The finite connectivity of linguistic structure*

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While there is no interesting limitation on the degree of right-embedding in acceptable sentences, center-embedding is quite severely restricted. Similarly, while there is no interesting bound on the number of nouns that can occur in acceptable noun compounds, there is a very low bound on the number of causative morphemes that can occur in the verb compounds of agglutinative languages. Turning to the clause-final verb clusters of West Germanic languages, we find another similar bound. A cluster including verbs from one embedded clause may be acceptable, but clusters formed from the verbs of two or three or even more deeply embedded clauses are much more awkward (regardless of whether the subject-verb dependencies are crossing or nested). And in languages that allow multiple wh-extractions from a single clause, extractions of more than one element with a given case quickly become unacceptable. More careful experimental study of the nature of these limitations is needed, in a range of languages, but here a preliminary attempt is made to subsume them all under a single generalization, a version of the familar idea that the human parsing mechanism is limited in its ability to keep track of many grammatical relations of the same kind. To make this idea more precise, we assume in the first place,

(1) **(Weak competence hypothesis)** Human syntactic analysis typically involves the explicit recognition of all grammatical relations.

Then we define the **connectivity** of each constituent α in a linguistic structure as the number of linguistic relations which relate α (or any part of α) to any constituent external to α. We conjecture that there is a universal finite bound on the connectivity of acceptable structures in every language. In fact, we will argue that the bound is not only finite, but extremely low. Relativizing the measure to a typology of relations, we propose the following hypothesis about the connectivity of both completed constituents and those partial constituents constructed during parsing. (For the moment, a partial constituent can just

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be regarded as a set of nodes, a set of nodes completed at any point during a human parse.)

(2) **(Bounded connectivity hypothesis)** There is a natural typology of linguistic relations such that the psychological complexity of a structure increases quickly when more than one relation of any given type connects a (partial) constituent α (or any element of α) to any constituent external to α.

We can make this claim more specific as follows. In advance of more careful experimental study, and subject to qualifications that will be discussed in §7, we predict significant increases in complexity when more than one relation of any kind crosses a (partial) constituent boundary; structures with connectivity two are slightly awkward or marginal; and three and four connecting relations are always unacceptable.[1] We defend this claim by beginning the articulation of an appropriate typology of relations, one that yields the desired results about acceptable structures and one that is fairly natural given recent syntactic theory. Surprisingly, if (2) is on the right track, it appears that neither θ-assignment relations in general, nor the particular types of θ-assignment relations (agent, theme, experiencer, etc.) should be included in the typology relevant to characterizing acceptability bounds, contrary to the proposals of Pritchett (1988; 1992), Gibson (1991), Stabler (1992) and many others.

The bounded connectivity hypothesis interacts with another familiar sort of hypothesis which we formulate as follows:

(3) **(Left-to-right incremental parsing hypothesis)** Human syntactic analysis is typically incremental, in the sense that people typically incorporate each (overt) word into a single, totally connected syntactic structure before any following words. Incremental interpretation is achieved by interpretation of this single connected syntactic structure. The psychological complexity of a structure increases quickly when processing proceeds with more than one independent completed substructure.

Hypotheses (1)-(3), which have been accepted in one form or another by many linguists and psychologists, have some surprising consequences. In particular, it follows that human syntactic analysis is not achieved by any standard top-down, bottom-up, left corner, or head-driven phrase structure analysis strategy. When we consider what kind of parser we do need, it appears that our linguistic resources have a definite finite structure which imposes particular limitations on processing, not like a machine with a potentially infinite, homogenous tape or stack, but like a machine with finitely many registers whose roles are very tightly constrained. The restrictions that (2) aims to account for are specifically linguistic structural constraints, and are *not* due to a general restriction on a

[1] It is important to notice that high connectivity is being proposed as a *sufficient* condition for unacceptability. Of course, a structure can be unacceptable for other reasons too!

(potentially infinite) available memory store. Some informal considerations in favor of this view are mentioned here, but a more careful development of a computational model along these lines is beyond the scope of this preliminary study (see Stabler, 1993).

1 A limitation on causativization

In Swahili, there are a couple of causative suffixes, one of which is *-lish*, translated as *-make*, in (5):[2]

(4)	Msichana	a-li-u-fungu-a	mlango.
	girl	SUBJ-PAST-OBJ-open-IND	door

'The girl opened the door'

(5)	Mwalimu	a-li-m-fungu-lish-a	msichana	mlango.
	teacher	SUBJ-Past-OBJ-open-make-IND	girl	door

'The teacher made the girl open the door'

It is impossible to causativize the verb twice:

(6)	* Mwalimu	a-li-m-fungu-lish-ish-a	msichana	mlango.
	teacher	SUBJ-Past-OBJ-open-make-make-IND	girl	door

'The teacher made someone make the girl open the door'

Considering the fact that it makes perfect sense to have someone make the girl open the door, this inability to iterate the causative morpheme may be surprising, but morphological restrictions of this sort are common. However, there are other languages which allow iteration of causatives.[3] These are of particular interest, because they may indicate what limits there are on iteration when there is no reason to think that general morphological, syntactic and semantic principles disallow iteration in general.

Consider the following constructions from Bolivian Quechua, an SOV language with the causative suffix *-chi* which we see in (8) and (10):[4]

[2] In this paper, SUBJ stands for subject marker, OBJ stands for object marker, TOP stands for topic marker, IND for indicative, PROG for progressive, FUT for future, NEG for negative, CMP for complementizer, S for singular, PL for plural, DAT for dative, ACC for accusative, ERG for ergative, INS for instrumental, BEN for benefactive, GEN for genitive, LOC for locative, DEL for delimitative, DUR for durative, and EMP for emphatic elements. Examples (4) and (5) are essentially those of Comrie (1976, p287), with minor changes for the dialect of my consultant, Deogratias Ngonyani. The inability to iterate the Swahili causative which I observe in (6) is also noted in other Bantu dialects by Givón (1976, pp337-339) and Abasheikh (1978, p133).

[3] This is found in Hungarian (Hetzron, 1976), Turkish (Zimmer, 1976), Kashmiri (Syeed, 1985), Kannada (Schiffman, 1976), Kuki (Mahajan, 1982), Amharic (Hetzron, 1976), Awngi (Hetzron, 1969), West Greenlandic (Fortescue, 1984), Chichewa (Alsina, p.c.), Malagasy (Keenan, p.c.), and other languages.

[4] The Quechua judgements in this paper are those of Jaimé Daza, from Cochabamba. (7) is from a popular folk song.

(7) Tata-y-pis Mama-y-pis wañu-sa-nku
father-POSS1S-EMP mother-POSS1S-EMP die-PROG-3PL

'My father and mother are dying'

(8) Tata-y-ta-pis mama-y-ta-pis yarqay-manta
father-POSS1S-ACC-EMP mother-POSS1S-ACC-EMP hunger-from
wañu-chi-sa-nku
die-make-PROG-3PL

'They are starving my father and mother'

(9) Řiku-ni
see-1S

'I see it'

(10) Řiku-chi-ni
see-make-1S

'I show it' or 'I make him see it'

Double causatives are found in Bolivian Quechua, and they are typically semantically regular, though they are often slightly awkward:

(11) Řiku-chi-chi-ni
see-make-make-1S

'I have it shown'

(12) Tata-s-niy-ta wañu-chi-chi-sa-nku
father-PL-POSS1S-ACC die-make-make-PROG-3PL

'They are having my parents killed'

Interestingly, we seem to hit some sort of complexity boundary here. There is some variability among speakers, but in general verbs with more than two occurrences of *-chi* are extremely awkward or impossible:[5]

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[5]A construction with three occurrences of *-chi* is listed in Herrero and Sánchez de Lozada's (1978, p216) descriptive grammar of Cochabamba Quechua:

