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The Lexical Basis of Sentence Processing: Formal, computational and experimental issues
Edited by Paola Merlo and Suzanne Stevenson

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Formal, computational and experimental issues

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Preface

This volume derives from the special conference session entitled "The Lexical Basis of Sentence Processing: Formal and Computational Issues," held in conjunction with the 11th Annual CUNY Conference on Human Sentence Processing, March 19–21, 1998. The special session highlighted talks and posters on current theories of the lexicon from the perspective of its use in sentence understanding. Lexical influences on processing are currently a major focus of attention in psycholinguistic studies of sentence comprehension; however, much of the work remains isolated from the vast amount of scientific activity on the topic of the lexicon in other subdisciplines. In organising the special session, we felt that the time was ripe to bring together researchers from these different perspectives to exchange ideas and information that can help to inform each others' work. Participants included a multi-disciplinary slate from theoretical linguistics, computational linguistics, and psycholinguistics, representing various theoretical frameworks within each of these disciplines. The special session was quite successful with about 250 registrants, many of whom do not belong to the usual CUNY crowd.

A primary motivation for the special session was that a focus of attention on the lexicon has the potential to bring the structural and probabilistic approaches to sentence processing closer together. To gain a deeper understanding of the lexicon and its impact on processing, we need to elaborate both the structure and the probabilistic content of lexical representations, which together influence sentence interpretation. These questions bring up general issues in the architecture of the mind, and meet up with work in computer science, linguistics, and philosophy on the relation between conceptual knowledge, grammatical knowledge, and statistical knowledge.

The contents of this volume reflect this range of issues from various perspectives in the multidisciplinary study of the lexicon in language processing. A selection of the contributors to the special session were invited to prepare written versions of their presentations to be included in the volume. The preparation of the final version of the papers was assisted by very careful and detailed multiple peer reviewing. Very few of the reviewers were also contributors to

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Reduced relatives judged hard require constraint-based analyses

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We take as our point of departure Stevenson and Merlo's (1997) observation that the differences in the processing difficulty of sentences with reduced relative clauses (RRs) are strongly determined by the inherent lexical semantic class of the verbs used as passive participles in RRs: namely, the unaccusative vs. unergative class. Our main claim is that among the linguistic variables responsible for the relevant differences a crucial role is played by semantic variables, rather than just category-level syntactic complexity and/or complexity associated with word-internal lexical structure of verbs (see Hale and Keyser, 1993). First, we observe a considerable overlap in the distributions of acceptability judgments between sentences with RRs based on unaccusative verbs and those based on unergative verbs, and even more importantly, clear gradient effects with respect to acceptability judgments for both types of sentences that are influenced by the lexical semantics of the main verb in the matrix clause. Second, such data can be successfully motivated, if we characterize the crucial unaccusative-unergative distinction in terms of thematic Proto-Role properties (Dowty, 1988, 1991). Third, the linguistic analysis is consistent with recent constraint-based grammars, most notably HPSG, and our constraint-based model that uses the integration-competition architecture developed by Spivey (1996) and applied to reduced relatives by McRae et al. (1998) and Spivey and Tanenhaus (1998).

1. Introduction

Beginning with Bever's (1970) classic article, sentences with reduced relative clauses, such as *The horse raced past the barn fell*, have served as an important empirical testing ground for evaluating models of sentence processing. Bever observed that sentences with reduced relative clauses are difficult to under-

