoscopic flux*, which language represents as *CONTENT FORM*, a greatly simplified set of categories, varying from one language to another.

Although Hjelmslev made the distinction between form and substance without reference to the cognitive systems of human beings, we do so here, in keeping with the requirement of neurological plausibility. Also, we have to recognize that the distinction is not quite that simple, since substance, on both the expression and content sides, is actually multi-layered, and some of those layers are internal, represented in the brain. Considering articulatory phonetics, for example, there are multiple layers of structure between the distinctive articulatory features of expression form and the actual speech sounds (as they might be measured in acoustic phonetics), subserved in large part by subcortical structures of the brain, including the basal ganglia and the cerebellum and the brain stem, as well as by the musculature that operates the organs of speech.

A fourth basic observation is that texts have various functions, both social and private. The private functions are often overlooked, but thinking (to oneself) is a linguistic activity that for many people occupies more of their waking hours than social interaction through language. The social functions can be divided into various subtypes, such as schmoozing (Halliday's *interpersonal function*), sharing observations, seeking information ("What is his wife's name?"), and changing societal structure ("I now pronounce you man and wife").

These and other commonplace observations, well known among linguists of different persuasions, will be taken for granted in what follows. On the other hand, there are some widespread beliefs that we want to avoid, since they do not stand up to scrutiny, such as the doctrine that the linguistic world is made up of a number of discrete objects called languages (Lamb 2004b).

Since the aim of this enterprise is to figure out the nature of linguistic structure, such observations require that we come up with a realistic hypothesis of what kind of structure might be responsible. And, to be realistic, the hypothesis must satisfy the requirements of plausibility described above.

4. Combinatory levels

Much of the structural linguistics of the twentieth century was hampered by failure to distinguish levels of different kinds. One type is *combinatory*: we can say that combinations are on a different combinatory level from their components. This type of difference is quite different from that between the level of concepts and that of phonological representations (content form and expression form). For example, a concept is in no way a combination of phonemes. So we need to distinguish what can be called *STRATA* from *COMBINATORY LEVELS* (Lamb 1966). We have to recognize at least three strata for spoken language, conceptual, lexico-grammatical, and phonological. (We shall see later that *conceptual* is not actually the right term, but it will do for now).

The first of the "basic observations" above, that both phonemes and graphemes occur in largely linear and largely recurrent combinations of different sizes, including words, is a matter of combinatory levels. It requires that we posit some kind of sequencing structure—a structural device that produces and recognizes linear combinations. The ordinary way of representing combinations of phonemes or graphemes is with combinations of symbols from ordinary language: "boy", "toy".

This simple notational practice, largely taken for granted, *avoids the issue*: It is just a notational convention, which *leaves the structure undescribed*, and thus renders such accounts lacking in operational and developmental plausibility. According to the convention, the left-to-right direction represents time. Such notation is very useful for many language-related studies, but it is not suitable for representing linguistic structure, for three important reasons. First, this notation uses symbols derived from language. But language is the object whose structure we are trying to discover. To use language as a notation for such exploration is akin to building a fireplace of wood. The second problem is that it leads us to overlook the essential fact that when we use the same symbols ("o", "y") in two or more different locations, as when we write "boy" and "toy", we are talking about the same objects ("o", "y"). The notational convention is failing to make explicit that "-oy" in "boy" and "-oy" in "toy" are just two *different notational occurrences of what is one and the same object.* The third problem is that simply writing the letters from left to right ("boy" and "toy") is taking the sequencing for granted, failing to indicate that there has to be a structure responsible for it.

In order to make such facts explicit, we can encatalyze the situation as in Figure 1, in which there is only one "-oy". Parts a, b, and c of the figure are alternative catalyses showing different degrees of detail. Focusing first on Figure 1a, the triangular node signifies that when it is activated from above both of the lower lines (e.g. to /t/ and to /-oy/) are activated, but in sequence, represented in this notation as left-to-right attachment of the lines to the bottom of the triangle. As this definition illustrates, the nodes of this network notation are defined

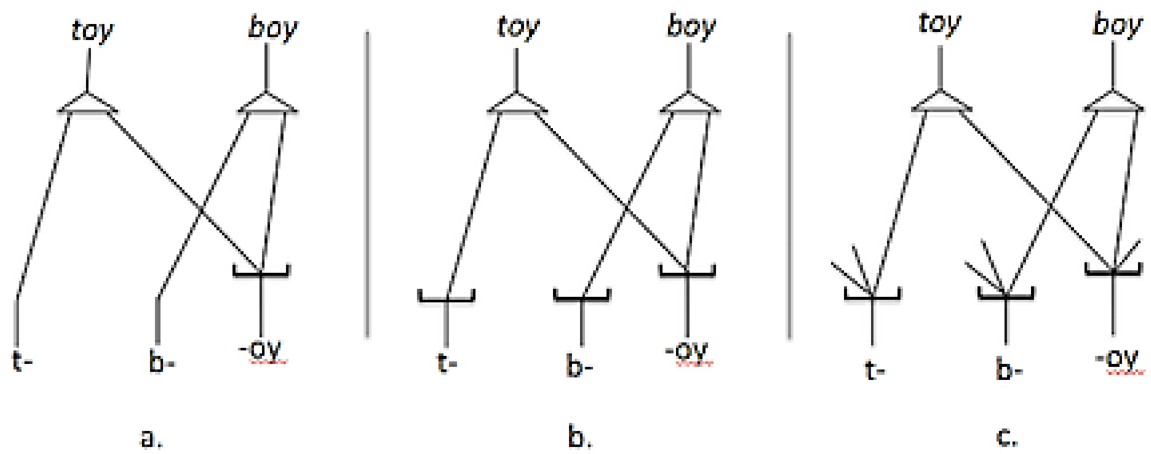


Figure 1. Relationship of toy and boy to their phonemic expressions

in terms of the passage of activation, and activation can be either downward—from content to expression—or upward—from expression to or toward content (i.e. function/meaning). So upward activation from /boy/ travels upward as /b-/ followed by /-oy/, and activation from both these lines connecting to the triangular node (called an AND node) satisfy it so that it sends activation on up to *boy*. On the other hand, activation from/-oy/ up to the AND node for *toy* is blocked by that node if /t-/ has not also been activated, since the AND condition will not have been satisfied. Notice that since the notation is defined in terms of operation, it concerns itself directly with the criterion of operational plausibility.

The other node, a square bracket rotated 90°, is called an OR node, since downward activation from *either* of its incoming lines passes through. On the other hand, upward activation to this node (i.e., coming up from /-oy/) goes to both (or all) outgoing lines. There is normally an either-or condition but not at the node itself. In the case that the input is /boy/, the AND node for *boy* is satisfied but that for *toy* is not (since there is no activation from /t-/), and so the overall effect is that only one succeeds, even though *locally*, at the OR node itself, both (or all) are tried. The situation can be seen as somewhat Darwinian (all are tried, only a few survive) if one cares to look at it that way.

Turning now from Figure 1a to 1b, a little more information is added, indicating that such an OR node is needed also for /t-/ and /b-/ since they also need connections upward to other AND nodes, such as those for *ten, tune, ben, boon,* and many others. This situation is indicated more explicitly in 1c, which shows that there are additional connections, without showing the other ends of them, as to do so would make the diagram harder to read, and such information would not be relevant to the point under discussion.

Now /-oy/ is generally recognized as a combination with its two components /o/ and /y/. But within the linguistic structure we *do not have such combinations; rather, they exist external to the structure itself.* Combinations outside of the structure are generated by (and recognized by) AND nodes. So to recognize that the (external) combination/oy/ is composed of /o/ and /y/, the structure needs an additional node as shown in Figure 2.

Notice that in this figure the symbol "-oy" is written at the side of a line. This symbol is not part of the structure; it is just a label, included to make the diagram easier to read, just like labels that are included on maps. When a highway map shows, say, "I-95" next to a line for a highway, it doesn't represent anything that will be found on the landscape at the location indicated. It is not part of the highway structure, just a label on the map that makes it easier to read. Note that this symbol "-oy" could be erased with no loss of information. Of course, a symbol could serve no function anyway as part of the structure, since the structure has no little eyes to read it, much less a visual perception system to interpret it. The structure consists only and entirely of nodes and their interconnections, represented as lines.

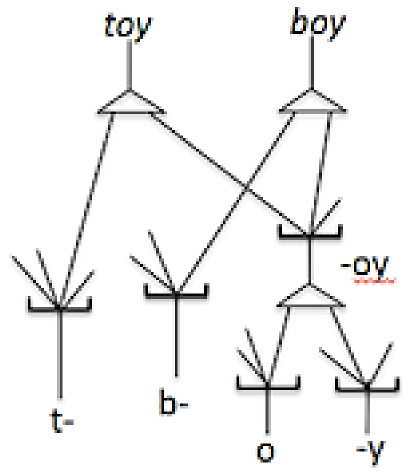


Figure 2. Relationship of *toy* and *boy* to their phonemic expressions, showing structure for combinatory levels in phonology

In Figure 3, we extend the "map" downward, to show phonemic components. Those shown here are articulatory components, and only the distinctive components are indicated at this level, on the assumption that the non-distinctive ones are supplied at lower articulatory levels. The same line of thinking applies to the sequencing of phonemes indicated at this level of structure. At lower articulatory levels, handled mainly or entirely by subcortical structures of the brain, timing is more complicated in that, for example, the mouth is put into the position for the vowel at about the same time the initial consonant is articulated rather than after articulation of that consonant.

Also left out of consideration, since it is not pertinent to the central argument, is the question of whether phonological components should be defined on an articulatory basis as opposed to an auditory basis. In fact, both bases have validity, as would have to be shown in a more detailed network diagram in which the two directions of processing would be represented by separate lines (see below, section 9).

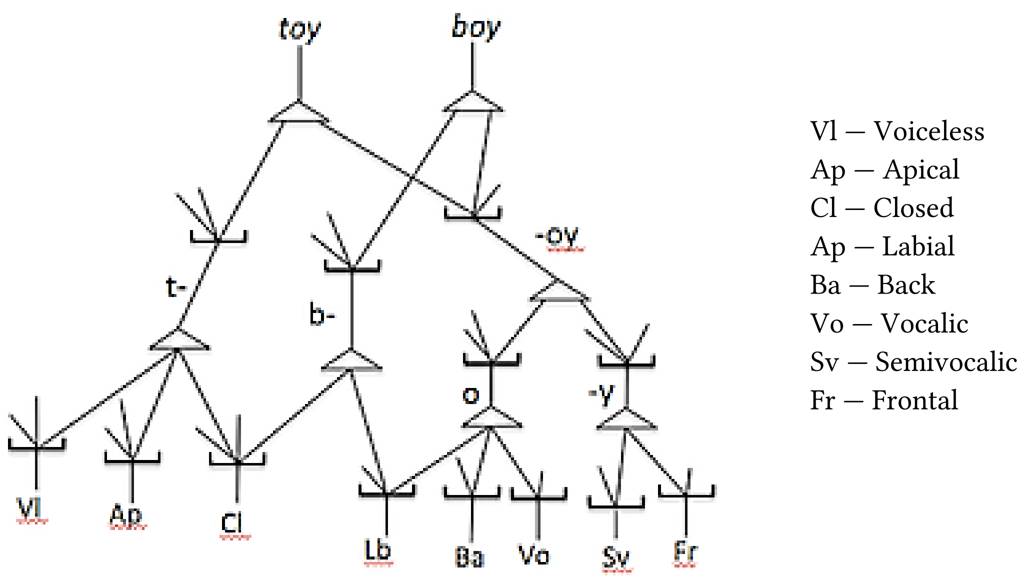
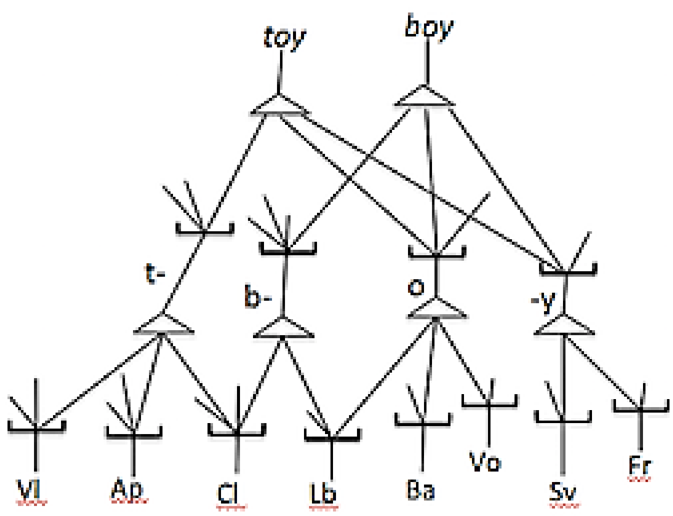