(a) Susanitapaj t'impuchichichiy lecheta

'Have someone make boiling milk for Susanita'

However, the translation given by Herrero and Sánchez de Lozada for this triple causative is the one shown here, the one expected for the simpler double causative *t'impuchichiy*. It is interesting that Mohanan (1982, p570) also lists a triple causative in Malayalam, but gives it the same translation as the corresponding double causative. And in Turkish as well, verbs like *göster-* (show) can take 2 causatives (yielding a verb that means "make someone have something shown"), and when further causative affixes are added they do not introduce additional intermediate causees, but add only an emphatic or humorous effect (Murat Kural, p.c.). In short, iteration beyond two causatives ceases to be valency-increasing. In Quechua such forms are certainly very awkward and quite rare. Jaimé Daza, my consultant from Cochabamba, Bolivia, finds (a) just as bad as (13) and (14). And I have been unable to find any triple causatives at all in any other Quechua literature. Hetzron (1969, §2.2.1; 1976, p383) describes

(13) * Řiku-chi-chi-chi-ni

(14) * Tatasniyta wañuchi-chi-chi-chi-sa-nku

The possibility of two causatives as in (11)-(12) shows that the problem here is not simply due to an inability to repeat an affix, and it is certainly not due to some absolute upper limit on the number of affixes that can appear on a verb stem. Many more complex forms are perfectly acceptable:

(15) Suldadu-s wañu-chi-chi-lla-sa-nku-ña-puni.
soldier-PL die-make-make-DEL-PROG-3PL-DUR-EMP

'soldiers are still just having people killed as always'

Nor does the lack of productivity have any apparent semantic explanation. Notice that the causal morpheme makes a regular semantic contribution in all of the acceptable examples shown here, and so it is puzzling that we do not accept and interpret (13) in the regular way.[6] This lack of productivity in morphological causatives has been noted before in various dialects of Quechua, and in every other language in which morphological causatives have been studied.[7] The collection of languages known to respect the bound includes both verb-final languages like Quechua, and also verb-initial languages like Amharic (Hetzron, 1976) and Arabic (Comrie, 1976).

Two basic types of theoretical approaches to morphological causatives and other valency-changing affixes can be distinguished in the literature. One approach with a long history maintains that these constructions are derived from biclausal syntactic structures by some kind of incorporation of the verb from the lower clause into the higher causative. Recent prominent views of this sort are provided by Baker (1988), Marantz (1984), and Perlmutter and Postal (1983), for example. Baker (1988) argues that causatives are formed by verb raising in the syntax, an instance of head movement. We can schematize the basic idea of such approaches with a picture like the following:

(16) *Syntactic Causativization*

$[_{VP} \ldots [_{V}$ make-$V_i]_{\ldots}$ $[_{VP} \ldots t_i \ldots]]]$

Baker treats other reflexive and reciprocal markers similarly, as independent syntactic units that are incorporated into the verb:

(17) *Syntactic Reflexivization*

$[_{VP} \ldots [_{V}$ V-self$_i] \ldots [_{DP}\ t_i]]]$

two Awngi constructions as triple causatives, but does not provided detailed information about their interpretation. It would be interesting to study these exceptional constructions more carefully with speakers who find them acceptable.

[6] Like other languages with morphological causatives, some Quechua causatives have irregular, idiomatic meanings. No surprise here. All languages have idiomatic phrases.

[7] On the limitations in various dialects of Quechua, see Muysken (1977, pp125f), Weber (1989, p164), Cole (1985, p183). For the general claim, see Comrie (1981).

The order of constituents in these schemata is irrelevant, and for present purposes it does not matter whether we suppose that the parts of a causative complex come together by movement. The important point is that causatives are treated like verbs with their own syntactic phrasal projections and argument positions, somehow incorporating or merging with verbs from an embedded phrase which also have their own argument positions. At some level of representation, there is a connection between the valency-changing elements of the complex verb and other syntactic positions.

An alternative approach treats the combination of the causative morpheme with a verb as a lexical operation. Causatives induce a certain lexical mapping between argument structure and syntactic expression, a certain "morpholexical operation on argument structure." We could use the following sort of picture to indicate that causativization adds an argument position:[8]

(18) *Morpholexical Causativization*

$$\begin{array}{c} \emptyset \\ \Downarrow \\ \langle \theta \ldots \theta_{causer} \ldots \rangle \end{array}$$

Reciprocalization and reflexivization are similarly treated as morpholexical operations that "suppress" one role of the verb, as indicated in the following schema:

(19) *Morpholexical Reflexivization*

$$\begin{array}{c} \langle \theta_i \ldots \theta_i \ldots \rangle \\ | \\ \emptyset \end{array}$$

This approach thus fits with the general program of resisting the "syntacticization of grammatical phenomena" by providing a purely lexical account of causativization.

In the present context, it is clear that nothing in either of these basic approaches to causatives explains the limitations on causative morpheme iteration. On the syntactic approach, morphological causatives are derived from complex syntactic structures, and yet periphrastic causatives do not seem to be subject to the same sort of restriction:

[8]This schema for causativization is modeled on Bresnan and Moshi's (1990) schema for applicative, and the following schema for reflexivization is exactly the one they suggest for reciprocalization. Clearly, these representations suppress details about what the operations involve. In his study of causatives in Chicheŵa, Alsina (1992) proposes that the Chicheŵa causative denotes a three place relation between a causer, a patient, and the caused event, and that when this morpheme combines with another "embedded" predicate, the patient argument of the causative is fused with some argument of the embedded predicate. For present purposes, this account fits the scheme (18), since the net increase in arguments is one. Mohanan (1982) also proposes a morpholexical analysis of causatives in Malayalam.

(20) The private killed the reporter.

(21) The sergeant always made the private kill the reporter.

(22) The general made the sergeant make the private kill the reporter.

(23) The president made the general make the sergeant make the private kill the reporter.

(24) The corporate executives made the president make the general make the sergeant make the private kill the reporter.

(25) ? No one makes the corporate executives make the president make the general make the sergeant make the private kill the reporter.

Since complex periphrastic causatives like these are acceptable, what explains the restriction on morphological causatives?[9] Similarly, the puzzle remains unsolved in the morpholexical approach. Since it is plausible that at least some morpholexical operations can iterate, as we see in double and triple causatives, what explains the restriction on iteration?

This paper will argue that the restriction on causatives follows from a very simple and intuitive complexity bound on syntactic structures. Since this bound can be independently motivated, it actually supports a syntactic analysis like Baker's rather than threatening it, whereas the morpholexical approach would have to propose a separate morphological restriction, in spite of the striking similarity between this restriction and other syntactic restrictions.

2 Explaining the limits on causativization

The complexity of a constituent is sometimes gauged by the number of morphemes it contains, but we do not assume that there is any interesting bound on the number of morphemes in X^0 constituents in general. For example, English noun compounds can have many nouns and still be perfectly acceptable:

(26) The customer asked about [$_N$ ticket validation].

(27) The customer asked about [$_N$ parking ticket validation].

(28) The customer asked about [$_N$ parking lot ticket validation].

(29) The customer asked about [$_N$ grocery parking lot ticket validation].

[9] Baker (1988, p71) points out that we can always assume that there are special morphological filters which simply rule out unacceptable forms that we would have predicted, on syntactic grounds, to be well-formed. Two points about this idea. First, this is clearly a move of last resort. There are certainly regularities here that we just do not understand yet, and it is not clear exactly what *morphological* filtering will be needed. Second, notice that even in the extreme case where every morphological causative is assumed to be learned separately, we would still face a version of our basic puzzle in trying to explain why languages tend not to call on the child to learn double or triple causatives, and never quadruple causatives. Cf. Pinker (1984, §8) on the peculiarities of causatives and how lexically-based variations on their productivity might be learned.