stand, with people often judging the sentences to be unacceptable, because they initially assume that the 'NP V PP' sequence is a main clause. In subsequent decades one of the central controversies revolved around the question of whether structural complexity plays a primary causal role in processing difficulty of sentences with reduced relative clauses, and other sentences with temporary ambiguities. For example, in recent constraint-based models, the difficulty of reduced relative clauses is argued to arise from an interaction of multiple constraints, many of which are lexically-based (e.g., MacDonald, Pearlmutter and Seidenberg, 1994; Tanenhaus and Trueswell, 1995; Boland, 1997), but which do not include any factors directly attributable to intrinsic ease or difficulty of processing syntactic structures. Important empirical evidence in support of constraint-based approaches has come from gradient effects in the processing difficulty of reduced relatives. For example, *The eggs cooked in butter tasted delicious* is clearly much easier to process than *The horse raced past the barn fell*. In constrast to *raced*, *cooked* is much more often used transitively, it is more frequently used as a passive, and *eggs* is a very poor Agent, but a very good Theme, in a cooking event. Due to such constraints the active intransitive reading of *The eggs cooked with butter...* is less likely and the passive participle reading more likely. Gradient effects in processing difficulty for reduced relative clauses have been successfully modeled using computational implementations of multiple constraint models (McRae, Spivey-Knowlton and Tanenhaus, 1998; Spivey and Tanenhaus, 1998).

Recently, Stevenson and Merlo (1997) made the important observation that the processing difficulty of sentences with reduced relative clauses is strongly determined by the inherent lexical class of the verbs used as passive participles in reduced relatives. Sentences with reduced relatives headed by passive participles derived from unergative[2] verbs are "all mostly or completely unacceptable" (p. 355). In particular, manner of motion verbs "lead to a severe garden path in the RR construction" (p. 353), as is shown in Stevenson and Merlo's (p. 353) examples, here repeated in (1). In contrast, "unaccusative RRs are all completely acceptable or only slightly degraded" (p. 355). Stevenson and Merlo's examples are repeated here in (2):

(1) a. The clipper sailed to Portugal carried a crew of eight.
b. The troops marched across the fields all day resented the general.
c. The model planet rotated on the metal axis fell off the stand.
d. The dog walked in the park was having a good time.

(2) a. The witch melted in the Wizard of Oz was played by a famous actress.
b. The genes mutated in the experiment were used in a vaccine.

c. The oil poured across the road made driving treacherous.
d. The picture rotated 90 degrees was easy to print.

Stevenson and Merlo propose that the unergative/unaccusative difference can be explained using Hale and Keyser's (1993) syntax-in-the-lexicon model, couched within Government and Binding Theory, in which important aspects of lexical-conceptual structure are mirrored by syntactic structures within the lexicon. Unergative verbs are syntactically characterized (among other things) by having an external argument, but no direct internal argument, while unaccusative verbs have no external argument, and a direct (non-clausal, non-PP) internal argument. Due to such lexical properties, transitive and passive structures, including those in reduced relative clauses, which are derived from inherently unergative verbs are significantly more complex than those derived from unaccusative verbs "in terms of number of nodes and number of binding relations, and in having the embedded complement structure" (Stevenson and Merlo, 1997:364). When these linguistic assumptions are implemented in Stevenson's (1994a, b) competitive attachment parser, a kind of symbolic/connectionist hybrid, it turns out that the parser cannot activate the structure needed for a grammatical analysis of reduced relatives headed by passive participles with unergative verbs, "because of its limited ability to project empty nodes and to bind them in the structure" (Stevenson and Merlo, 1997:397). Hence, the parser is viewed as confirming the earlier judgment data, namely that there are "sharp distinctions between unergative RR clauses and RR clauses with other verbs" (p. 396).

In contrast to previous structural theories which attribute the difficulty of reduced relatives solely to category-level syntactic complexity differences, Stevenson and Merlo propose that lexical constraints play a central role in determining the processing difficulty of reduced relative clauses. However, in contrast to constraint-based models, they argue that differences among classes of lexical items are due to differences in structural complexity associated with their lexical structures. They argue that reduced relatives with participles based on unergative verbs are uniformly difficult to process, regardless of factors such as frequency and plausibility, that is, "structural complexity alone can cause failure to interpret a sentence, even when all other factors would help its correct interpretation" (Stevenson and Merlo, 1997:392).

If correct, Stevenson and Merlo's claims would have a number of important implications for theories of sentence processing. First, they would provide the clearest evidence to date for structural complexity effects in sentence processing, due to the internal syntactic structure of words, thus helping to resolve

a long-standing controversy in the field. Second, since there are both syntactic and semantic[3] aspects of the unergative/unaccusative distinction, Stevenson and Merlo's results would strongly support an approach in which syntactic correlates of semantic distinctions play the primary causal role in accounting for variation in processing difficulty.