Figure 3. Expansion of Figure 2 showing phonemic components



Vl — Voiceless
Ap — Apical
Cl — Closed
Ap — Labial
Ba — Back
Vo — Vocalic
Sv — Semivocalic
Fr — Frontal

Figure 4. Alternative to Figure 3

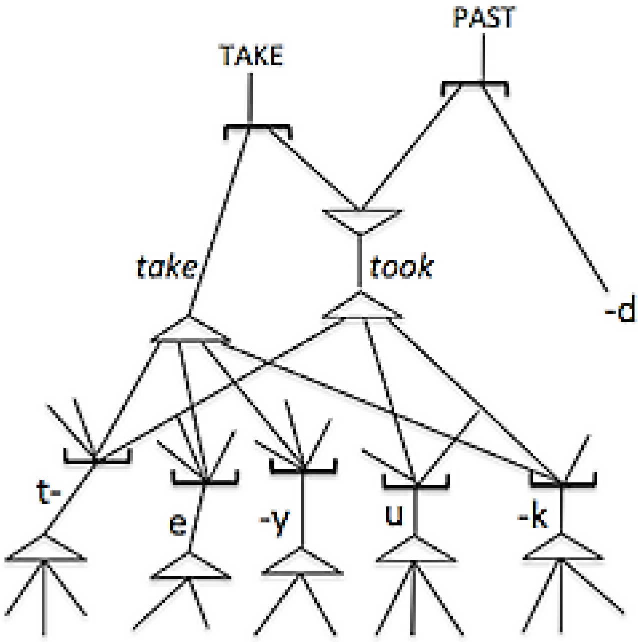
In Figure 3, the AND nodes connecting the phonemes to the phonological components are unordered—the lower lines all connect to the same point at the middle of the lower line of the triangle. So we have a distinction between *ordered* AND and unordered AND nodes.

Figure 4 shows an alternative structure for the same phenomena. Figure 3 and Figure 4 may be called alternative *CATALYSES*, that is, different structures posited to account for the same phenomena. There are arguments in favor of both, and I treat the situation here as unresolved, pending further study. On the one hand it can be argued that the syllable has two immediate constituents, as catalyzed in Figure 3. The catalysis of Figure 4, on the other hand, with its three-way ordered ANDs at the top, eliminates the need of a separate structure for /-oy/ and thereby has the advantage of shorter processing time, on the well-warranted presumption that it takes a certain amount of time for activation to pass through nodes.

5. Higher-level structure

The structures shown in these figures consist entirely of relations, forming networks. They suggest that perhaps the whole of linguistic structure is a relational network. As is mentioned above, there would be serious problems in defending a hypothesis that would also include symbols as part of linguistic structure, since symbols would entail some means of reading them and interpreting them, and the learning process would have to include some means of devising them (cf. Lamb 1999: 106–110). So the case in favor of relational networks, made up exclusively of nodes and their interconnections seems *prima facie* attractive.

The reasoning leading to this conclusion is presented in this paper in the third paragraph of the preceding section. It is only one of several quite different lines of reasoning that lead to the same conclusion. Others have been presented by Hudson (2007: viii, 1–2, 36–42), Lamb (1999: 51–62), and other investigators. But the exact form of the network varies from one investigator to another. For example, those of Hudson (2007) differ in some important respects from the *RELATIONAL NETWORKS* described in this paper, even though both ultimately derive from the systemic networks of Halliday. The relationships of relational networks to those of Halliday are described by Gil (2013) and Lamb (2013).



← *Ordered* OR *node:*

The line connecting off center takes precedence if conditions for its activation are present.

The line that goes straight through is the default line.

Figure 5. The irregular past tense

In the next several pages I look at various phenomena of grammatical and conceptual structure with the specific intent (not of describing them as such, but) of learning what additional properties are needed in relational networks to allow them to fulfill the goal of operational plausibility.

We may first take the case of PAST-TENSE, whose usual expression is the suffix *–ed*, but which has different representations in certain verbs: *went, saw, understood, took…* These are *ALTERNATIVE REALIZATIONS* of PAST-TENSE, and are therefore In an OR relationship to one another, as shown in Figure 5. But here, the alternative connections are on the lower side of the node. So we need to distinguish between *upward OR*, as in Figure 4 and the lower part of Figure 5, and *downward OR* as at the top of Figure 5. And that is not all. One of the realizations, *–d*, is the *default* form, used for most verbs, including those newly added to the system as part of the learning process. But when one of the other ("irregular") verbs is occurring, the other realization *takes precedence*, with the implication that the default realization must be blocked. This situation is represented in the network notation by the attachment of the lines at the bottom of the node. The default is the line that goes straight through while the line off to the side (either left or right of the default line just for considerations of readability) takes precedence. This type of OR node may be called a *precedence OR* (although in Lamb 1966 and most of the literature it is called *ordered OR*).

This figure also introduces the *upward AND* node, in this case for *took*. It is at this node that the conditions for taking the precedence lines from the two ordered ORs above it are either met or not met. That is, (considering the movement of downward activation) if the lines for TAKE and PAST are both activated, then the AND condition for *took* is met, and so the precedence lines are taken. Otherwise the activation proceeds along the default lines.

Clearly, there is some additional structure involved here when the network is operating that is not shown in this notation. The same can be said for the ordering of the ordered AND nodes, like those for *take* and *took*, and those in Figures 1–4. Thus we have the need for more

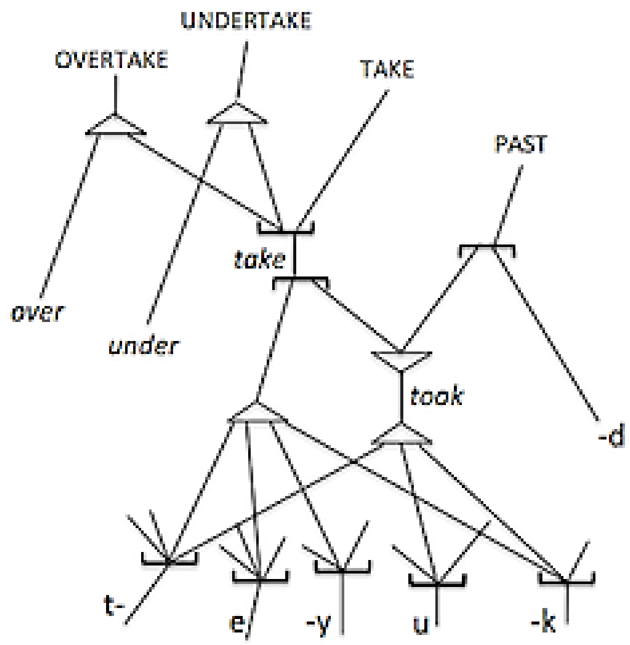


Figure 6. Present and past tense forms of three related verbs

refined modeling with a narrower notation system to specify such properties of the system (see below). The nodes of the relational network notation shown so far may be seen as abbreviations for such more detailed specification. Just as in chemistry, we have different notations showing different levels of detail.

Some analytical linguists might prefer to take account of the fact that both take and took begin with /t/ and end with /k/, so that the only difference between the present and past tense forms is the vowel or diphthong in the middle. That situation can also be represented, and in fact we can represent both catalyses within a single network diagram, as coexistent catalyses that can operate together, as shown in Lamb 1999 (pp. 235–236). But the catalysis shown in Figure 5 may be considered to represent the one that operates most for ordinary people, since learning mechanisms (see below) will assure that these forms will have become very well entrenched fairly early in the lives of typical speakers of English.

Figure 6 extends the view upwards to show the structure responsible for the fact that the past tense forms of *overtake* and *undertake* are *overtook* and *undertook* respectively, even though the meanings of these two verbs do not have any conceptual suggestion of TAKE.

6. Lexemes of different sizes and their meanings

It is often said that words have meanings, but *have* is not the correct term here, nor is *word*. Many lexical items are longer than words. This is why we need a more accurate term, and the term *LEXEME* (coined by B. L. Whorf in the 1930's) is less clumsy than *lexical item*. Also, some lexemes are shorter than words, for example, the prefix *re-*, which can productively be applied to verbs, as in *rethink, retry, renegotiate, refalsify, rehack, regoogle.*

Another thing to notice in Figure 6 is that, although *overtake* as an object occurring in a text is larger than *take*, it is *no larger in the linguistic system.* As an object in a text, *overtake* is a combination consisting of two parts, *over* and *take*, but in the linguistic system there is only a node and lines below it, connecting to structures for *over* and *take*. This is just another illustration of the fact that the linguistic system is a relational network and as such *does not contain lexemes or any objects at all.* Rather it is a system that *can produce and receive such objects.* Those objects are external to the system, not within it.

Using the term *lexeme* for the external object, we can say that lexemes (lexical items) come in different sizes. The larger ones, like *undertake* and *understand*, are represented in the system by nodes *above* and connected to those for their components. Such larger lexemes

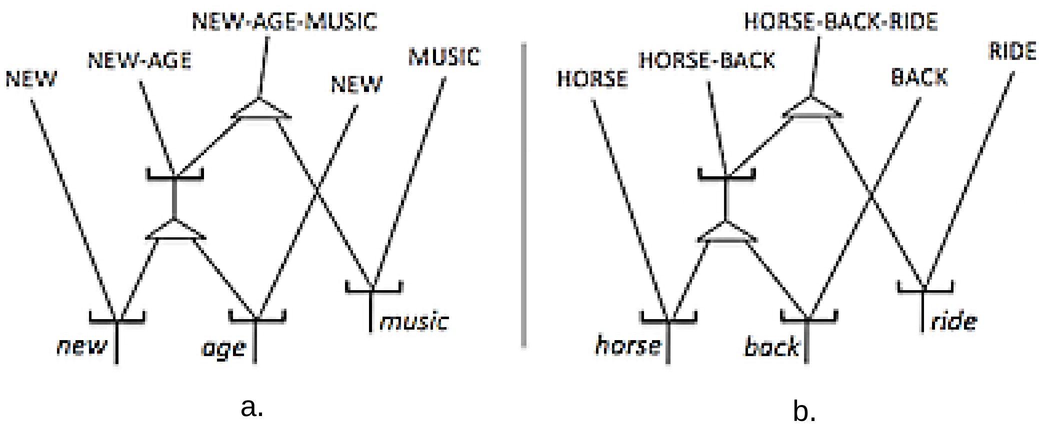


Figure 7. Linked hierarchies of lexical structure

may be called *COMPLEX LEXEMES*, and we should observe that they are very numerous, more so than may meet the eye of the casual observer. A few examples: *Rice University, The White House, give me a break, it's not rocket science, all you need to do is, comparing apples and oranges, connect the dots.*

We can also observe that the meaning of a complex lexeme may (*bluebird, White House*) or may not (*understand, cold turkey*) be related to those of its components. Those that are not may be called *IDIOMS*. Those that are may be called *transparent*, and transparency comes in degrees. But even if they are very transparent they still qualify as complex lexemes if they have been incorporated as units within the system of the language user. And they will have been incorporated if they have occurred frequently enough, according to the learning hypothesis described below. Thus idiomaticity comes in degrees. (Some people use a different definition of *idiom* that makes it roughly equivalent to what is here called a *complex lexeme*).