(30) The customer asked about [$_N$ grocery store parking lot ticket validation].

So what explains the difference between compounds like these and the complex verbs formed with causative morphemes?

One idea is based on the observation that, unlike noun compounding, and unlike affixation of tense, aspect, and emphasis markers, causativization increases the number of arguments taken by the verb. So the limits of causativization might be due to an absolute upper bound on the number of arguments any verb can take, a bound on "semantic valency." This idea does not explain, though, why transitives and intransitive verbs seem to have the same limits on iteration of the causative affix. Surely transitives take one more argument than intransitives, but intransitives do not regularly allow one more causative than transitives, as we saw in the Quechua examples (7)-(14) above with the intransitive *wañu-* and the transitive *řiku-*.[10] And in the second place, three causatives are not allowed even in the presence of an apparently valency-decreasing affix like a reflexive. In Quechua, reflexives seem to make both double and triple causatives more, not less complex:

(31) Řiku-chi-ni wawa-y-ta dujtur-man
see-make-REFL-PROG-1S child-POSS1S-ACC doctor-GOAL

'I had the doctor see my child'

(32) Řiku-chi-ku-ni
see-make-REFL-PROG-1S

'I have myself seen' (e.g. by a doctor), or 'I give myself away'

(33) * Řiku-chi-chi-ku-ni

(34) * Řiku-chi-ku-chi-ni

(35) * Řiku-ku-chi-chi-ni

So while we can agree that there may be a limit on the number of valency changing affixes that any stem can host, the reason is not simply that there is an upper bound on the number of arguments that any verb (complex or not) can take.

A second idea about the limits on causativization is that there is a bound on the number of positions in any clause where the arguments of the causatives could go, perhaps for case reasons.[11] This idea does not seem quite right either.

[10] Comrie (1976, p286) suggests that, when all the causatives allowed by all languages are considered, causative forms of transitive verbs are less common than causative forms of intransitives. It is not quite clear how to assess this idea. In languages with quite productive causativization like Quechua or Turkish, how can we count the numbers of forms allowed? And in languages where all causative verbs are just lexical items, would we expect an interesting theoretical basis for a trend toward causative intransitives? In any case, since the facts about causatives vary so significantly across languages, it is hard to know what would follow from the conjectured trend.

[11] Something like this is suggested by Givòn's (1976, p337) speculation that the reason iteration of causatives is blocked in Bantu languages is due to "the lack of sufficient case

It shares the main defect of the previous proposal: it does not explain why transitives and intransitives have the same limits on causativization. Furthemore, the noted restrictions on causativization hold equally in languages with very rich case marking and pre- or post-positional systems like Quechua, and in languages where all the intermediate agents need not and even cannot be mentioned with overt determiner phrases (DPs).

As suggested in the introduction, a more satisfactory idea is that the operation of forming a causative compound increases syntactic "connectivity," because it forms a constituent that enters into more relations of a particular kind. Various proposals along these lines are possible. If the verb raises from an embedded clause to amalgamate with the higher verb, then we have a verb movement relation to keep track of. If double causatives involve two verb movement relations, then perhaps keeping track of movements of this kind is difficult enough to account for the rather marginal status of double causatives, and the unacceptability of triple causatives. Assuming that verb movements are one of the relevant types of relations, then, the observed limitation on causatives is subsumed by our bounded connectivity hypothesis, repeated here:

(2) There is a natural typology of linguistic relations such that the acceptability of a structure degrades quickly when more than one relation of any given type connects a (partial) constituent α (or any element of α) to any constituent external to α.

This proposal has the advantage that it predicts the same complexity bound for transitives and intransitives, since the transitivity of the embedded verb does not affect the number of verb movements involved in forming the causative compounds.

A different (but compatible) hypothesis about the connectivity bound in causatives is that the arguments of the embedded clause must also be moved up into the higher clause to get case, but the theoretical accounts of the case marking relations in these constructions are less settled, so we will not pursue this idea.[12] Yet another idea (proposed in Stabler, 1992), is that the causative compound must enter into multiple θ-marking relations of the same kind, taking more than one agent, but this idea is disconfirmed by some of the multiple-extraction constructions discussed in §3 below, and it is also rather difficult to assess since, unlike case marking, θ-marking is not overtly indicated by the

markings to differentiate the semantic function of the various object nominals following the verb, since every application of lexical causativization increases the transitivity of the verb by one nominal object."

[12]In Bolivian Quechua, the intermediate objects always receive a distinct case marking from any of the overt arguments to the highest verb, suggesting that the objects may all raise to the matrix clause. Jake (1985), on the other hand, reports that in Ecuadorian Imbabura Quechua, it is possible for both the direct object of the highest verb and an intermediate causee to get ACC case marking, suggesting that the intermediate causee may get case in the embedded clause from the lower verb. See, e.g. Baker (1988), Johnson (1991), for other perspectives on object raising and case assignment.

morphology.

Notice that these connectivity hypotheses do not predict a restriction on noun compounds analogous to the one we see in morphological causatives, because additional nouns in a noun compound do not generally increase the connectivity of the complex.[13]

A challenge to the idea that we have trouble keeping track of multiple verb movements comes from the clause-final verb clusters of Dutch and German. Here, it is quite possible to have more than two verbs in a cluster, as in the following Swiss-German example from Shieber (1985):

(36) mer d'chind em Hans es huus haend wele laa
we the children-ACC Hans-DAT the house-ACC have wanted let
hälfe aastriiche
help paint

'we have wanted to let the children help Hans paint the house'

According to some analyses, these clusters are formed by verb raising, in which a verb in an embedded clause moves to get its inflection and then up into the higher clause, with the resulting complex moving to combine with the verb of the higher clause, and so on up to the matrix clause.[14] In this framework, one natural idea is that in the course of this derivation, auxiliary verbs form units with their associated main verbs, and so the relevant factor is how many main verbs occur in the cluster.

We do not have data about the online processing difficulty for (36), but Bach et al. (1986) studied similar constructions in both Dutch and German:

(37) dat [Jan [Piet [Marie t_3] t_2] t_1] [zag [laten $zwimmen_3$]$_2$]$_1$ (Dutch)
that Jan Piet Marie saw make swim

[13]Ward et al. (1991) point out that internal elements of noun compounds and other X^0 elements may sometimes increase connectivity because they may be involved in anaphoric relations, as in:

(1) Although [$cocaine_i$ use] is down, the number of people using it_i routinely has increased.

(2) [[McCarthy]$_i$ites] are now puzzled by him_i.

However, the anaphoric relations here are pronoun-antecedent relations, which are not local in the way most grammatical relations are. Berwick and Weinberg (1984) argued that since pronoun-antecedent relations apparently extend well beyond the local domain needed to make structural decisions, and since a speaker's determination of these relations is apparently based on inferences from general background knowledge, it is plausible that these relations are not computed by the same mechanism that builds syntactic structure. This argument continues to be persuasive, and so we do not assume that pronoun-antecedent relations are subject to the same sorts of low finite bounds that apply to other types of linguistic relations. That is, we assume that there is a finite bound on the number of pronoun-antecedent relations that any acceptable expression can involve, but it does not seem to be an interestingly low, roughly binary or ternary bound of the sort we have with other dependencies.

[14]Den Besten and Edmondson (1983), Den Besten and Rutten (1989), Hoeksema (1988), Haegeman and van Riemsdijk (1986), Koopman (1993).