In this chapter we evaluate Stevenson and Merlo's claims in light of additional empirical data and modeling within a constraint-based framework. Section 2 presents the results of a questionnaire study which replicates Stevenson and Merlo's finding that reduced relatives with passive participles derived from unergative verbs are, as a class, more difficult than reduced relatives with passive participles based on unaccusative verbs. However, the results also show that there is a considerable overlap in the distributions of acceptability judgments and parsing difficulty, as would be expected on a constraint-based account. Section 3 shows that the processing difficulty that is due to the unergative/unaccusative difference falls out of a computational implementation of a constraint-based model, using only those constraints that recent constraint-based theorists have claimed account for processing differences among reduced relatives (MacDonald et al., 1994; Tanenhaus and Trueswell, 1995). Thus the unergative/unaccusative difference does not require appeal to structural complexity differences. In section 4, we argue that a semantic approach based on thematic roles presents a promising alternative to the syntax-in-the-lexicon approach. The thematic properties, which characterize the two fuzzy cluster concepts Proto-Agent and Proto-Patient (Dowty, 1988, 1991), can account for a great deal of processing differences between sentences with reduced relative clauses based on unergative verbs, on the one hand, and on unaccusative verbs, on the other hand. One advantage of this novel way of looking at the garden-path phenomenon is that it allows us to understand the similarities between these two types of sentences in exhibiting clear gradient effects with respect to acceptability judgments and parsing difficulty that are influenced by the lexical semantics of the main verb in the matrix clause. The influence of the main predicate in a sentence on the magnitude of the garden-path effect has so far gone unnoticed and it is problematic for structure-based accounts that assume either category-level syntactic complexity and/or complexity associated with word-internal lexical structure of verbs. We also show that a constraint-based approach incorporating these semantic notions can be naturally embedded within recent constraint-based approaches to grammatical representation. We conclude by describing a rating study that shows the effect of the main verb on the processing difficulty of whole sentences with reduced relative clauses, as is predicted by our linguistic analysis.

2. Gradient effects

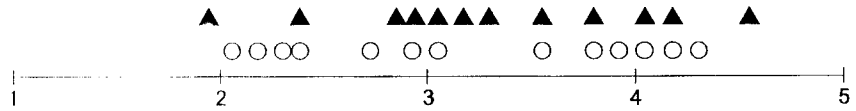
We observed that sentences with reduced relatives based on unergative verbs, including manner of motion of verbs, manifest a considerable degree of variability in acceptability, and, in fact, perfectly acceptable sentences of this type are easy to find. Examples are given in (3). At the same time, some reduced relatives with unaccusative verbs are relatively hard, such as those in (4).

(3) a. The victims rushed to the emergency room died shortly after arrival.
b. The pig rolled in the mud was very happy.
c. The Great Dane walked in the park was wearing a choke collar.
d. The prisoners paraded past the mob were later executed.[4]

(4) a. The theatre darkened for the movie frightened some preschoolers.
b. The Klingon disintegrated during the battle had launched a rocket.
c. The solution crystallized in the oven burned a hole into the petri dish.
d. The plaster hardened in the oven cracked with loud popping sounds.