Also, as Figure 7 illustrates, we find lexical hierarchies. While the output *horseback ride* is larger than *horse*, each of them is represented within the structure by a single AND node. And notice that although the lexemes whose structures are shown in 7a and 7b are altogether different in both expression and content, their network structures are identical. The difference between them is not in their structures but in the fact that they have differing connections above (to content) and below (to expression).

Lexemes can have simple or more complicated relationships to their meanings. If they were all simple one-to-one relationships, there would be no need to distinguish a stratum of meaning from that of lexical structure; but they are not. For example, *soft* has two clearly distinct meanings, represent as UN-HARD and UN-LOUD. This is an example of *polysemy*. Similarly, *hard* can representable either DIFFICULT or HARD (as opposed to SOFT), while DIFFICULT can be represented by

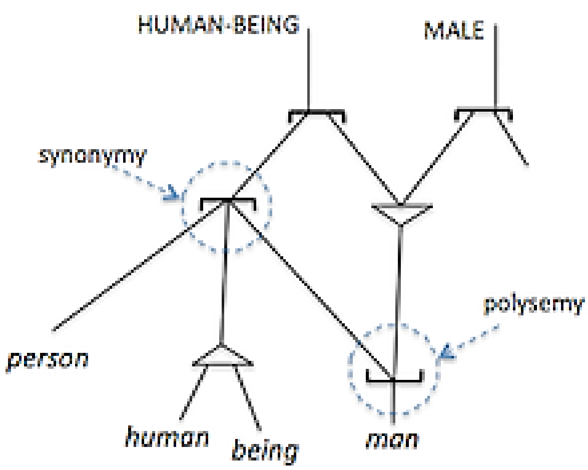


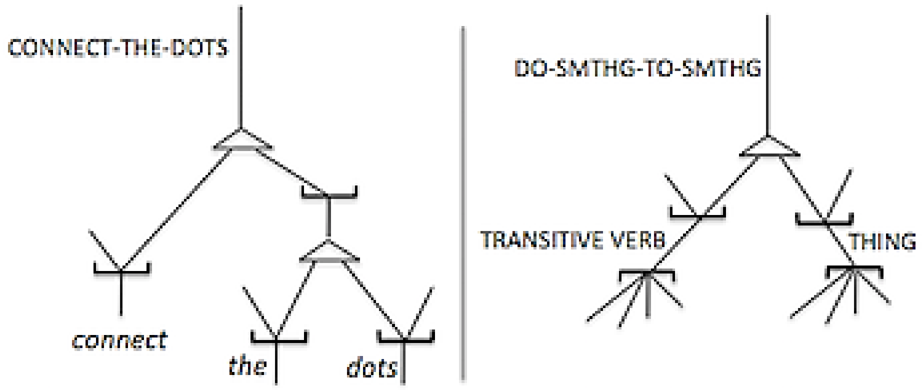
Figure 8. Example showing structure for synonymy, polysemy, and a lexeme longer than a word

either *difficult* or *hard* (synonymy). Similarly, *man* can represent either a human being or a male human being (Figure 8).

7. Syntax—Variable complex lexemes

In analytical approaches to language, those that focus on analyzing and describing texts rather than encatalyzing the system that lies behind them, syntax is often viewed as a large batch of information describable by rules. For a realistic structural linguistics (that is, an approach that takes seriously the criterion of operational plausibility) the objective is to encatalyze a reasonable hypothesis of the structure responsible for such phenomena.

We can view this information as made up of individual units of network structure added one by one to the system during the language development process, just as lexical information is added one unit at a time. These individual units of network structure correspond to the *constructions* of descriptive approaches. They are very much like the structural units for complex lexemes, the difference being that on the expression side there are multiple possibilities, such as a whole set of noun phrases, rather than just one (Figure 9).



a. *Fixed expression* b. *Variable expression*

Figure 9. Structures for a complex lexeme (left) and a construction (variable lexeme)

Another traditional term that is pertinent here is *linguistic sign*. The sign is pairing of a unit of content—the *signified*—with an expression—the *signifier*. Since it appears that at least most syntactic constructions are meaningful, we can view constructions as signs along with lexemes, and we can then say that the linguistic system as a whole is a structure that produces and interprets linguistic signs; that signs can have either fixed or variable expression; and that the process of language development consists of incorporating the structures for signs into the system, one by one. The structure in the linguistic system that corresponds to a sign may be called a *SIGN RELATION*. Using this term, we may say that the learning process consists of incorporating sign relations into the system, one by one.

To illustrate a little more relational syntax, we can expand on Figure 9b by adding other types of predicator, resulting in Figure 10, which shows the structure of Figure 9b along with two other types of predicator added at the left.

Meaning can also be expressed by the ordering of constituents. In English, we have the passive construction, the yes-no question, and the marked theme. Following the analysis of Halliday, we can say that the yes-no question is marked by expressing the finiteness element

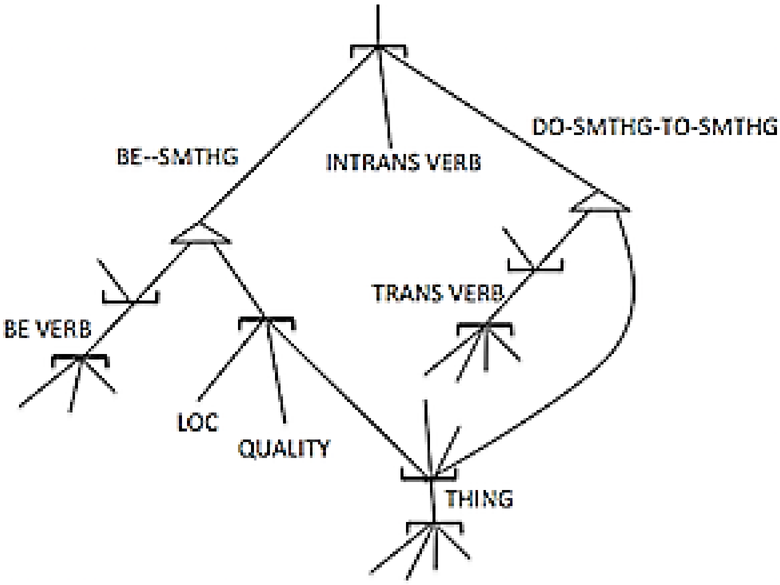


Figure 10. Some additional syntactic connections

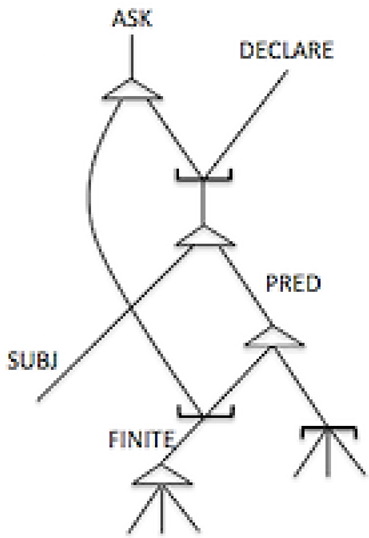
(e.g., modal auxiliary) before the subject rather than after it as in the unmarked situation (Figure 11). Similarly, the THEME-RHEME construction puts the theme first in the clause. *Subject* is the unmarked theme, but something else, like LOCATION, can be the marked theme, coming before the rest of the clause. For example, *At the lecture he dozed off.*

8. Meaning—Conceptual, perceptual and other cognitive structures

Network diagrams as shown so far have a vertical orientation such that downward is toward expression while upward is toward content (function/meaning). The ultimate bottom for the linguistic system, in the case of speaking, is the mechanisms of speech production, while for the input side of spoken language it is the cochlea and other structures of the ears, along with auditory processing structures of the midbrain. These interfaces constitute boundaries between two different kinds of structure, appropriately called *expression form,* a *relational network,* and *expression substance.* The study of expression substance, which is of course very complex, is left to other sciences.

Turning now to the upward direction, we can ask: how far does it go, does it end somewhere? Surely the system cannot keep extending upward forever. It may seem that somehow the top of the system is the locus of meanings and other communicative functions. It might also appear at first glance that meanings can be called concepts, but the situation is not that simple. To proceed, we have to take a look at some of the kinds of meanings we find.

Surveying various lexemes we see that only some of them have concepts as their meanings, including both concrete (e.g. DOG, DOCTOR) and abstract (CONFLICT, PEACE). Other lexemes have



Examples:
DECLARE: *Timmy can see it.*
ASK: *Can Timmy see it?*

Figure 11. The Yes-No question, expressed by ordering

meanings that are perceptual rather than conceptual, and others are of still other kinds, as indicated in Table 1. Far from giving a complete account, the table is intended only to be suggestive. The three-way distinction shown under Material Processes is likewise merely suggestive, as the actual situation is considerably more complex (Halliday and Matheissen 2004).

Table 1. Some kinds of meaning

Conceptual		
		Concrete—CAT, CUP
		Abstract—CONFLICT, PEACE, ABILITY
		Qualities/Properties—HELPFUL, SHY
Perceptual		
		Visual—BLUE, BRIGHT
		Auditory—LOUD, TINCKLY
		Tactile—ROUGH, SHARP
		Emotional—SCARY, WARM
Processes		
	Material	
		Low-Level—STEP, HOLD, BLINK, SEE
		Mid-Level—EAT, TALK, DANCE
		High-Level—NEGOTIATE, EXPLORE, ENTERTAIN
	Mental	
		THINK, REMEMBER, DECIDE
Relations		
		Locational—IN, ABOVE
		Abstract—ABOUT, WITH-RESPECT-TO

The difference between concepts and percepts is that percepts involve a single perceptual modality, such as vision, whereas concepts involve more than one; they thus occupy a higher level. Taking the concept DOG as an example, it has connections to percepts of multiple modalities, as the meaning DOG includes what dogs look like (visual), what a dog's bark sounds like (auditory), what a dog's fur feels like (tactile). It also includes memories of experiences with dogs within the cognitive system of the individual, and they of course differ from one individual to the next.

All these kinds of meaning are cognitive—engaging structural elements within the cognitive system—as opposed to referential, which covers all those dogs in the world outside of the mind. The latter may be said to belong to *content substance*, while the cognitive aspects of meaning belong to *content form.*

A distinction similar to that between concepts and percepts, not shown in the table, applies to processes. Considering processes of the kind performed by humans, like those mentioned in Table 1, the low level ones involve just a few relatively contiguous muscle groups while higher level processes involve multiple organs operating in coordination, both serially and in parallel. Accordingly it would be possible to draw a distinction like that between concepts and percepts: Using the stem -*funct* (as in function), we would have *confuncts* (complex processes involving multiple organs) and *perfuncts* (low-level, parallel to percepts). But in the interest of avoiding pedantry, I shall refrain from using such terms.

We can hypothesize that for both perception-conception and for motor activity we have multiple strata, as with language narrowly defined, such that each perceptual and motor modality has its own network structure, with the downward direction leading to an interface with substance while the upward direction leads to upper-level cognitive structure that, as upper level structure, integrates systems of different modalities.

As Table 1 demonstrates, the term *conceptual* is inadequate as a general term for the realm of meaning, since concepts constitute only one of several kinds of meaning. A more general term is *SEMEME*, first proposed by Adolph Noreen (1903–18) in the early days of structural linguistics, and adopted by Leonard Bloomfield (1933). Based on this term, we can use the term *SEMOLOGY* for the whole system of meaning structure.

The number of strata in different semological systems evidently varies. Vision, for one, appears to be far more complex than speech perception. It needs not only more strata but also different systems at its lower levels for different kinds of visual features, including color, shape, and motion.

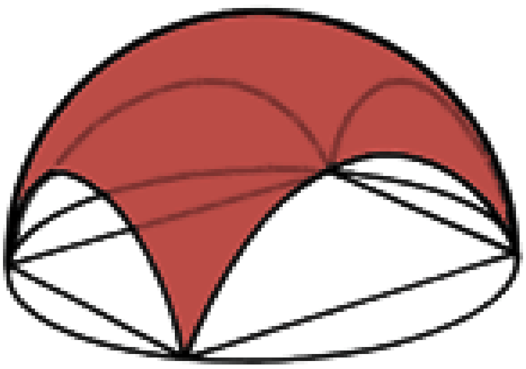
We can visualize an approximation to the situation as a *cognitive dome*, somewhat like than shown in Figure 12, in which semological structure is the large area at and near the top, while the four leg-like portions represent (1) speech input, (2) speech output, (3) extra-linguistic perception, (4) extra-linguistic motor activity. It is only a rough aid to visualizing the actual situation, since what we really have is a separate leg for each perceptual modality, and several to many legs for motor structures, depending on how we choose to count.