'that Jan saw Piet make Marie swim'

(38) dass Jan [Piet [Marie t_3] t_2] t_1 [[schwimmen$_3$ lassen]$_2$ sah]$_1$
that Jan Piet Marie swim make saw
(German)

'that Jan saw Piet make Marie swim'

Since the dependencies in the German examples are nested, and the dependencies in the Dutch examples are crossing, it is remarkable that they were found to have similar psychological complexity. In both constructions, there was a significant jump in psychological complexity when a third main verb was added to the clause-final clusters. Many German speakers find (38) completely unacceptable. Bach et al. (1986) found the center embedded German structures were actually slightly less intelligible than the Dutch. It would be interesting to account for this slight difference, but the more striking result is the similar jump in complexity in both constructions when we add a third verb. This is what the connectivity bound (2) would predict, if we assume that the verbs raise to the clause final cluster in both German and Dutch.[15]

3 Connectivity bounds in multiple extraction

Although English allows multiple questions when one or more wh-phrases are left *in situ*, it only marginally allows A-bar extractions of more than one wh-phrase (here we use bold to indicate stress on the *in situ* wh-constituent):

(39) Who$_1$ did you ask [t_1 to fix the car **how**]?

(40) ? Who$_1$ did you ask how$_2$ [t_1 to fix the car t_2]?

Other languages are much more liberal. For example, Mahajan (1990) points out that in Hindi, there are cases where wh-phrases cannot be left *in situ*, but must be extracted:

[15] A different account of these constructions has been proposed by Kroch and Santorini (1991), according to which the clause-final sequences of verbs in Dutch and German do not form a constituent. Rather, in Dutch the embedded verbs are extraposed, adjoining to the main clause, forming structures like,

(1) dat [[[Jan [Piet [Marie t_3] t_2] zag] laten$_2$] zwimmen$_3$], (Dutch)

while in German, the embedded verbs can stay in place:

(2) dass [Jan [Piet [Marie schwimmen] lassen] sah] (German)

Even on this alternative analysis, our proposals predict the observed limitations. Notice that in (1), if the minimal indicated boundary containing *Jan...zag* is regarded as a real constituent boundary, we can see that two verb movements cross that boundary. The German construction, on the other hand, becomes a center-embedding construction. As indicated in the introduction, this is ruled out by the application of our connectivity bound to partial structures created during parsing, as we will discuss in detail in the next section.

(41) * [rām-ne kahā ki kɔn kis-ko māregā]
Ram-ERG said that who whom-DAT hit-FUT

'Who did Ram say will hit who?'

(42) kɔn$_1$ kis-ko$_2$ [rām-ne kahā ki t$_1$ t$_2$ māregā]
who whom-DAT Ram-ERG said that hit-FUT

'Who did Ram say will hit who?'

Extraction of two or three wh-elements is not uncommon, though sometimes just slightly awkward:[16]

(43) ? kis-ne$_1$ kɛse$_2$ [rām-ne kahā ki t$_1$ t$_2$ gaRīThīk kī]
who-ERG how Ram-ERG said that car fixed?

'Who did Ram say fixed the car how?'

(44) ? kis-ne$_1$ kis-ko$_2$ kyā [rām-ne sītā-ko batāyā kī t$_1$ t$_2$ t$_3$
who-ERG whom-DAT what Ram-ERG Sita-DAT told that
diyā hogā]
gave-FUT

'Did Ram tell Sita who gave what to whom?'[17]

(45) ? kɔn$_1$ kis-ne$_2$ t$_1$ socā ki mohan-ko t$_2$ maregā
who who-ERG thought that Mohan-DAT hit-FUT

'Who thought that who hit Mohan'

However, when we have more than one A-bar chain with any particular case crossing any boundary, the construction really becomes unacceptable:

(46) ??? kis-ko$_1$ rām-ne kis-ko$_2$ t$_1$ t$_2$ kahā ki sar dard hɛ
who-DAT Ram-ERG who-DAT tell that head pain is

'Who did Ram tell that who has a headache?'

These limitations in Hindi suggest a possible way to elaborate the connectivity hypothesis (2). If we count outstanding A-bar movement relations, or outstanding θ-marking relations, we see that three or more can occur with only slight awkwardness. In (45) we even have two A-bar extractions of elements with the same type of θ-roles (agent). However, if we classify A-bar DP movement relations by their case, then we can stay with our extremely low bounds, allowing structures like (42)-(46), while predicting the difficulty of (46) because it has two A-bar extractions with dative case.[18]

[16] Example (43), like the previous Hindi examples, is from Mahajan (1990, §3). Thanks to Anoop Mahajan for providing the additional examples and judgements below.

[17] The Hindi sentence here can be interpreted either as a multiple question, or as a multiple indirect question where the wh-elements have been topicalized.

[18] It remains unclear how to classify A-bar adjunct extractions of elements other than DP, since they may not bear case. This question is currently under study.

4 Connectivity bounds on center-embedding

Connectivity bounds for linguistic constituents do not predict the well-known unacceptability of deeply center embedded sentences. This can be seen by observing that in a simple constituent structure tree, as in any context free grammar derivation tree, regardless of the depth of center embedding, every constituent is connected to the rest of the structure by only one constituency relation, the relation represented by the arc drawn from the constituent to its parent.[19] In English center embedded clauses we presumably have somewhat greater connectivity than in context free languages, since more different kinds of relations are involved, but connectivity need not increase with depth of embedding. For example, in the following examples there is some modification relation between each embedded clause and the N' phrase it modifies, but we do not have increasing numbers of connections to elements in the matrix clause when we add a second or third center-embedded clause:

(47) The house [(that) the malt lay in] was built by Jack

(48) * The house [(that) the malt [(that) the rat ate] lay in] was built by Jack

So why should center embedding be subject to such similar bounds as the other constructions we have surveyed? As in the other cases, when we have two clauses as in (47), the construction is perhaps significantly more complex, but still within bounds of normal acceptability. But with three center-embedded clauses, as in (48), the construction is extremely awkward or impossible.

To capture the difficulty of these center-embedded constructions, we simply assume that not only completed constituents, but also the partial constituents constructed by the parser, are subject to our connectivity bound. For the moment, we can be rather vague about what the partial structures are like, exactly. We can think of them as sets of nodes, or as descriptions of some sort, or as sequences or stacks of subtrees. The relevant parameter is the number of relations connecting nodes in any partial structure to nodes that are not in that partial structure. If we assume that parsing proceeds from the beginning of a sentence to the end (and that parsing never involves the prediction of overt, lexical elements), then after seeing the first two DPs in our example (48), the parser presumably has a structure with something like the following form:

(49) [The house [(that) the malt ...] ...]

This structure already has two DPs, each of which must be assigned nominative case by constituents that have not been found yet. So let's make the natural assumption that each type of case assignment relation (nominative, accusative, etc.) is relevant for the bounded connectivity hypothesis. Then, at the step indicated by (48), the parse is already complex, since it is connected by two

[19] If we count precedence as a relevant linguistic relation, then there is perhaps also an immediate precedence relation to a sister node.

relations of the same kind to the rest of the structure. As the parse continues, we get to

(50) [The house [(that) the malt [(that) the rat ...] ...] ...]

But now the elaboration of this structure to get (48) would involve relating three DPs by nominative case-marking to elements outside of this partial structure, and so we correctly predict that the structure should be extremely awkward or impossible. Notice that we get this prediction no matter how much of the syntactic structure is built for these elements, since whatever the structure is, it will somehow involve relations to three case-marking elements which have not been found yet. According to recent theories in the transformational framework, this element could be any tensed inflection node, which might be filled by a modal like *will*, for example.

It is widely observed that whereas it is unacceptable to have two center embedded relative clauses in subject position, two relative clauses in object position is not quite so bad. Compare the subject relative in (48) with:

(51) ?? She loves the house [(that) the malt [(that) the rat ate] lay in].