In a questionnaire study we had twenty-four University of Rochester undergraduates recruited in introductory courses use a five point scale (1 = very easy, 5 = very difficult) to rate the difficulty of a mix of sentences that included reduced relative clauses with inherently unaccusative and unergative verbs, as well as transitive and passive main clause sentences using the same verbs. The full set of materials used in the rating studies are available by request from either of the first two authors. Table 1 presents the mean ratings. There was a significant effect of construction type, $F1(1,23)=62.00$, $p<.01$; $F2(2,32)=82.02$, $p<.01$. Reduced relatives were significantly harder than passives or transitives, regardless of verb type (all planned comparisons were significant at $p<.01$). We replicated Stevenson and Merlo's finding that sentences with reduced relatives headed by passive participles based on unergative verbs are harder to process than sentences with reduced relatives headed by participles derived from unaccusative verbs. For reduced relatives with passive participles derived from unaccusative verbs, the mean was 2.95; and for those with unergative verbs, the mean was 3.45. This difference was reliable in the analysis by subjects, $F(1,23)=5.51$, $p<.05$. However, there was substantial overlap in the distributions, and in fact the difference between the unaccusatives and unergatives was only marginally reliable in an item analysis, $F(1,32)=3.15$, $p=.085$. Four of the eighteen unergative verbs used as passive participles in reduced relatives were rated as yielding sentences with reduced relatives judged easier than the mean rating for sentences with reduced relatives based on unaccusative verbs. The sentences with these verbs are in (3) above. In addition, some sentences with

Table 1. Judged difficulty of reduced relatives



Class	RR	Trans	Pass
○ Unaccusatives	2.95	1.63	1.60
▲ Unergatives	3.45	1.52	1.81

reduced relatives headed by passive participles derived from unaccusative verbs were rated as more difficult than the mean rating for sentences with unergative-based reduced relatives (3.45). Six of the sixteen unaccusative verbs fell into this category, including the sentences in (4).

To summarize, the ratings showed that sentences with unergative-based reduced relatives were on the whole more difficult to process than sentences with unaccusative-based reduced relatives, but also that there was a considerable degree of overlap between these two types of sentences with respect to the processing difficulty. The overlap in the distributions and the continuum of difficulty is problematic for an account in which the inherent structural complexity of unergative verbs predicts "sharp distinctions between unergative RR clauses and RR clauses with other verbs" (Stevenson and Merlo, 1997:396). They do not, however, provide definitive evidence against such a proposal, however, because measurement error or other differences among materials could lead to overlap in the data even if the underlying distributions did not overlap.

3. A constraint-based model

We implemented a constraint-based model using the integration-competition architecture developed by Michael Spivey and applied to reduced relatives by McRae et al. (1998) and Spivey and Tanenhaus (1998). In this model alternative syntactic structures compete within a probability space with multiple constraints providing probabilistic evidence for the alternatives. This model is not a fully implemented parser; rather, it is an architecture for predicting the difficulty of ambiguity resolution using principles common to constraint-based approaches. The question we addressed was whether an unergative/unaccusative