As the figure suggests, the numerosity of distinguishable features is greater at higher strata than at lower. For example, in spoken language we have only about a dozen articulatory features, two to three dozen phonemes, a few thousand morphemes, tens of thousands of lexemes, and hundreds of thousands of sememes. The same type of relationship evidently exists for the other systems.

The conclusion of this line of reasoning is that meaning structures are not simply *above* lexicogrammatical structures, in the same way that lexicogrammatical structures are above phonological structures. Rather, they are *all over the cognitive system*: Some, including concepts, are above, while others, including percepts, are not.

At this point we encounter the question of how far linguistic structure extends. We could take the position that these other systems are not part of linguistic structure and therefore don't have to be included in the investigation. That proposal would lead to an impoverished understanding. Conceptual structure and perceptual structure and the rest are so intimately tied up with the rest of linguistic structure that the latter cannot be understood without including the former. There are two major reasons for this conclusion: (1) the semological categories are highly relevant to syntax; (2) semological structure is largely organized as a hierarchical system of categories, and this categorical structure, along with the thinking that depends on it, varies from language to language and is largely learned through language (cf. Whorf 1956, Boroditsky 2009, 2011, 2013, Lamb 2000, Lai & Boroditsky 2013).

Moreover, the boundaries between conceptual structure on the one hand and perceptual and motor structures on the other are also at best very fuzzy, so there seems to be no clear



The four legs can be construed as (1) speech input, (2) speech output, (3) extra-linguistic perception, (4) extra-linguistic motor activity.

(figure from Wikipedia: http://en.wikipedia.org/wiki/Dome)

Figure 12. The cognitive dome

boundary anywhere within the cognitive dome. And so the quest for boundaries for language comes up empty: *There is no discernable boundary anywhere within the cognitive system*. We conclude that the investigation of linguistic structure takes us to a way of understanding cognition in general, including the structures that support perception and motor activity.

Unless and until we encounter evidence to the contrary, it is reasonable to continue with the hypothesis that conceptual structure and other cognitive structures consist of relations forming a network. But we need to be prepared for differences of network structure, and to adjust the relational network notation as needed.

9. Narrow Notation

The relational network notation as described up to this point operates in two directions. This bidirectionality suggests that there are actually separate structures for the two directions that are not shown in the notation as described thus far. There are also additional structural features so far left unspecified, including the temporal ordering implied in the ORDERED AND node and the precedence implied in the PRECEDENCE OR (ORDERED OR). To make such details explicit we need a more refined notation. It can be called *NARROW NOTATION*. In narrow notation all lines have direction (i.e., they are *directed*), it generally has two lines of opposite direction corresponding to each line of *ABSTRACT NOTATION*. Similarly, every node of abstract notation (also known as *COMPACT NOTATION*) corresponds to two (or more) nodes of narrow notation, as illustrated in Figures 13 and 14 (for details, see Lamb 1999: 77–83). The two levels of notational delicacy are like different scales in maps. In a more abstract map, divided highways are shown as single lines, while maps drawn to a narrower scale show them as two separate lines; and if narrow enough, the structures of the interchanges are shown.

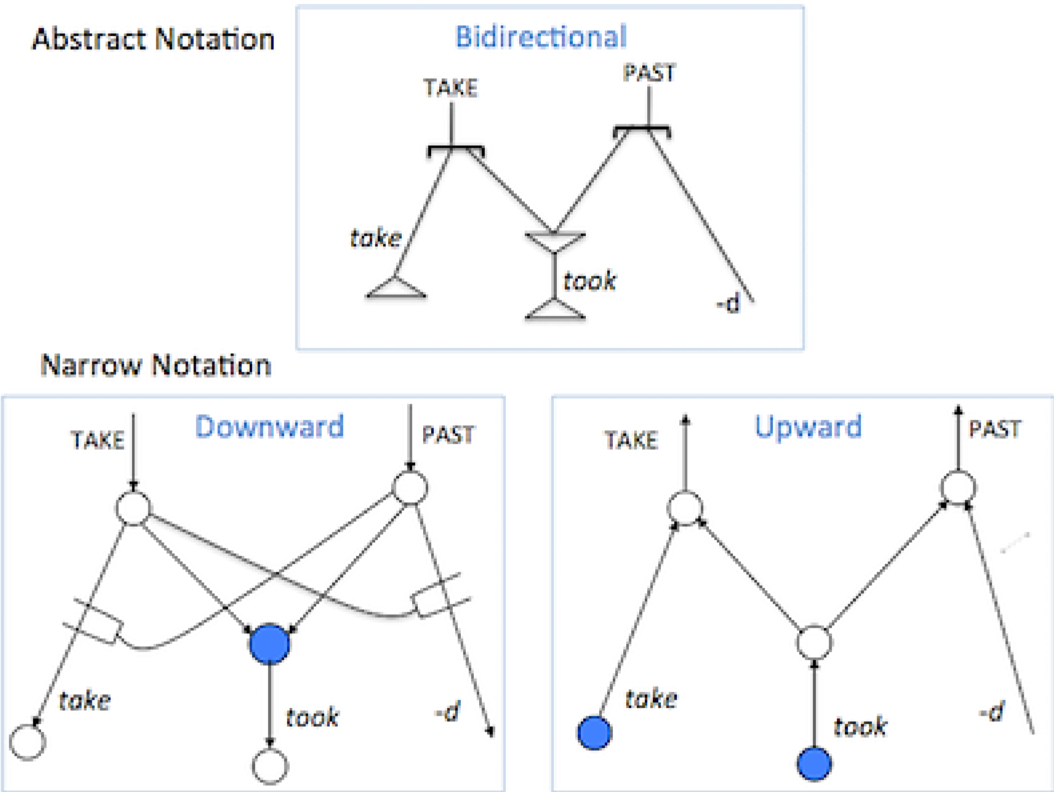


Figure 13. Abstract and Narrow Notation: the ORDERED OR

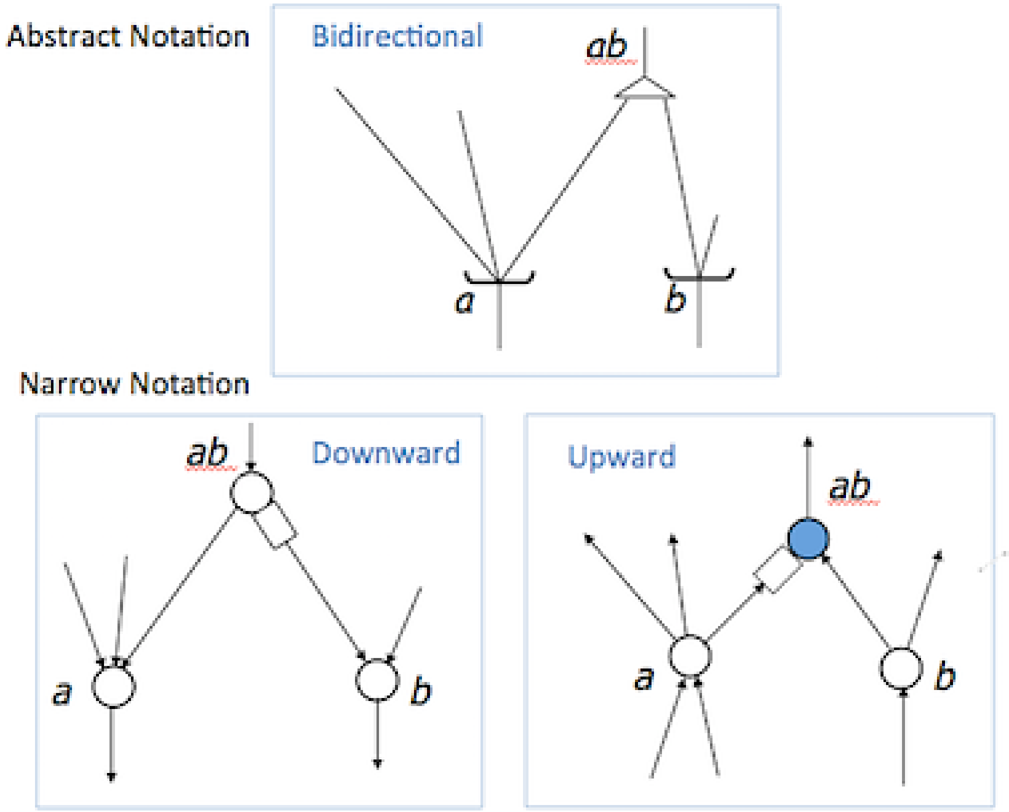


Figure 14. Abstract and Narrow Notation: the ORDERED AND

In narrow notation every node is drawn as a little circle, and the difference between AND and OR is recognized as a difference in threshold of activation: The AND requires both (or all) of its incoming lines to be activated to satisfy its threshold of activation, indicated by a filled-in circle, while the OR node needs only one incoming line to be active. A notational alternative is to write a little number inside the circle indicating the number of incoming lines that need to be active for the node to send activation onward, 1 for OR, 2 for AND.

For the PRECEDENCE OR, illustrated in Figure 5 above, further specification is needed to show the structure responsible for precedence. In abstract notation the line connected off to the side takes precedence. Therefore there must be a means of blocking the other line, the default representation. So in Figure 13 we have, in the downward direction, a *blocking element* from the node for TAKE to the line leading to the default realization of the past tense element, and a *blocking element* from the node for the past tense element to the line leading to the default realization *take*. The blocking element blocks any activation that might be traveling along the line it connects to.

Figure 14 shows the structure needed to make the ORDERED AND work. The little rectangle in the narrow notation is the *WAIT ELEMENT*. When the node ***ab*** is activated in the downward direction, the activation proceeds to both of the output lines, but the connection leading to ***b*** goes first through the WAIT element since ***b*** has to be activated *after* ***a***.

Clearly, this WAIT element likewise requires further specification. The amount of waiting time evidently varies from one type of structure to another, suggesting that there are different varieties of WAIT element. In phonology the amount of delay from, say, one segment to the next is small and relatively fixed, so the timing might be specified by the regular “ticking” of a "clock". In terms of brain structures such "ticking" may be provided by the thalamus, which sends signals throughout the cortex at fixed short intervals. For a wait element in syntax, on the other hand, the amount of delay is variable. In the case of the construction providing for a *subject* followed by a *predicate* (Figure 11), the activation for the predicate proceeds only after that for the subject, which can be as short as one syllable or long enough to include a relative clause. In such cases the timing seems to require feedback control; that is, the waiting of the wait element continues until a feedback signal is received (from 'f'), as indicated in Figure 15. Notice that the little loop keeps the activation alive until the feedback arrives, and that the feedback activation goes not only to the high-threshold node so that it can proceed to ***b***, but also turns off the little loop. (For details, see Lamb 1999: 98–102 and http://www.langbrain.org/Ordered-and).

10. Variation of thresholds and connection strengths

The study of conceptual and perceptual systems soon makes it apparent that there is much more to the question of the threshold than the simple distinction between AND and OR that seems to work so well in phonology and grammar. I say "seems to" in the preceding sentence because a closer look just at these levels suggests that we need refinement there as well. In a noisy room, for example, a hearer doesn't have to have every AND node fully satisfied in order to understand the words being received.

What we evidently need are thresholds of intermediate value, *between* AND and OR. A simple case of *intermediate threshold* would be a node with three incoming lines any two of which can activate the node; or we might have one with any three out of four, and so forth. Such intermediate thresholds can be indicated by little numbers written inside the circle, or more roughly by degrees of shading of the fill, solid fill for high threshold, intermediate degrees of shading for intermediate thresholds. For reasons given below, such rough indication, while not very accurate, is nevertheless quite useful, since accurate portrayal of thresholds in a simple notation is not practical.