We can allow for this contrast, since after we have parsed

(52) She loves the house [(that) the malt [(that) the rat ...] ...]

we have just two DPs with outstanding case-assignment relations, because *loves* has already case-marked its object, not three relations as we had in the partial structure (50) of (48). So we correctly predict that (51) should be better than (48), while (53) should be just as bad as (48) (assuming other contributors to complexity are approximately alike):

(53) * She loves the house [(that) the malt [(that) the rat [(that) the cat chased] ate] lay in].

Our previous discussion and the heading of this section might have given the impression that degree of center embedding *per se* is the contributor to complexity. That idea is corrected by these examples. Connectivity of constituents does not increase with center-embedding. Connectivity of the partial structures built by a left-to-right parser, on the other hand, does tend to increase with depth of center embedding, but even here the two measures cannot be equated.[20]

Let's turn now to sentential subjects. It has often been observed that a relative clause inside a sentential subject is not as bad as a relative clause inside a relative clause in a subject DP, nor is it as bad as a sentential subject inside a sentential subject. Consider relative clauses in sentential subjects first, as in:

(54) ? [That the rat [who the cat chased] lives in the house] surprised Jack.

[20]Similarly, in our implementation, we do not assume that stack depth should correlate perfectly with depth of center embedding, unlike Church (1980, p27), for example.

Here, the parser presumably builds a partial structure like the following,

(55) $[_{CP}$ That the rat [who the cat ...] ...]

In this structure, we seem to have two DPs that need case, and also a CP in subject case position, so why isn't the structure as awkward as the structure (48) beginning with (50)? This question is easily answered when the structure of sentential subjects is considered more carefully. Stowell (1981), for example, observes the contrast between structures like (56)-(57), on the one hand, and topicalization and dislocation structures like (58)-(59):[21]

(56) * Is that the rat lives in the house likely?

(57) * John doubts (that) that the rat lives in the house is likely.

(58) That the rat is in the house, Mary could not doubt (it) for a minute.

(59) That the rat is in the house, who could possibly doubt (that)?

Examples like these suggest that a that-clause, a finite CP, can occur in the position of a topic or left dislocation, but cannot occur in a subject or object position. Stowell (1981) proposes that there is a "case resistance principle" at work here: a tensed CP (and certain other categories) cannot appear in case-marked positions. But then we must conclude that the "sentential subject" in (54) is misnamed in the sense that the CP is not really in subject position at all, but is rather in a non-case-marked A-bar position, a position that may somehow license an empty subject. Many other linguists have come to similar conclusions. Let's tentatively assume something along the lines of Koster's (1978) and Safir's (1985, §3.4) proposal that sentences with sentential subjects like (54) or the simpler (60) have the structure (61):

(60) $[_{TopicP}$ $[_{CP}$ That the rat lives in the house] $[_{CP}$ e_1 e_1 surprised Jack]]

(61) $[_{TopicP}$ CP $[_{CP}$ e_1 $[_{IP}$ e_1 I']]]

where the fronted CP is not part of a case marked chain, but is in the position of a left-dislocated phrase that stands in a special "control" relation to the indicated empty positions. Such an analysis provides exactly what we need to explain the relative acceptability of (54). The partial structure (55) has only two DPs with case-relations to elements outside of that structure, since the fronted CP is not in a case position. Of course, we still can predict the unacceptability of more complex structures like:

(62) * [That the rat [who the cat [who the dog bit] chased] lives in the house] surprised Jack.

[21] Structures (57)-(59) are said to involve "topicalization" when they do not include the parenthesized pronouns, and they are called "left dislocation" structures when they do include the parenthetical material. We discuss some of the differences between these constructions immediately below.

Now consider sentential subjects within sentential subjects. It is widely noted that these are completely unacceptable, as we see in (64):

(63) [That the rat ate the malt] surprised Jack.

(64) * [That [that the rat ate the malt] surprised Jack] bothered Mary.

We suggested just above that sentential subjects are in the position of a topic or dislocation. Our earlier examples did not show this, but Baltin (1982), Lasnik and Saito (1992, §3.2) and others have observed that left-dislocation is more awkward than topicalization in embedded clauses, as we see for example in:

(65) a. The basic theorem, Mary has proven (it).

b. I know that the basic theorem, Mary has proven.

c. * I know that the basic theorem, Mary has proven it.

(66) a. I know that Mary could not doubt that the rat is in the house.

b. ? I know that the rat is in the house, Mary could not doubt.

c. * I know that the rat is in the house, Mary could not doubt it.

On the basis of examples like these, these linguists propose that left dislocation involves base generation of the topic in TopicP, while topicalization involves movement inside of CP. (Perhaps, as Lasnik and Saito suggest, topicalization is an adjunction to IP.) This idea fits perfectly with our earlier idea that sentential subjects have the structure (61), where the two indicated empty categories are related by an A-bar movement. This also leads us to expect to find similar subtle differences between left-dislocated and topicalized clauses in sentential subject constructions. This prediction is borne out:

(67) ? [[That the rat ate the malt] surprised Jack], it bothered Mary.

(68) * [That [that the rat ate the malt] it surprised Jack] bothered Mary.

(69) * [[That the rat ate the malt] it surprised Jack], it bothered Mary.

These data clearly suggest that the sentential subjects in (64), (68) and (69) are not bad simply because of the way the clauses are nested. Rather, something specific about topicalization structures causes the problem. Furthermore, in contrast to the DPs with relative clauses in (51), these bad sentential subjects are not significantly improved by being embedded as complements to a verb:

(70) * I know [(that) [that the rat ate the malt] surprised Jack] bothered Mary.

So a grammatical account of these observations seems more appropriate than a performance or connectivity based account. In fact, assumptions already introduced provide the account we need. Notice that, given our structural assumptions, both (64) and (68) try to form a phrase from the complementizer *that* and a TopicP, but complementizers combine with IPs. TopicP is a different category from IP, and it is no surprise that complementizers do not combine with them. The unacceptability of (69), on the other hand, and the subtle contrast with (67) is explained by the mentioned generalization that standard left dislocation can only occur in a matrix clause.[22]

5 Incremental processing

If the hypothesized connectivity bounds hold up to further empirical study and elaboration, they will support the intuitive idea that the human parsing mechanism is limited in its ability to keep track of many grammatical relations of the same kind. Furthermore, the bounds are distinctively linguistic, sensitive to the detailed articulation of linguistic relations. And they are very low, with difficulties arising when the *unary* bounds are exceeded, much like grammatical constraints (cf. subjacency). These ideas do not fit well with performance models according to which the human processing mechanism has available a homogenous memory store of some kind with some fixed, linguistically arbitrary bound. If that picture were right, we would expect, for example, that instead of keeping track of 2 verb movements, 2 constituency relations, and 2 nominative case assignment relations, the parser could keep track of just 6 constituency relations, or 5 verb movements and 1 case relation. But this is exactly the kind of thing we are not finding. The wh-movements in languages that allow extractions, or the arguments of various cases that appear before the verb in SOV languages, do not each impose a unit of additive complexity. Rather, so long as the relations are different and few in number (essentially 1!), parsing may proceed easily. These observations suggest quite a different picture, according to which the human parser has a very rigid and limited memory store, with fixed registers for various roles, registers that cannot be redeployed for other purposes.

This picture of a parsing mechanism with strict connectivity bounds imposed by its architecture interacts in an interesting way with the hypothesis that interpretation is "incremental," typically proceeding morpheme by morpheme.[23] Let's assume that incremental interpretation results from processing a connected syntactic structure, an idea that has been proposed in a number of places.[24] This kind of view is expressed by our left-to-right incremental processing hypothesis, repeated here:

(3) Human syntactic analysis is typically incremental, in the sense that people typically incorporate each (overt) word into a single, totally connected syntactic structure before any following words. Incremental inter-

[22]This generalization is discussed by Lasnik and Saito (1992, §3.2), for example. It would be nice to derive this special property of left dislocation constructions from deeper principles, and the prospects for doing so look good, but this would take us too far afield.