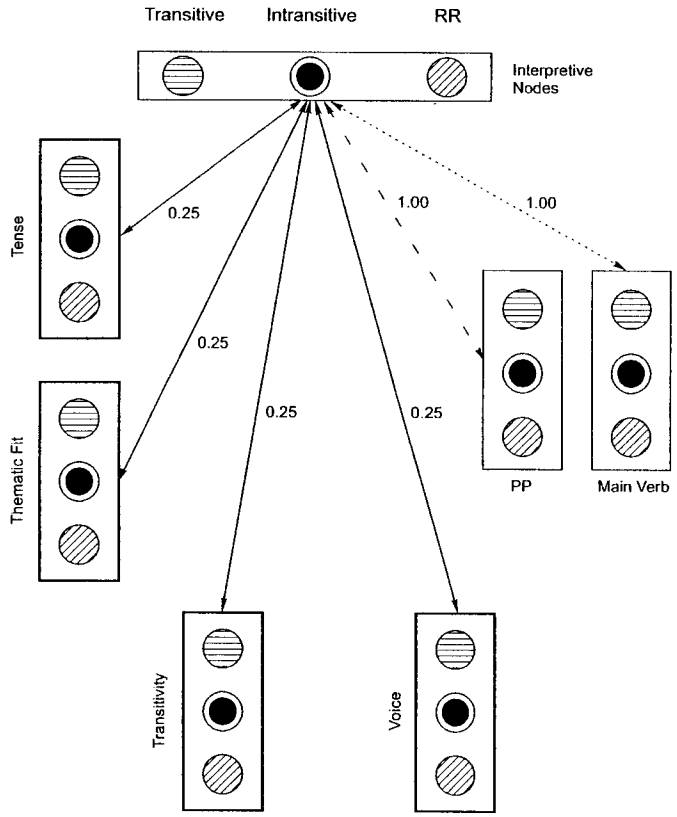


Figure 1. The Integration and Competition model used in the current simulations. Each vertical rectangle represents the input of a particular constraint. The horizontal rectangal represents the output of the model at any point in time for the three integration nodes for the embedded clause: the active transitive, active intransitive and passive in a reduced relative. Constraints for tense, voice, transitivity and thematic fit were introduced at the embedded verb. The PP constraint was introduced after the model completed cycles (i.e., until the dynamic criterion was reached) for each input at the embedded phrase. Similarly, the main verb constraint was introduced after processing was completed for the PP. The weights shown are those that were used when a constraint was first introduced, i.e., before normalization at the next input.

difference would fall out of such a model using just those constraints that have been previously identified in the constraint-based literature.

Figure 1 presents a schematic representation of the model. In the model, three constructions competed, beginning with the first verb in a sentence with a reduced relative clause: NP V(*-ed*) PP V. The constructions were: active tran-

sitive, active intransitive, and passive in a reduced relative. The full passive was ruled out at the *-ed* verb form because of the absence of a preceding copula, and thus was not included.

The constraints used were those identified by MacDonald and colleagues (e.g., MacDonald et al. (1994)) and by Tanenhaus and his colleagues (e.g., Tanenhaus and Trueswell, 1995). The following four constraints came into play at the *-ed* verb form: (1) The frequency with which a verb was used transitively or intransitively; (2) the frequency with which it was used in tensed vs. tenseless constructions; (3) the frequency with which the *-ed* verb form was used in the passive and active voice, and (4) the plausibility with which the first NP could function as subject of an active transitive, subject of an intransitive, and subject of a passive ("thematic fit"). An additional frequency constraint came into play at the PP, and another at the main verb.

In the integration-competition model, each constraint provides probabilistic support for the syntactic alternatives. The normalized bias on the constraint is multiplied by the weight assigned to the constraint. The weights of all the constraints applying at a given input are normalized so that they sum to 1.0. The model works in three steps. First the biases are multiplied by the weights to determine the evidence (activation) each provides in support of the competing interpretation (integration) nodes. Activations are summed at each integration node. Second, feedback to the constraints is provided by multiplying the probability of each integration node by its weight and adding that value to its previous bias. Third, the biases for each constraint are then renormalized. The model continues cycling until a designated criterion; the criterion is lowered after each cycle. (For details, see McRae et al., 1998; Spivey and Tanenhaus, 1998.) When the criterion is reached, the model moves onto the next region of the text, in this case the PP. The new constraint provided at the PP, namely, strong evidence for either an intransitive or a passive, was assigned a weight of 1.0, following the procedure used in McRae et al. (1998). All of the weights were then renormalized, resulting in a weight of .5 for the PP and .125 for tense, voice, thematic fit and transitivity. The same procedure for normalizing weights was followed when the model moved on to the main verb.

Because we did not have an independently motivated way of setting the weights on the four constraints at the *-ed* verb form, we assigned each an equal weight of .25. Biases for transitivity, tense, and voice were determined from corpus analyses using the ACL/DCI corpus, comprising the Brown corpus and 64 million words of the Wall Street Journal that were kindly provided to us by Paola Merlo and Suzanne Stevenson. The biases for thematic fit were determined by typicality ratings collected using the procedure developed by

McRae and colleagues (cf. McRae et al., 1998). Ratings were collected using a five point scale. Questions we used are here exemplified using the verb *melt* as an example: 'How common is it for ice to melt someone or something?' (Active Transitive), 'How common is it for ice to melt?' (Active intransitive), 'How common is it for ice to be melted by someone or something?' (Passive in RR). We tested the model on six unergative verbs, *danced, raced, paraded, rushed, marched, hurried*, and on four unaccusative verbs, *dissolved, cracked, hardened* and *melted*. This small subset of verbs represents those for which we had corpus counts, difficulty ratings and ratings for thematic fit. Table 2 presents the biases used in the model for each of the four constraints that applied at the *-ed* verb form.