Nodes of intermediate threshold turn out to be essential in accounting for conceptual and perceptual structure, since most concepts and percepts do not have a fixed number of defining properties. For example, within the category of drinking vessels, an object will generally be recognized as a CUP rather than a GLASS or a MUG if it has just two or three significant properties like SHORT, HAS-HANDLE, NOT-MADE OF-GLASS, ACCOMPANIED-BY-SAUCER, TAPERED (top larger than bottom) (Labov 1973). But that is only a first approximation, since there are many other properties albeit of lesser—but not neg-

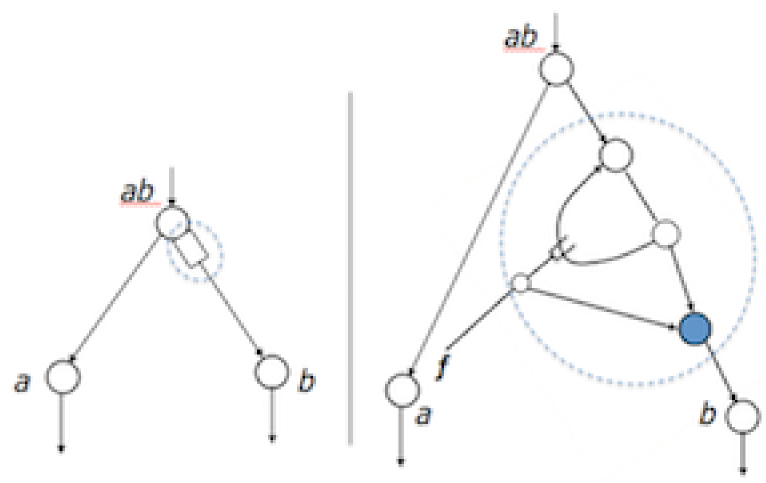


Figure 15. The Wait Element (with feedback control), abbreviated and detailed notations

(For animation see: http://www.langbrain.org/wait-anim-fb.html) ligible—importance (Labov 1973, Wierzbicka 1984). Their lesser importance may be accounted for if we posit that nodes for different properties have different strengths of connection to the concept node. Strengths of connection can be roughly indicated in graphs by the thickness of lines. The node will be activated by *any of many different combinations* of properties.

The situation is roughly depicted in Figure 16, in which the lines have varying thickness and the nodes are shown with varying degrees of shading, indicating intermediate thresholds of differing value, such that if *enough of* the incoming connections are active, the threshold is satisfied. The key word is *enough*—it takes *enough* activation from *enough* properties to satisfy the threshold.

Since the property MADE-OF-GLASS is a negative indicator—a vessel is more likely to be a cup if it is *not* made of glass—its connection to the CUP node has to be inhibitory. And so we need to have both *excitatory connections*, which if active contribute to satisfaction of the node's threshold of activation, and *inhibitory connections*, which if active *detract from* satisfaction of the threshold. The inhibitory connection is indicated with a tiny circle (Figure 16). This is actually the second of two types of inhibitory connections needed in relational networks. The first, seen in Figures 13 and 15 above, attaches to a line rather than to a node.

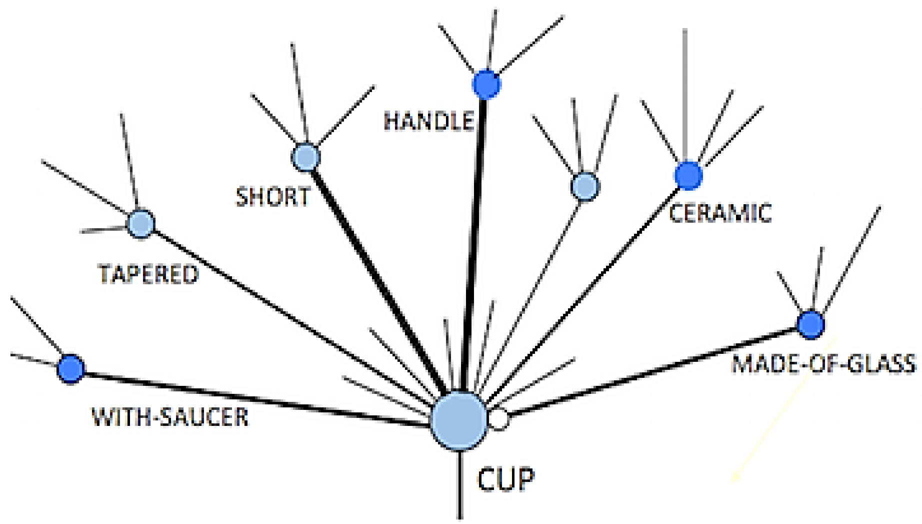


Figure 16. A concept node of intermediate threshold with connections of varying strength (higher is *not* more abstract, as this structure is near the top of the cognitive dome)

And there is yet more to the story. The structure shown in Figure 16 guarantees that a node like that for CUP will be activated *to different degrees* by different combinations of properties. For example, more activation will enter the node for prototypical cups than for peripheral members of the category, since the prototypical ones are those that provide activation from stronger connections and from more connections. Therefore the threshold of the node is not only satisfied, it is *strongly* satisfied for a prototypical cup.

Prototypicality effects have been *described* in numerous publications beginning with those of Eleanor Rosch in the 1970's, but that literature does not provide an account of the structure that *explains* the phenomena.

From the foregoing it is apparent that threshold satisfaction is a matter of degree. It seems reasonable to hypothesize that a higher degree of incoming activation causes a higher degree of activation along the output connection(s) of that node. Thus if the CUP node is strongly activated, as in the case of a prototypical cup, it sends out stronger activation than if it is weakly activated, as would be the case for a vessel that is short, has no handle, and is made of glass; in such a case the node might just barely be activated. Stronger activation would contribute, for example, to faster recognition. So prototypical exemplars provide stronger and more rapid activation.

And so threshold is not specifiable by a simple number. Rather we must assume that every node has a *threshold function*, such that (1) weak incoming activation produces little or no outgoing activation, (2) a moderate amount of incoming activation produces a moderate amount of outgoing activation, (3) a high degree of incoming activation results in a high degree of outgoing activation. Thus outgoing activation is a function of incoming activation, but the relationship is doubtless more complex than a simple linear proportion (that would be graphed as a straight line). It is far more likely that any node has a maximum level of activation that is approached asymptotically beyond some high level of incoming activation. Such considerations lead to the assumption of a sigmoid function, as illustrated in Figure 17 (see also Lamb 1999: 206–212).

To summarize this group of hypotheses, we have to recognize three kinds of variability:

(1) Connections (shown in graphs by lines) differ from one another in strength. A stronger connection transmits more activation than a weaker one, if both are receiving the same amount of activation.

(2) Nodes have threshold functions, so that outgoing activation varies with amount of incoming activation; and different nodes have different threshold functions.

(3) A connection of a given strength can carry varying degrees of activation from one moment to the next, since each node is sending out varying degrees of activation in accordance with property 2.

Further observation of language and linguistic processing requires the catalysis of additional properties in narrow relational networks (Lamb 2013: 157–160). Of particular importance, we have to recognize that the downward and upward structures (as in Figures 13 and 14) need not be contiguous or even close to each other.

11. Neurological plausibility

We now turn to the question of how relational networks (RN) are related to neural networks (NN). Relational networks were devised to account for linguistic structure; their properties, as sketched above, depend on properties of language. Evidence for these properties comes from language, not from the brain. But we know that the brain is the locus of linguistic structure and that it is a network of neurons. And so *we may view every property of narrow RN notation as a hypothesis about brain structure and function.*

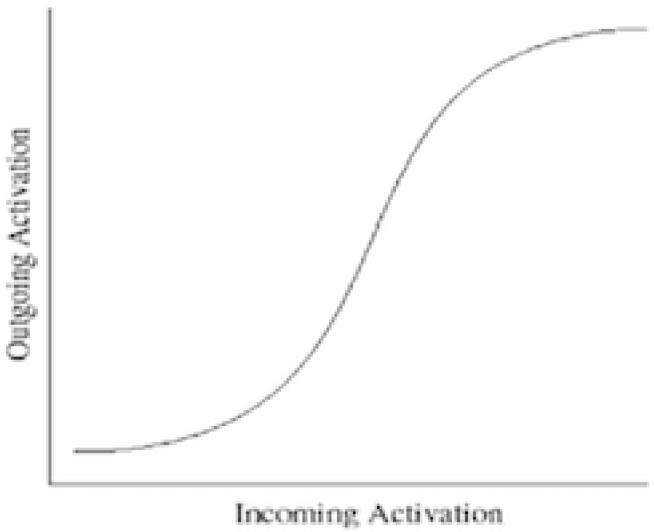


Figure 17. A threshold function: greater incoming activation produces greater outgoing activation (different slopes for different nodes)

Relevant properties of brain structure are known partly from neuroanatomy and partly from experimental evidence. Let us begin with properties of RN structure that can be tested against neuroanatomical findings. First, RN and NN are both connectional structures. Neurons do not store symbolic information. Rather, they operate by emitting activation to other neurons to which they connect via synapses. This activation is proportionate to activation being received from other neurons via synapses. Therefore, a neuron does what it does by virtue of its connections to other neurons.

In relational networks, connections are indicated by lines, while in NN, connections consist of neural fibers and synapses. The fibers of NN are of two kinds, *axonal* and d*endritic*. A neuron has an *axon*, typically with many branches, carrying electrical output from the cell body, and (typically) many *dendrites*, bringing electrical activity into the cell body. Dendrites allow the surface area for receiving inputs from other neurons to be very much larger than the cell body alone could provide for. This property is not present in RN but some corresponding notational device would be needed if diagrams were drawn to reflect the complexity of connectivity more accurately. For example, the actual number of connections to the concept node for CUP is considerably larger than what is shown in the simple representation of Figure 16, in which the surface area needed for showing incoming lines has been made large enough simply by increasing the size of the node. To show hundreds of incoming connections would require a greatly expanded circle for the CUP node—too awkward and inelegant—or else (and preferably) a new notational device that would correspond to dendritic fibers.

As Table 2 shows, there is a remarkable degree of correspondence between RN and NN, especially considering that the properties of RN structure come just from examination of language; that is, relational networks were constructed *without using neurological evidence*. So the old saying that language is a window to the mind turns out to have unexpected validity. On the other hand, this correspondence should not really come as a surprise. *The brain is where linguistic structure forms. If cortex had a different structure, then linguistic structure would not be the same.*

Table 2. Properties of connections in relational networks (RN) and neural networks (NN)

Properties of RN Connections	**Properties of NN Connections**
Lines have direction (they are one-way)	Nerve fibers carry activation in just one direction
Connections are either excitatory or inhibitory	Connections are either excitatory or inhibitory (from two different types of neurons, with different neurotransmitters)
Inhibitory connections are of two kinds: Type 1: Connects to a node (Figure 16) Type 2: Connects to a line (Figures 13, 15)	Inhibitory connections are of two kinds: Type 1: Connects to a cell body (“axosomatic”) Type 2: Connects to an axon (“axoaxonal”)
Connections come in different strengths	Connections come in different strengths—stronger connections are implemented as larger numbers of connecting fibers, hence larger numbers of synapses
A connection of a given strength can carry varying amounts of activation	A nerve fiber (especially an axon) can carry varying amounts of activation—stronger activation is implemented as higher frequency of nerve impulses (“spikes”)
Nodes have threshold functions such that amount of outgoing activation is a function of incoming activation	Neuron cell bodies have threshold functions such that amount of outgoing activation is a function of incoming activation

More on the varying degrees of activation: A neuron receives activation from other neurons via synapses located on dendrites and on the cell body. Summation of the incoming activation takes place at the *axon hillock*, from which the axon extends. The summation consists of adding together all of the currently incoming excitatory activation and subtracting the inhibitory activation. The result of summation determines the amount of activation sent out along the axon and to its branches. The amount of activation varies from roughly 1 to 100 pulses per second. Each axon branch ends in a presynaptic terminal. A synapse consists of the presynaptic terminal plus a postsynaptic terminal located on the cell body or a dendrite of another neuron, together with an intervening synaptic cleft, typically about 20 nanometers across. When activation reaches a synapse, it sends neurotransmitter molecules into the synaptic gap, and their quantity is proportional to the amount of electrical activation arriving at the presynaptic terminal (see animation by Jokerwe at https://youtu.be/HXx9qlJetSU).