[23]See, for example, the papers in Marslen-Wilson (1989).

[24]See for example, Frazier and Rayner (1988), Steedman (1989).

pretation is achieved by interpretation of this single connected syntactic structure. The psychological complexity of a structure increases quickly when processing proceeds with more than one independent completed substructure.

Stabler (1991) points out that we could make the alternative assumption, according to which unconnected pieces of syntactic structure are interpreted incrementally. And Johnson and Shieber (1993) point out that an interpretive component could even make assumptions about relationships among unconnected pieces before the parser has connected them. But (3) yields a simpler, more natural, and more restrictive theory. Here we will just observe some consequences that this simpler idea has when taken together with the bounded connectivity hypothesis (2).

Standard top-down (LL) parsers for context free grammars have the property that the partial structures they build in the course of a parse always form a single, connected structure. In standard stack implementations, interpretation of this completed structure can begin while the stack keeps track of constituents that have been predicted but not found yet. Unfortunately, as is well known, these parsers cannot handle left recursion. Standard bottom-up (LR) parsers can handle left recursion, since they build subconstituents before attaching their parents, using the stack to keep constituents which have been built but not attached to parents yet. However, there is no bound on the amount of memory required to process simple right-branching structures with this strategy.[25] If we want to find a parsing strategy whose resource demands predict appropriate acceptability bounds, corresponding to those we have characterized with the notion of connectivity, we must consider strategies that mix top-down prediction with bottom-up analysis.

Perhaps the most familiar mixed strategy is "left corner" (LC) parsing. The "left corner" of any constituent is just its leftmost immediate subconstituent. The intuition behind LC parsing is this: begin working bottom-up, but after completing each constituent, each left corner, build its parent and predict any potential siblings of the left corner. We can diagram an LC parse of a sentence by circling the nodes that have been completed at each step. We have done this for the first 10 steps of a left corner parse in Figure 1.[26] The steps indicated there are the following, beginning with the smallest circle:

i. The word *the* is heard.

ii. The parent D is built, since *the*, its left corner, has been completed.

iii. The parent D$'$ is built, since its left corner D is complete, and the sibling NP is predicted. Notice that completed categories are indicated by upward arcs

[25]This is a familiar point, at least since Miller and Chomsky (1963). For recent discussions, see Gibson (1991) and Abney and Johnson (1991).

[26]The structure here is, obviously, considerably simplified. In particular, there is evidence that I and D projections both have more structure than shown here, syntactic features have not been indicated, and only constituency relations are drawn.

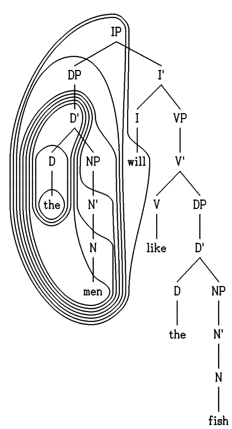

Figure 1: A structure (showing only constituency relations) and the first 10 steps of an LC parse

across each circle, and predicted categories are indicated by downward arcs. The arcs which connect the completed structure to the rest of the structure are what must be kept on the stack in standard stack-based implementation strategies – these are the points in the structure that the parser still needs to be working on, so they must be held in memory.[27]

iv. The word *men* is heard.

v. The parent N is built, since its left corner is complete.

vi. The parent N' is built, since its left corner is complete.

vii. The parent NP is built, since its left corner is complete, and this constituent is attached as the predicted NP.

viii. The parent DP is built, since its left corner D' is complete.

ix. The parent IP is built, since its left corner DP is complete.

x. The word *will* is heard.

The LC parser continues in this way until the whole structure is built. Notice that at step (iv), the parser has defined two disconnected subtrees: the D' and the N. We can see this in Figure 1: the third largest circle encloses two separate subtrees, and the nodes inside this circle are connected to the rest of the structure by 3 constituency arcs. The two subtrees are not joined until step (vii). And then again at step (x), two separate subtrees are being processed. At every step, the nodes in the partial structures all have completed left corners; the node to be processed next is also one whose left corner is complete; the other nodes are all those whose left corners have not been completed.

Two pertinent aspects of this parsing strategy are easily seen. First, at the points where disconnected subtrees are waiting, the connectivity of the partial structure increases. This increased connectivity translates into an increased burden on the memory resources of the parsing mechanism. And second, this strategy does not conform to our incremental processing hypothesis, since disconnected subtrees can end up waiting to be completed and assembled. We see the problem more clearly in the primarily right branching structure of Figure 2, in which we have indicated with a solid line the stage in the LC parse at which the connectivity of constituency relations is highest. There are 6 outstanding connections: 3 arcs leaving the loop downward to indicate predicted categories, and 3 arcs leaving the loop upward to indicate categories that need to be attached when they are completed.

Notice that a parsing strategy that tried a little harder to maintain a single connected structure could have done so with the structure in Figure 2 just by attaching N' to a predicted NP, and by attaching D' to DP as specifier of the predicted IP, before they were complete. This would reduce memory demands significantly, leaving only a single outstanding prediction, indicated by the dotted loop. Let's call this alternative strategy a left attaching (LA)

[27] See Johnson and Stabler (1993) for more detailed discussion.

parse. For the moment, let it be like LC parsing, with additions that can be roughly described as follows:

(a) if XP has been predicted and if the next word is a head X, this item can be projected to XP and attached (predicting siblings at each level, left-corner-style)

(b) if XP has been predicted and allows a specifier YP and if the next word is a head Y, this item can be projected to YP and attached as specifier of XP (predicting siblings at each level)

Some further aspects of these additions will be discussed in the next section, but it may be helpful to quickly sketch how the LA parsing strategy is intended to apply to some of the constructions considered earlier.

Figure 3 shows a center-embedded construction, with relativization on the subject position. The stage of the LC parse with maximum memory demands is again indicated by a solid line, and here we see that the partial structure has 4 disconnected subtrees, connected by 11 constituency relations to other parts of the structure (6 arcs leaving the loop upward, indicating constituents to be attached, and 5 arcs leaving the loop downward, indicated predicted constituents). On the other hand, the corresponding stage of the LA parse indicated by the dotted loop, defines one totally connected structure, with two outstanding predictions of exactly the same category.[28] We can accordingly predict that this structure should be difficult, as it is, now assuming that constituency relations are bounded by the bounded connectivity hypothesis. In fact, the prediction will follow even if we classify constituency relations according to category or "role," since in this case we have two predictions of exactly the same type of constituent.

Considering our treatment of multiple A-bar extractions, suppose we adopt the idea that extracted wh-elements are adjoined to IP (Mahajan, 1990). Then for a sentence like (44), we might have a structure of roughly the form indicated in Figure 4. In that figure, we have again indicated a stage in the LA parse of this acceptable sentence. At the indicated stage, we see three A-bar movement relations connect the partial structure to unbuilt elements, but these three A-bar chains each have a distinctive case. Notice that in a left-to-right parse of this structure, five DPs are encountered before any case or θ-assigners. This poses a problem for any theory of psychological complexity which assumes that each of

[28]The sentences in Figures 3 and 2 are Gibson's (1991) examples (110) and (113), respectively. Gibson reports that in his left corner parser, the unacceptable sentence (110) requires only 6 stack elements while the acceptable sentence (113) requires 7 elements, and he concludes that "the number of categories locally stored by a left corner parsing algorithm does not give a satisfactory metric for sentential complexity." I chose these examples to show that we get quite different results here, emphasizing the important point that Gibson's conclusion depends on the details of both his parsing algorithm and his grammar! There are a wide range of parsing strategies, such as the "arc-eager" LC or LA strategies described here which, with plausible structural assumptions, have significantly different memory requirements. See Johnson and Stabler (1993) and Stabler (1993) for further discussion.