Table 2.

Word	Constraint	Bias		
		Transitive	Intransitive	RR
Cracked	Tense	0.31	0.31	0.38
	Thematic Fit	0.12	0.38	0.50
	Transitivity	0.37	0.45	0.18
	Voice	0.41	0.41	0.19
Danced	Tense	0.40	0 40	0.21
	Thematic Fit	0.21	0.56	0.24
	Transitivity	0.15	0.77	0.08
	Voice	0.43	0.43	0.14
Dissolved	Tense	0.16	0.16	0.68
	Thematic Fit	0.17	0.43	0.41
	Transitivity	0.50	0.25	0.25
	Voice	0.21	0.21	0.58
Hardened	Tense	0.05	0.05	0.91
	Thematic Fit	0.21	0.49	0.30
	Transitivity	0.43	0.36	0.21
	Voice	0.23	0.23	0.55
Hurried	Tense	0.32	0.32	0.37
	Thematic Fit	0.31	0.35	0.34
	Transitivity	0.39	0.42	0.19
	Voice	0.34	0.34	0.31
Marched	Tense	0.45	0.45	0.09
	Thematic Fit	0.22	0.43	0.35
	Transitivity	0.06	0.91	0.03
	Voice	0.49	0.49	0.01
Melted	Tense	0.15	0.15	0.71

Table 2. *(continued)*

Word	Constraint	Bias		
		Transitive	Intransitive	RR
Jewelry	Thematic Fit	0.16	0.31	0.53
	Transitivity	0.34	0.49	0.17
	Voice	0.28	0.28	0.44
Melted	Tense	0.15	0.15	0.71
Witch	Thematic Fit	0.35	0.32	0.33
	Transitivity	0.34	0.49	0.17
	Voice	0.28	0.28	0.44
Paraded	Tense	0.25	0.25	0.50
	Thematic Fit	0.26	0.28	0.46
	Transitivity	0.30	0.55	0.15
	Voice	0.31	0.31	0.39
Raced	Tense	0.50	0.50	0.01
	Thematic Fit	0.10	0.45	0.45
	Transitivity	0.05	0.93	0.02
	Voice	0.50	0.50	0.01
Rushed	Tense	0.40	0.40	0.20
	Thematic Fit	0.26	0.33	0.41
	Transitivity	0.14	0.80	0.07
	Voice	0.44	0.44	0.12

As can be seen from Table 2, unergative verbs tend to be used more often than unaccusative verbs in intransitive constructions and less often as passives. For unergative verbs these factors mean that the active intransitive reading of an 'NP V(*-ed*) PP' fragment will be more strongly biased relative to the reduced relative clause reading.

In order to evaluate the output of the model, we considered three measures. The first was the total number of cycles until the criterion was reached at the main verb (cycles at the *-ed* verb form, + cycles at the PP, + cycles at the main verb). The second was the probability assigned to the reduced relative structure at the main verb. The third was the number of cycles it would take the model to assign the reduced relative a probability of .9 at the main verb. We assumed that each of these measures should correlate with the difficulty of the sentence. All three measures predicted that as a class reduced relatives with passive participles derived from unergative verbs would be more difficult than reduced relatives with passive participles derived from unacccusative verbs: for total number of cycles, $t(9)=3.16$, $p<.01$; for probability at the main verb $t(9)=2.95$, $p<.02$; and for cycles to a criterion of .9, $t(9)=2.99$, $p<.02$, all tests two-tailed. The model also correctly predicted some gradient effects. For example, the reduced relative beginning with *The witch melted...* was correctly predicted to be harder than the reduced relative beginning with *The jewelry melted...* . In addition, the reduced relative with *paraded* was predicted to be easier than the reduced relatives with *danced, raced* or *marched*. However, *The victims rushed to the hospital died* was incorrectly predicted to be quite difficult even though it was rated as fairly easy by subjects.