Types of cortical neurons

Cells with excitatory output connections
- Pyramidal cells (about 70% of all cortical neurons)
- Spiny stellate cells (in layer IV)

Cells with inhibitory output connections (differing in axonal branching structure)
- Large basket cells (two subtypes)
- Columnar basket cells
- Double bouquet cells
- Chandelier cells
- Other

There is great variation in length of axon fibers
- Short ones—less than one millimeter
- Long ones—several centimeters
- Only the pyramidal cells have such long axon fibers

See also:
www.langbrain.org/Neurons.html
http://www.ruf.rice.edu/~lngbrain/Sidhya/#Types of Cells

Excitatory and inhibitory activation use different neurotransmitters, produced by two different kinds of neurons; that is, every neuron is either excitatory or inhibitory in nature. Figures 13 and 15 above show both excitatory and inhibitory connections coming from the same node, a property which might seem at first glance to be a discrepancy; but it is not, since the node of RN corresponds to a group of neurons, not to just one (see below).

Having observed close correspondences between RN and NN with respect to connectivity and activation, we come to the next question: What kind of neurological unit corresponds to the node of (narrow) RN notation? For several reasons, the possibility that a node of RN could correspond to a neuron has to be ruled out. To mention two of them, a single neuron (1) is rather unreliable in its firing patterns—it can occasionally fire even when not receiving any incoming activation, and (2) is quite fragile. So to operate reliably a system needs to have the redundancy that is provided by groups of neurons working together.

At this point, examination of language is of no further help so we turn to neuroscience, not for confirmation as above but for new information. The findings that are most pertinent come from the work of Vernon Mountcastle (1918–2015) and several of his colleagues, including in particular David Hubel (1926–2013) and Torsten Wiesel (1924—). From their voluminous experimental findings, summarized recently (Mountcastle 1998), it is clear that, as Mountcastle says (1998: 192), "[T]he effective unit of operation…is not the single neuron and its axon, but bundles or groups of cells and their axons with similar functional properties and anatomical connections". More precisely, these bundles are *columns* of neurons, called *cortical columns*, in which cell bodies are stacked vertically. Mountcastle discovered and characterized the columnar organization of the cerebral cortex in the 1950s. Many in neuroscience did not accept his findings (and some still do not accept them), but for others the discovery was considered a turning point in investigations of the cerebral cortex. David Hubel in his Nobel Prize acceptance speech said Mountcastle's "discovery of columns in the somatosensory cortex was surely the single most important contribution to the understandding of cerebral cortex since Cajal".

Some properties of the (mini)column

Roughly cylindrical in shape

Contains cell bodies of 70 to 110 neurons (typically 75–80), about 70% of which are pyramidal, while the rest include other excitatory neurons and several kinds of inhibitory neurons

Diameter is about 30–50 µm, slightly larger than the diameter of a single pyramidal cell body

Two to five mm in length, extends thru the six cortical layers

If expanded by a factor of 100, the dimensions would correspond to a tube with diameter of ⅛ inch and length of one foot

The entire thickness of the cortex (the grey matter) is accounted for by the columns

(Based on Mountcastle 1998)

A typical cortical minicolumn is about 3 mm tall (the thickness of the cortex) and contains 70–100 neuronal cell bodies. Larger columns consisting of bundles of adjacent minicolumns also have functional importance (see below). All of the cell bodies of a minicolumn have the same response properties; that is (as numerous experiments have shown) when one cell in a column is activated all of them are.

In a typical experiment, a microelectrode, tiny enough to detect activation in a single neuron, is inserted into the paw area of a cat's sensory cortex (Mountcastle 1998). It detects electrical activity in response to stimulation of one precise point on the cat's paw. As the electrode is gradually inserted further, to vertically adjacent neurons, it detects activity in response to stimulation *of the same point*; and so forth, for every neuron in the column. Of course, the neuronal cell bodies are very small and adjacent columns are tightly packed, so it is easy for the electrode to detect a cell of a neighboring column upon deeper penetration, instead of one in the same column. In this case, the electrode responds to stimulation of *an adjacent point* on the cat's paw.

Experiments of this kind have been done also for visual cortex and auditory cortex of cats and monkeys, with corresponding results. As Mountcastle writes (1998: 181), "Every cellular study of the auditory cortex in cat and monkey has provided direct evidence for its columnar organization". He further points out that the columnar theory is confirmed by detailed studies of visual perception in living cat and monkey brains, and that this same columnar structure is found in all mammals that have been investigated. They establish as a general property that the neurons of a cortical minicolumn have the same response properties, indicating that the minicolumn functions as a unit. Accordingly, he concluded that the column is the fundamental module of perceptual systems, and probably also of motor systems.

In addition to the cell bodies, a cortical column contains axonal and dendritic fibers, including axonal fibers from distant cortical locations, which extend to the top layer of the cortex, where they have liberal branching providing connections to columns in the vicinity. Every pyramidal cell—the most common type in any column—has an *apical dendrite* extending upward to the top layer of the cortex, with many branches extending up to a few millimeters into the territory of neighboring columns. They are especially copious at the top layer, where they are available to receive activation from any of the many axonal fibers from more or less distant cortical regions. There are additional dendrites extending outward from the cell body. The axon of a pyramidal cell extends downward from the bottom of the cell body. It is typically very long, extending into the white matter and to a more or less distant location, up to several centimeters away. The axon also has numerous branches, not only at those distant locations but also quite close to its point of origin at the cell body. These *collateral* branches extend upward, as do axonal fibers from *spiny stellate cells*, activating other pyramidal cells in the same column, thus guaranteeing their activation.

These excitatory connections from cells in a cortical column to other cells of the same column provide neurological confirmation for the hypothesized WAIT element of RN used for sequencing (Figures 14 and 15 above). The vertical connections of pyramidal and spiny stellate cells activate other cells in the column, and reciprocal vertical connections between upper and lower layers keep the activation alive while the column awaits further input. The blocking element needed for turning off the WAIT element is provided by one or more inhibitory neurons within the column such as the chandelier cell, whose vertical axon terminates with inhibitory synapses on axons of pyramidal cells within the same column.

Some cortical quantities

The cortex accounts for 60–65% of the volume of the brain, but has only a minority of the total neurons of the human brain
Surface of the cortex: about 2600 sq cm (about 400 sq inches)
Weight of brain: 1,130–1,610 grams, average: 1,370 grams
Thickness of cortex: 1.4–4.0 mm, average: 2.87 mm
Number of neurons in cortex (avg.): ca. 27.4 billion
Number of minicolumns in cortex: ca. 350 million (i.e., 27,400,000,000 / (75–80))
Neurons beneath 1 mm^2 of surface: 113,000
Minicolumns beneath 1 mm^2 of surface: 1,400–1,500 (i.e., 113,000 / (75–80))
Minicolumns beneath 1 cm^2 of surface: 140,000–150,000
Approximate number of minicolumns in Wernicke's area (est. 20 cm^2): 2.8–3 million
(Based on Mountcastle 1998)

Since the columns extend from bottom to top of the cortex, they account entirely for what is called the *GREY MATTER*. The *WHITE MATTER* consists of *cortico-cortical connections* (connections from one part of the cortex to another), which are *axons* of *pyramidal neurons*, each of them surrounded by a *myelin sheath*. It is called white matter because that is the color of the myelin. The myelin greatly enhances the speed of transmission of the neural impulse, to the extent that an impulse can travel along a myelinated axon up to 100 times faster than (unmyelinated) axons traveling through grey matter. The myelin also provides insulation, which is needed since different axons are generally closely contiguous to one another in bundles.

A column also has several kinds of inhibitory neurons, with some axon branches connecting to other points within the same column, while others extend horizontally within the grey matter from a minicolumn to neighboring minicolumns. These axons are generally very short, up to one or two millimeters.

In the middle of each column (layer IV) are spiny stellate cells, which receive activation at regular intervals from the *thalamus*, centrally located under the cortex. A wondrous organ with fibers reaching out to cortical columns throughout the cortex, it sends activation sweeping across the cortex at varying rates of speed depending on the state of consciousness, up to 40 times per second. Like the conductor of a vast orchestra, it provides the timing coordination needed for mental activity. It is available to provide the clock timing mentioned above in connection the WAIT element. It is also vitally important for other situations requiring timing coordination. Consider, for example, a person receiving speech input at the rate of around 3 syllables per second. While one syllable is being processed phonologically, the next is already entering the system. And when activation from the phonological layer is reaching lexicogrammatical portions of the network, new phonological input is simultaneously being received. For the management of this extremely complex and little understood processing we have to be grateful to the thalamus, a truly marvelous neural structure.

12. Learning—Developmental plausibility

Since all of the information in a relational network structure is in its connectivity, learning would seem to be a matter of building connections. But that is not the only possibility: The alternative is to assume that all or most of the connections that will be needed for representing the information that will be learned during a lifetime are *already there in a latent form* and that the learning process consists of *strengthening these* LATENT CONNECTIONS and *activating* LATENT NODES. This assumption, which may be called the *ABUNDANCE HYPOTHESIS*, while presumptuous, confers the great advantage of allowing us to treat entrenchment and development as basically the same process.

The process of *ENTRENCHMENT,* which goes on throughout life, or up to limits imposed by senility, is accounted for in a relational network model as strengthening of established connections as a result of repeated use. Lexical items as well as syntactic constructions (variable lexemes) vary widely from one another with respect to how often they have been used. So for example we can say that for most people *strange* is more heavily entrenched than *bizarre*, and that the 'respectively' construction, as in *Jimmy and Tommy dated Jane and JoAnn respectively*, is not at all entrenched in most English speakers other than mathematicians, and not even established at all in many.

So we need to ask, how does a connection get stronger? We have already observed (Section 10) that different links have different strengths, crudely representable in diagrams by different line thicknesses. Stronger links represent more heavily entrenched information. The answer to the question is simple: A connection gets stronger through repeated successful use, just as a pathway through a field becomes more worn and therefore easier to walk on as a result of repeated use. That notion can be defined more precisely as follows: (1) *Links get stronger when they are successfully used*; (2) *successful use* means that activation of the link in question has contributed to satisfaction of the threshold of the target node; that will be the case if one or more other connections to same node is simultaneously active such that the node's threshold is satisfied. A typical simple scenario is illustrated in Figure 18, in which latent links and a latent node at left (initially with very low threshold) become dedicated (right). This hypothesis is similar to one proposed by the psychologist Donald Hebb (1949), or it can be seen as a formal specification of the hypothesis proposed by Hebb in a vague form.

A third part of the specification concerns the threshold of the activated node: As a result of successful activation, the threshold of the node is raised. The adjustment (moving the curve of Figure 17 to the right and possibly altering the slope) is needed since the increased strength of the incoming links would otherwise allow the threshold to be too easily "satisfied" in the future.

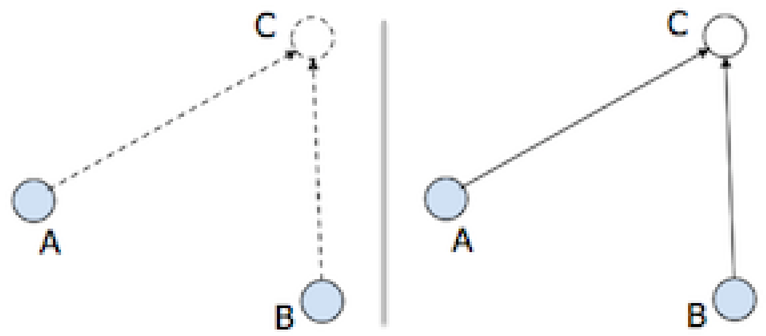


Figure 18. Basic learning process: If connections AC and BC are active at the same time, and if their joint activation is strong enough to activate C, they both get strengthened and the threshold of C is adjusted

This simple hypothesis, along with the *ABUNDANCE HYPOTHESIS* proposed above, provides an answer to the basic question of relational network formation: How does the system get those seemingly hard-wired connections that are seen in linguistic network diagrams? How can it ‘know’ how to build the precise connections that it must build for linguistic performance, during the process of language learning? The answer is that it doesn’t need to know at all; it just *proliferates possibilities beforehand* (the abundance hypothesis), and the *learning process is one of selection*. It is a Darwinian process, analogous to that which leads to the origin of species and to complex biological structures (compare Edelman 1987). At each of many steps in the process it proliferates possibilities, and those that succeed pass their genetic material to the next generation.