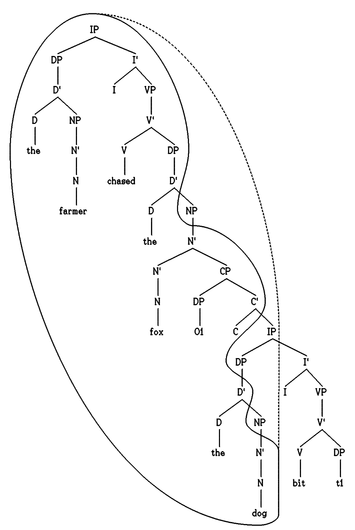

Figure 2: A structure (showing only constituency relations), with a stage in an LC parse shown by the solid line, and a stage in an LA parse shown by the dotted line.

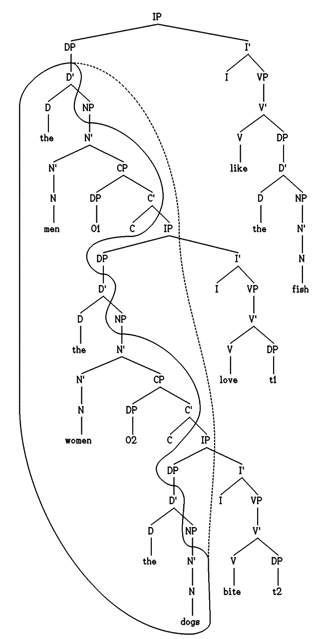

Figure 3: A center embedded structure (showing only constituency relations), with a stage in an LC parse shown by the solid line, and a stage in an LA parse shown by the dotted line.

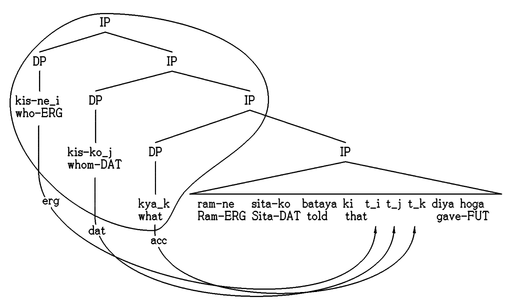

Figure 4: A structure (showing only constituency and wh-movement relations), with a loop indicating a stage in an LA parse.

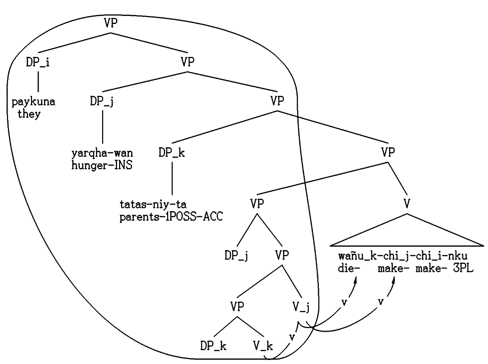

Figure 5: A structure (showing only constituency and V-movement relations), with a loop indicating a stage in an LA parse.

these DPs simply adds a unit of load to the parse, but it can be accommodated once the various case roles are distinguished as suggested in §3.

The structure of Quechua clauses is still a matter of controversy, but adapting the proposals of Lefebvre and Muysken (1988), we might tentatively suppose that a Quechua VP has a structure like the one shown in Figure 5, with VP-internal subjects. A stage of an LA parse is shown, just before the complex verb has been parsed. At this point, two V-movement relations and one predicted constituent are outstanding. Clearly, if the verb had three causatives, the partial structure would have too many V-movement relations, as suggested in §2.

6 Incremental processing and the surface recursion restriction

A fundamental problem arises for any parsing strategy which tries to bound memory requirements while also maintaining a connected structure. The puzzle begins with the observation that there is no interestingly low bound on the length of left branches, even when they are not on the left frontier of the sentence structure. Let's consider the example of English possessive structures first:

(71) He saw [Dave's] car.

(72) He saw [[Dave's] mother's] car.

(73) He saw [[[Dave's] mother's] brother's] car.

(74) He saw [[[[Dave's] mother's] brother's] friend's] car.

In any left-to-right parse of these sentences that respects the incremental parsing hypothesis, the length of the branch that connects the DP *Dave's* to the V' must be increasing, and presumably the connectivity of the first partial structure incorporating this VP is increasing too. Yet acceptability is not decreasing in the way that the bounded connectivity hypothesis would predict. Consider for example the partial structure indicated by the loop in Figure 6.[29] Something has to give way here. We cannot maintain the bounded connectivity hypothesis (2), have left-to-right parsing, and have a single connected structure too. To handle left recursive structures like the one in Figure 6, we propose that the human parser must, at least briefly, define sets of nodes from two independent subtrees. Linguists have observed that there are, cross-linguistically, significant restrictions on recursion in these left branching structures, suggesting that they impose a special, additional processing load. But we will argue that the observed

[29]See footnote 26 for our caveat about the structures depicted in this paper. In particular, it is important that our proposals do not hang on the assumption that the English possessive marker is the head D of DP. Szabolcsi (1993) points out that, cross-linguistically, possessives and determiners are not complementary, as we see for example in sentences like *Dave's every move was watched by the police.*

restrictions can be explained without any new assumptions. This makes our account entirely consistent with Frazier and Rayner's (1988) failure to find any significant increases in online complexity associated with left branching *per se.*

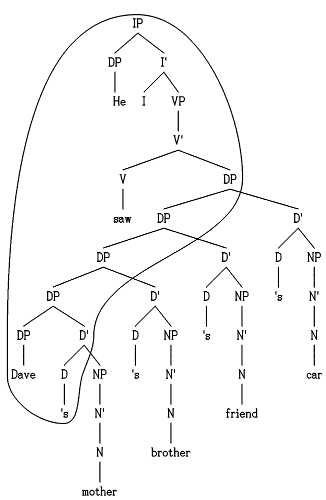

Figure 6: A structure (showing only constituency relations), with a loop indicating a partial structure with high connectivity

To handle left recursive determiner phrases with bounded connectivity, we could elaborate the LA parsing strategy in something like the following way. On hearing the first three words of (74) including the possessive marker, the parser builds the following connected structure, with one predicted NP (in the position of the ellipsis):

(75) [$_{\text{IP}}$ He [$_{\text{VP}}$ saw [$_{\text{DP}}$ Dave's ...]]]

After attaching *mother* to get,

(76) [$_{\text{IP}}$ He [$_{\text{VP}}$ saw [$_{\text{DP}}$ Dave's mother]]]

the parser hears the possessive marker and realizes that a mistake has been made. At this point, the current analysis is revised. The attachment of the DP *Dave's mother* as the complement of V is revised by making this DP the specifier of a new DP parent, attaching this new DP as the V complement, and predicting the new D'. While this revision is occurring, the completed nodes of the parser form two independent subtrees. The next possessive marker is attached as D and projected to attach to the predicted D' with a predicted NP sibling. Continuing in this way, we see that there is never more than one outstanding predicted category, no matter how deep the left recursion in the possessive. There are various ways to execute this sort of strategy in a computational model, as discussed in Stabler (1993). Note that it is not at all essential to this story to assume that revision is involved (though, in advance of experimental studies, it is a natural assumption). To get the right structure on the first parse, the strategy would simply build up the first DP, attach it to a higher one, and so on, until attachment to the predicted complement of V' is the correct thing to do. Again, it is clear that during this process of building up the possessive DP, there are two independent subtrees.