In the application of this principle to learning, what corresponds to the next generation is the next higher layer of network structure. This scenario is consistent with bottom-up learning: Lower levels are generally established (to some extent) before higher levels. This property of the learning process is easily observed in the progress of children acquiring their linguistic and other skills and is confirmed by neuroanatomy in that the growth of myelin sheaths around axons of pyramidal neurons spreads from lower to higher levels during early childhood.

As mentioned, the process of new learning (for example, of a new lexical item) is the same as that for entrenchment of already established information. In the case of new learning, previously *LATENT* links and nodes become *ESTABLISHED* or *DEDICATED*. In the case of entrenchment, established connections become stronger.

Two aspects of this hypothesis need to be checked for neurological plausibility: (1) mechanisms of connection strengthening, (2) the abundance hypothesis. Both appear to be supported by the neurological evidence.

The processes of strengthening of neural connections have been under active investigation for years in neuroscience. They include biochemical changes at synapses, formation of new synapses, and growth of dendritic spines (increasing the receptive area of a dendrite).

The abundance hypothesis, a prerequisite for this view of learning, is that there must be enough latent nodes and links available throughout the system to support a lifetime of learning. Note that this requirement, while presumptuous, is not as outrageous as it may appear at first glance. We are *not* requiring that there be enough latent nodes and links to learn anything at all. Our human brains, while marvelous, are limited. We can *not* in fact learn anything at all. The great preponderance of information we are bombarded with every second passes by unretained; in fact, most of it is simply unnoticed. Another factor is that learning takes time and our time on Earth is limited. This quantitative question is explored further elsewhere (Lamb 1999: 341–343, Lamb 2005), along with considerably more discussion of learning (Lamb 1999: Chapters 10 and 12).

Extent of neuronal fibers in the cortex

Estimated average 10 cm of fibers per neuron (a conservative estimate)
Avg. cortex has about 27 billion neurons
27 billion × 10 cm = 2.7 billion meters
Or 2.7 million kilometers
– About 1.68 million miles
– Enough to encircle the world 68 times
– 7 times the distance to the moon

Number of synapses in cortex

40,000 synapses per neuron (4×10^{4})
And 27 billion neurons (27×10^{9})
$4 \times 10^4 \times 27 \times 10^9 = 108 \times 10^{13}$
or about 1.1×10^{15} (over 1 quadrillion)

The abundance hypothesis implies that most of the thousands of fibers connecting one neuron to others along with their associated synapses are very weak—that is, latent, available to be called upon if needed—and as such are not actively functioning in information processing, but are available for new learning. It thus asserts that the number of connecting fibers of the typical cortical neuron is very large just for the purpose of providing for flexibility of learning—to enable (the neurological bases of) latent nodes to be available to assume any of a very large number of functions, which, especially at higher levels of the cognitive dome (corresponding neurologically to higher cortical levels), could not have been foreseen in advance and could not have been specifically prepared for by processes of evolution in any way other than the development of mental flexibility. Thus there is no other way than through development of extreme cognitive flexibility that humans could have evolved to be able to fly aircraft and spacecraft, design and program computers, go skydiving, write plays, compose operas, etc.

In support of the abundance hypothesis, with its apparent gross redundancy, it can first be noted that abundance *cum* inefficiency is a very widespread property of biological systems and one that goes along with Darwinian processes generally. Take for example the thousands of acorns that fall from an oak tree, or the thousands of eggs laid by a sea turtle, only a few of which will lead to viable offspring. Like these other biological processes, learning works by a process of trial and error: Thousands of connection possibilities are available (the abundance hypothesis), and those few that succeed are strengthened and become available for the next steps—in this case, for the next layer of learning. Gerald Edelman (1987, 1989) calls this process *neural Darwinism*. He also writes (1987), "… if one explores the microscopic network of synapses with electrodes, the majority of them are not expressed, that is, they show no detectable activity. They are what have been called silent synapses".

A typical pyramidal neuron has thousands of incoming synapses from other neurons connecting to its dendrites and its cell body, and thousands of output synapses at the many branches of its axon. But only a very few of these are ever recruited for specific functions. The typical lexical node, for example, has perhaps only a few dozen links, and a typical conceptual node has maybe up to a few hundred. These vast numerical discrepancies between (1) number of available connections and (2) number of dedicated connections are multiplied when we consider that the effective unit of operation, corresponding to the node of RN, is the column, a unit containing many pyramidal neurons. And so we safely conclude that by far the great preponderance of the available links are indeed latent.

13. Inter-nodal proximity

I conclude this sketch of linguistic structure and cortical structure—from which, as we see, it can't be separated—with a look at the importance of locations of nodes in the network. Much of this section consists of proposals that are new to neuroscience and thus are offered as contributions from the study of linguistic structure to cognitive neuroscience. Whether they will be accepted remains to be seen.

The starting point is a property of relational networks and cortical networks that may be called *FUNCTIONAL SPECIFICITY*. It is implicit in all of the RN diagrams of the figures above but has not yet been explicitly discussed. *FUNCTIONAL SPECIFICITY* is a property of every node of an RN (and every column of an NN): *Every node has a specific local function.* For example, the node for CUP in Figure 16 has a specific conceptual value, suggested by the label CUP. We can't say exactly what that value is, of course, not even for one person, although we can be quite sure that it varies from one individual to the next, depending on each one's previous experience with cup-like objects, for that experience will have resulted in connections of definite but varying strengths from each of a large number of other nodes representing properties, along with a connection to and from a node representing the lexical item *cup.*

To appreciate the feature of functional specificity of RN, we have to be clear that while the cup node is specifically dedicated to a particular concept, *it does not on its own represent any of the multitudinous facts and impressions of cups.* Hardly. It is just a node in a network, connected to other nodes. As such it gets activated when it receives sufficient activation from incoming connections, and passes it on. Those multitudinous items of information relating to cups are captured *not in the cup node itself but in the network consisting of thousands of nodes that are connected to it.* In other words, *there is a CUP node and there is also a CUP network.* What I am calling the CUP node at the "center" of the network, may be called the *CARDINAL NODE*.

Moreover, in accordance with this same principle of functional specificity, each of those other nodes in the CUP network likewise has a specific property, since the principle of local specificity applies throughout the system, to every node. The CUP node is at the top of a very complex hierarchical network, and it is this network as a whole that represents all the information about cups that a given individual has. The property labeled WITH-SAUCER, for example, is itself at the top of a complex hierarchy of network structure. And so forth, all the way down to elementary perceptual properties connected to the sense organs. And each of those properties also has a specific function.

And so what we have in relational networks is *both local representation and distributed representation* (cf. Lamb 1999: 329–341). It is *local representation* in that there is one local node exclusively dedicated to, say, the concept, existing at the top of the hierarchy (e.g., the CUP node); and it is *distributed representation* in that what represents the concept CUP (for example) is a large network, consisting of perhaps thousands of nodes, connected in many layers to that node at the top. This important feature of relational networks and evidently also of actual neural networks has yet to be recognized by most cognitive neuroscientists, who instead believe that the issue is a choice between local representation and distributed representation, and who generally opt for the latter and reject the former.

Evidence for functional specificity comes from several directions. First, it provides a direct simple solution to the basic problem of communication in networks, a solution that is implicit in all of the RN diagrams above. The problem (which remains unresolved in neuroscience) can be illustrated by an example: How does the network provide for connecting a specific lexical item, say *cup,* with a specific concept, say CUP? For relational networks, the answer is simple and obvious: by means of a direct connection from the one node to the other (Lamb 1999: 366–369). *This method works because each of these two nodes conforms to the property of functional specificity*: Such a direct connection is possible only if there is a node specifically dedicated to the lexical function *cup* and another specifically dedicated to the conceptual function CUP. I have a challenge for any reader who does not like this solution: Come up with another.

As a second piece of evidence, functional specificity follows automatically from the learning process described above. In Figure 18, for example, the newly recruited node C has the specific function *A and B—whatever A and B may be, a new node has been recruited to represent their combination.*

A third item of evidence is provided indirectly by the discovery of what are (misleadingly) called mirror neurons. The so-called (and widely misunderstood) mirror neurons are just ordinary high-level motor neurons. They are in (columns of) motor cortex representing nodes at the top of a hierarchy for, say, GRASPING-AT. There is a column specifically dedicated to that process. In the distributed hierarchical network to which it connects are both the lower level motor processes needed for grasping at an item, and also, over in the visual area of the cognitive dome, the network representing what it looks like to see someone grasping at an item. Such sensory associations for activities will naturally have been built up during a long learning process consisting of multiple steps of the simple procedure described above. Notice that the communication in this case between visual cortex and motor cortex is another example of direct connection from one node to another, made possible by functional specificity.

Now, in the context of a scientific approach, we would like to have some direct experimental evidence to support the principle of functional specificity. Well, we have such evidence, and it has already been described. It is the many experiments of Mountcastle, Hubel and Wiesel, and others, all of which have revealed that perceptual functions are very highly localized in the cortex such that *every column has a very specific local function*. For example, in the paw area of a cat's sensory cortex, each column represents a specific point of the cat's paw; in auditory cortex, each column represents a specific frequency; in visual cortex, there are individual columns for specific orientations of short lines and individual columns for specific directions of motion (Mountcastle 1998).

To be sure, these investigators have not performed such experiments for human language or human conceptual structure. The reason is that they are deemed too invasive. But neuroanatomy tells us that the structure of the cortex is (1) quite uniform across mammalian species and also that it is (2) uniform across different cortical regions. Therefore it seems fairly safe to assume that the findings of Mountcastle and others for perceptual cortices of cats, monkeys and rats apply also (1) to humans and (2) to other cortical areas. This extrapolation of the experimental findings has not previously been proposed in cognitive neuroscience.

The next property, closely related to functional specificity, may be called *FUNCTIONAL ADJACENCY*: *Adjacent network locations have adjacent functions.* Again we have neurological evidence from the experiments of Mountcastle and others, described for example by Mountcastle (1998), demonstrating that adjacent cortical locations respond to properties that are functionally adjacent. For example, adjacent locations in the cat's paw are represented by adjacent cortical locations. Similarly, adjacent columns of auditory cortex respond to neighboring sound frequencies, and adjacent columns of visual cortex respond to slightly different orientations of line segments; and in the motion detection area of visual cortex, adjacent cortical locations respond to slightly different directions of motion.

Extending this principle to language (a step justified by the uniformity of structure across cortical areas and across mammalian species) we can posit that nodes for recognizing /p/ and /k/, for example, are adjacent, since /p/ and /k/ are auditorily very similar; and we can likewise posit that the nodes for CUP and MUG are adjacent.

The advantage of adjacent positioning of functionally adjacent nodes is apparent when we consider that similar functions are necessarily in competition: When we hear someone say *pick*, especially if the speech volume is low or there is noise, it may sound a lot like *kick*. To aid in the correct perception it is altogether likely that the node for /p/ sends an inhibitory signal to that for /k/, and vice versa, as in Figure 19, which shows three competing nodes. (The figure is a bit misleading in showing the nodes as merely close to each other rather than adjacent). Such mutual inhibition enhances the contrast between such otherwise functionally close neighbors. And experiments have indeed shown that perception of contrasting phonological pairs is binary; that is, an experimental subject who hears a computer-generated sound intermediate between the sounds of two competitors generally hears it as one or the other rather than as the intermediate sound that it actually is. Such enhancement of contrast has also been confirmed by experiments in visual perception, for example of edges. Similarly, we can posit that the nodes for CUP, MUG, and GLASS have mutually inhibitory connections, as in Figure 19.