There is evidence from a number of languages that this process imposes a burden on the human parser. Notice first that not just any DP can occur in English possessive constructions of the sort we have been considering:

(77) a. I saw the [[famous Peruvian] author]'s car.
   b. ? I saw the [author [of my favorite book about laughter]]'s car.
   c. ?? I saw the [man [who just left]]'s car.

It seems that prenominal modifiers on the left side of the CP are fine, but a relative clause to the right of N is very awkward. Horvath (1985) reports similar contrasts in Hungarian, where the VP is right branching. A preverbal NP, presumably left adjoined to a projection of V, cannot have a relative clause on its right:

(78) a. Az asztal, ami az erkélyen állt bepiszkolódott
   the table which the balcony-on stood dirty-got
   'The table that stood on the balcony got dirty'
   b. * Mari [az asztalra, ami az erkélyen állt] tette az
   Mary the table-onto which the balcony-on stood put the
   edényeket
   dishes
   'Mary put the dishes on the table that stood on the balcony'

What explains this restriction on recursion in these NPs?

A plausible account is ready at hand, given the parsing strategy just described. The problem is that in these constructions we have configurations of center-embedding. The English construction (77c) is as awkward as the center embedded relativized object in (51), but not, I think, as bad as the center embedded doubly relativized object in (53), and our account here can be similar. Consider the partial structures formed in analyzing (77c). Using the parsing strategy described above, the correct parse will be one that posits two separate structures. So the partial structure might be depicted as follows:

(79) [I saw ...] $[_{DP}$ the man who$_i$ t$_i$ ...]

where a DP complement has been predicted in the position of the first ellipsis, and the DP we are currently building is *not* the predicted one. In this circumstance, the DP we are currently constructing has an outstanding case marking relation (to the possessive marker that we have not yet heard), and the (empty) subject of the relative clause has an outstanding case relation to the verb that we have not yet heard. So there are two outstanding case-marking relations, exactly as in the partial structure (52) of the marginal (51).

Emonds (1976, §1.3) suggests that the restriction we see in (77c) and (78) is an instance of a very general "surface recursion restriction," a restriction that also explains the very slight awkwardness of (77b) and the following much more severe contrasts:

(80) a. He saw the [weary] student.
b. * He saw the [weary [of his girlfriend]] student.

(81) a. He was [magnificently] attired.
b. * He was [magnificently [to his admirers]] attired.

(82) a. He [quickly] reads the paper.
b. * He [quickly [to the end]] reads the paper.

Giorgi and Longobardi (1991, pp97) describe similar contrasts in Italian:

(83) a. una triste avventura
a sad adventure

b. * una triste per Mario avventura
a sad for Mario adventure

(84) a. Quell'uomo d'affari, ora sorpredentemente ricco, era partito
That businessman, now surprisingly rich, had left
dall'Italia in condizioni miserevoli
Italy in conditions miserable

b. * Quell'uomo d'affari, ora sorpredentemente per noi ricco,
That businessman, now surprisingly for us rich,
era partito dall'Italia in condizioni miserevoli
had left Italy in conditions miserable

The proposed restriction (Emonds, 1976, §1.3; Giorgi and Longobardi, 1990, p97) can be stated roughly as follows:

(85) **(Surface recursion restriction)** If a lexical category X takes complements on the right (left), then if YP attaches to a projection of X on the left (right), the lexical part of YP cannot branch to the right (left).

This proposal is very different from most grammatical principles, but it is unsurprising from a processing perspective, since alternating directions of branching is exactly what causes center embedding. However, I suspect that it is a mistake to assume that all of the restrictions mentioned should be subsumed under this single idea. Notice, to begin with, that (77b) is very much better than any of the latter examples (80b)-(84b).

The latter examples are sometimes assumed to be ruled out by a special head final filter (HFF) (Williams, 1982) but I think that the facts actually follow in a natural way from fundamental properties of adjectives and other modifiers. Abney (1987, §3.2) proposes that prenominal As are not adjuncts but heads selecting DP. Then the (b) cases above could be ruled out on the grounds that the modifiers only can take one complement, the DP. It is natural to extend this idea to adverbs, and this would fit well with Rochette's (1990) arguments for the view that adverbs select their VPs. If these proposals are on the right track, or if the HFF is right, then (80b)-(84b) are out because they violate basic grammatical principles.[30]

Many related problems deserve much more attention than they can be given here. Notice that post-head adjunct modifiers in English are fully recursive, though on traditional conceptions of phrase structure they also can form long left branches. To handle these, the extensively studied "closure conditions" for these constructions, conditions which restrict the range of attachment options in the human parser, are obviously of critical importance.[31] But an examination of how these ideas should be accommodated in the present framework must be left to another occasion. Obviously these rough sketches need to be worked out in much more computational detail before they can be properly assessed.

7 Conclusions

Most of the data discussed in this paper is drawn from conventional linguistic study. The acceptability judgements that underpin this work need more careful experimental verification, but they seem fairly clear and robust, and they suggest

[30] Giorgi and Longobardi (1991, §2.9) defend a generalization of Emonds' idea on the basis of facts about the positions of prepositional particles in German and Dutch. A careful study of this argument is beyond the scope of this paper, but it appears that these facts can be handled by independently motivated "incorporation" analyses of Dutch and German PPs (Koopman, 1991, 1993).

[31] Frazier and Fodor (1978), Church (1980), Frazier and Rayner (1988), Frazier (1990), Gibson et al. (1993), Langendoen and Langsam (1984).

a picture of the language processor which is at odds with the traditional one. The limitations observed here do not appear to be linguistically arbitrary. On the contrary, they are clearly sensitive to structural detail. And they do not appear to be uninterestingly high limitations, like a limitation to 6 or 12 cells in a stack automaton. Rather they appear to be essentially unary, like most other interesting linguistic constraints. If these ideas hold up under further exploration, it will be interesting to explore the possibility that they reflect fundamental properties of the architecture of the human sentence processing mechanism.

Some first steps in this direction are taken here. This paper suggests that in addition to "locality constraints," human languages respect the following very general connectivity constraint:

(2) There is a natural typology of linguistic relations such that the psychological complexity of a structure increases quickly when more than one relation of any given type connects a (partial) constituent α (or any element of α) to any constituent external to α.

We argue that the relevant typology includes V-movement relations, case-assigment relations for each case, A-bar chain relations for each case, and constituency relations (though perhaps these will need to be subcategorized further according to the role of the constituent). We speculate that it will include specifier-head agreement relations, control relations, local binding relations and others as well. Furthermore, we argue that, at least for the range of constructions considered here, the bounded connectivity hypothesis can be maintained in conjunction with a simple incremental processing hypothesis. It is tentatively suggested that together, these hypotheses fit with a picture of the parsing mechanism which may explain Emonds' surface recursion restriction, which has been attested in a range of languages.

In a more speculative vein, it is suggested that the human processing mechanism may have tightly constrained, finite resources, with something like registers alloted for particular tasks. This idea about the human sentence processing mechanism fits well with attempts to design parsers that could be realized in finite asynchronous networks lacking a (potentially infinite) recursively accessible memory store. Then, rather than assuming that acceptable or intelligible structures whose connectivity exceeds one relation of each kind are processed recursively, it is natural to consider the idea that in these cases the human parser must resort to limited and special purpose mechanisms to assemble whatever results it can deliver. This idea would motivate an important qualification to the tentative construal of the bounded connectivity hypothesis presented in the introduction. There we suggested that, for all types of constructions, structures with a connectivity of two are awkward while structures with three or more connections of the same kind should always be unacceptable. But we have already seen evidence that, beyond one relation of a given kind, different kinds of structures break down differently. It appears that the attempt to define acceptability bounds more precisely, on any approach, will have to carefully distinguish the various properties of different kinds of structures.

8 References

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