The neurological plausibility of Figure 19 is supported by consideration of the connectivety of cortical minicolumns. They send out inhibitory connections horizontally to adjacent columns, as depicted in Figure 20, which also shows that all distant connections are excitatory (all are myelinated axons of pyramidal neurons). According to Mountcastle (1998), *columnar specificity is maintained by pericolumnar inhibition* (p. 190), and *activity in one column can suppress that in its immediate neighbors* (p. 191). It is also the case that inhibitory cells can inhibit other inhibitory cells (p. 193), and that large basket cells send myelinated projections as far as 1–2 mm horizontally (p. 193), implying that a column can inhibit not only immediately adjacent columns but also those that are merely nearby.

A further property that is implicit in the above discussion is that, in general, members of the same category, whether it is phonological or visual or conceptual or whatever, will be in same area. Why? Well, they are in the same category because they have similar functions. In other words, they share many functions and differ in relatively few. They will thus be in the same area as a consequence of how learning works (Lamb 1999: 218),

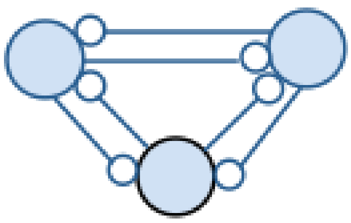


Figure 19. Nodes of related function, hence in competition: competition is enhanced by mutual inhibition

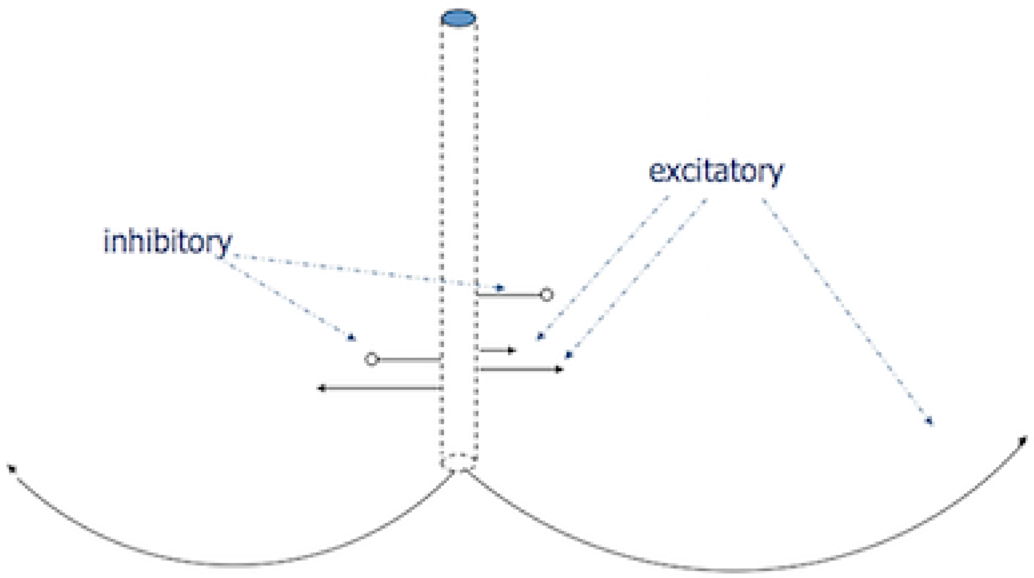


Figure 20. Model of cortical minicolumn showing types of connections: proximate connections are inhibitory and excitatory, distal connections excitatory only

and as competitors. We can also put it the other way around: Neighbors in the same area of a network can be expected to have some shared general function along with additional differentiating functions, and they are in mutual competition with respect to these differentiating features. Such a group of neighboring nodes of related function may be viewed as a cluster of nodes. As an example, the nodes for CUP, MUG, and GLASS may be expected to be together in such a cluster along with other nearby nodes for other types of drinking vessels, and also, fairly nearby, soup bowls, etc.

We thus come to clusters of contiguous nodes (RN) or contiguous columns (NN). And here is where we see why Mountcastle uses the term *minicolumn*. It is because minicolumns come in clusters, that is, larger columns. The *MAXICOLUMN* is a bundle of about 100 continuous minicolumns. It has a diameter of 300–500 microns (thousandths of a millimeter). Still larger modules also exist—up to 1 mm in diameter. The minicolumns within a maxicolumn respond to a common set of features, and differ from one another with respect to additional features. So *they represent subcategories of a category*. We are talking here about what Hudson (2007) and others call the "isa" function, but with a different means of network representation from that used by Hudson (2007) and in earlier versions of relational networks.

The properties of functional specificity and functional adjacency also apply to such larger columns. According to Mountcastle (1998: 165), "The neurons of a [maxi]column have certain sets of static and dynamic properties in common, upon which others that may differ are superimposed". These others that differ are the features that distinguish the subcategories from one another.

We may use the term *FUNCTIONAL COLUMN* as a general designation for bundles of columns of varying sizes, including bundles intermediate in size between minicolumns and maxicolumns. So we can say that different functional columns within a larger column are distinct because of non-shared additional features. Similarly, all columns of a larger module may have similar response features, upon which others that differ may be superimposed, resulting in maxicolumns sharing certain basic features while differing with respect to others

(Mountcastle 1998: 189). Such maxicolumns may be further subdivided into functional columns on the basis of yet additional features.

And so as a more general statement, we can say that functional columns of different sizes within a very large column represent hierarchical category structures: categories, subcategories, sub-subcategories, etc. In other words, *columnar structure directly maps categories and subcategories.* By the extrapolation mentioned above, this is a property that can be applied to conceptual categories, representing another contribution from the study of linguistic structure to cognitive neuroscience.

Many or most of the nodes of relational networks doubtless correspond not to minicolumns but to larger functional columns.

The size of a given functional column is determined by experience/learning. In initial stages, a node recruited for a function, as in Figure 18, will normally represent a bundle of minicolumns, perhaps a fairly large bundle in the case of a child in the early stages of learning conceptual categories. Such functional columns will be subdivided with the learning of finer distinctions.

As a consequence of these processes and structural principles of cortical organization, closely related cortical functions tend to be in adjacent areas. This principle, which applies quite generally, not just to conceptual categories, may be called the *PROXIMITY PRINCIPLE* (Lamb 1999: 217–219, 322–327, 352–362). According to it, for example, we can expect that the area for phonological recognition ought to be close to the primary auditory area and that the area for phonological production should be close to the portion of the primary motor area that controls the organs of speech production. If such expectations are taken as predictions from theory, we find that they too are confirmed, in this case by findings from aphasiology. They also provide a good example of the principle that in converting from abstract notation to narrow notation (section 10 above), there is no reason to suppose that the lines and nodes for the downward direction are adjacent, or even close, to those for the upward direction (cf. Lamb 2013: 157–158).

Further evidence for the hypothesis of local organization of conceptual categories comes from studies of people who have suffered brain damage. If it is indeed the case that related concepts are represented in contiguous areas, then we would expect that if damage affects a conceptual node of a given category, then other nodes of the same category should also be affected. Just this situation has been found in numerous cases of brain damage. As an example, two such cases are discussed by Rapp and Caramazza (2001: 905b–906a). The temporal lobes of both had been affected by herpes simplex encephalitis. They could not define animate objects, such as ostrich, snail, wasp, duck, holly, but were much better at defining inanimate objects, including tent, briefcase, compass, wheelbarrow, submarine, umbrella. Another study describes three patients with damage in different portions of the left inferior temporal (IT) lobe (Damasio et al. 1996). One of them, with damage to the posterior IT, had a deficit in retrieval of words for tools; another, with damage to anterior IT, had a deficit in retrieval of animals; while the third, with damage to the most anterior section of IT, had a deficit in retrieving names of persons.

14. Concluding remarks

The foregoing account is replete with evidence that linguistic structure, viewed realistically, is a network. Yet the recognition of this finding can be misleading to those whose acquaintance with networks is limited. They are likely not to realize that many different kinds of networks have been proposed, with quite different structural properties, even among those whose declared interest is in brain structure. Relational networks (RN), as described in this paper, are in fact rather unusual among the range of networks that have been promulgated, such as those of Rumelhart and McClelland (1986). Ironically, although some such other networks have been claimed to offer insights into brain operation and have been called “neural networks”, they lack neurological plausibility (Lamb 1999: 61–62, 329–336).

There is a long-standing debate about local representation vs. distributed representation, based on the (unstated and unwarranted) assumption that it has to be one or the other. But as shown above, with direct support from neurological evidence, representation is *both local and distributed.*

Why are there such wide differences between different kinds of networks, and how are we to choose among them? The simple answer is that most of them have been based on false assumptions and faulty reasoning, such as the assumption that representation of information has to be either local or distributed and the assumption that the cerebral cortex works like a computer (Churchland and Sejnowski 1992). Relational networks acquired their particular form solely from linguistic evidence, as I have endeavored to show in this paper. Every feature, from the first steps of their construction, is motivated by linguistic evidence.

To review, the relationship of RN to neural networks (NN) was brought into question (section 12) only after the basic structural properties of RN were developed based on linguistic evidence. These properties were then checked against NN properties known from neuroanatomy, and the checking showed a (surprisingly?) high degree of correspondence. Then, for the question of what kind of grouping of neurons corresponds to the node of narrow RN, we turned to the evidence from neuroscience, specifically that provided by the research of Mountcastle (1998) and his colleagues. To repeat: this was the first step at which neurological evidence was used to enhance the understanding of network structure rather than to confirm hypotheses already formed on the basis of linguistic evidence. This step represents a contribution from neuroscience to structural linguistics. Finally, we see that bringing additional evidence from language into play we can offer contributions to neuroscience.

And so we end up with a series of steps from linguistic structure to cortical structure, each with its appropriate notation (cf. Lamb 2013). At an abstract level (yet not as abstract as Halliday’s systemic networks) we have RN in its original form, the abstract RN notation. For greater precision, we have the narrow RN notation; it comes in varying degrees of narrowness (Lamb 2013). Then at a still more refined level we have representation of various details in terms of cortical columns (e.g., Figure 20 above); and still more detailed representation would show the actual neurons within the cortical column.

This exploratory sketch has taken us to distant shores, and yet we haven’t left the subject matter that we started with: linguistic structure. When we take a realistic view of language structure we reject a narrow definition that would not include concern with meaning. And the range of meaning covers every aspect of cognition, so we find no boundary to separate linguistic structure from the human information system as a whole. And neurologic structures also are inseparable from linguistic structure. So it seems that while the brain looms large in this account, we haven't left the subject of the title.

Back in earlier days of structural linguistics the criterion of neurological plausibility would have had little force, since not enough was known about the brain. Hjelmslev did not consider the brain and chose to treat language in and of itself. Yet he too found that the study of linguistic structure, even considered on its own, led to a breathtaking vista because of its relationship to semiotic structure as he defined it. He concludes his *Prolegomena to a Theory of Language* (1943/61) with these words:

> Accordingly, we find … no object that is not illuminated from the key position of linguistic theory. Semiotic structure is revealed as a stand from which all scientific objects may be viewed.
> … In a higher sense than in linguistics till now, language has again become a key-position [sic] in knowledge. … Linguistic theory is led by an inner necessity to recognize not merely the linguistic system…but also man and society behind language, and all man's sphere of knowledge through language.

By bringing neurological structure into the picture we are able to find still greater justification for this view of the centrality of language.

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Sydney Lamb graduated from Yale University with a B.A. in Economics and earned his Ph.D. in Linguistics from the University of California, Berkeley, where his dissertation was a description of a California Indian language. He taught linguistics at the University of California, Berkeley, at Yale University, and, after spending some time with an electronics start-up in California, at Rice University, where he became the Agnes Cullen Arnold Professor of Linguistics. He is best known as the father of the relational network theory of language, known in its early versions as ‘stratificational theory’.