It is important to note that the model we presented is incomplete in important ways. There are constraints that are not included and as a result the model generally overestimates the availability of the reduced relative analysis. Moreover, we were working with only a few verbs for which we had data. Nonetheless, it is clear that the processing distinction between reduced relatives headed by passive participles derived from unergatives and unaccusatives falls out of a small set of constraints, primarily verb-based frequencies, that have been independently argued for by proponents of constraint-based models.

In the light of the results we reached so far, a proponent of the syntax-in-the-lexicon approach might appeal to two types of counterarguments. The first might be that frequencies reflect the unergative/unaccusative distinction; however, the structural complexity associated with the lexical structures of these two classes of verbs results in those frequencies and actually plays the causal role (but cf. MacDonald, 1997). The second argument is that the syntax-in-the-lexicon approach implemented in Stevenson's parser is superior because it presupposes a full-fledged linguistic theory, namely, Government and Binding Theory, whereas the constraint-based approach is not supported by independent linguistic assumptions in a similar way. In the next two sections we address these issues in turn. First, we explore and motivate the claim that among the linguistic variables responsible for the processing distinction a crucial role is played by semantic variables, rather than just syntactic variables. Second, we show that the ideas implemented within our simple model are broadly consistent with recent constraint-based grammars, most notably HPSG.

4. The linguistic basis of unaccusative/unergative distinction in processing

Our primary observation, and one that has so far gone unnoticed, is that both types of sentences with reduced relatives exhibit similar gradient effects in acceptability judgments that are crucially influenced by the lexical semantics of the main verb in a matrix clause. To put it in the simplest terms, the fewer

agent-like properties and the more patient-like properties the main verb assigns to its subject, the easier the whole sentence with a reduced relative clause is judged. This idea will be discussed in detail in Section 4.2, but let us illustrate it here with a few examples. In (5a) the subject of *complained, the patients*, is a volitional agent in the denoted event, and we see that the whole sentence is less acceptable than (5b) with *died* as the main verb, whose subject undergoes a change of state. A similar contrast can be found in (6):

(5) a. The patients rushed to the emergency room *#complained to the nurse.*
b. The patients rushed to the emergency room *died.*

(6) a. The Great Dane walked in the park *#tugged at the leash.*
b. The Great Dane walked in the park *wore a choke collar.*

Similarly in reduced relatives with passive participles derived from unaccusative verbs, such as *darkened* in (7), we see that the use of *frightened* as opposed to *smelled* in the matrix clause is correlated with a difference in the acceptability of the whole sentence. The reason is that *frightened*, but not *smelled*, presents the subject *the theatre* as the cause of the change of the psychological state in the referent of the direct object *some preschoolers.* Other similar examples are given in (8):

(7) a. The theatre darkened for the movie *#frightened* some preschoolers.
b. The theatre darkened for the movie *smelled* like popcorn.

(8) a. The genes mutated in the experiment *#attacked* their host.
b. The genes mutated in the experiment *were used* in a new vaccine.

Most importantly, different degrees of acceptability observed in (5)–(8) resist an explanation in structure-based terms as well as explanations couched in the syntax-in-the-lexicon approach of Stevenson and Merlo (1997). Recall that the latter predict that *all* sentences with reduced relatives headed by inherently unergative verbs are predicted to pose 'sharp difficulty' (p. 392) for an interpreter, and they cannot be assigned a grammatical analysis by the parser. In order to account for unaccusative-based reduced relatives that are *not* easy to interpret, such as those in (9), Stevenson and Merlo resort to the semantic distinction between 'internal causation' and 'external causation' (see Levin and Rappaport Hovav, 1995:210–211) to argue that they are unergative. According to them, verbs like *caramelise, solidify* and *yellow* entail 'internal causation' in their semantic description, a feature that distinguishes unergative verbs from unaccusative ones, the latter being 'externally caused' (see ibid.). Since unaccusative verbs have one internal direct object argument, the external subject

argument position is unfilled, and it can be filled by an 'external cause' argument, when they are used transitively. This does not hold for unergative verbs, because they already have one external subject argument. By this test, *yellow* in (10a) and *solidify* in (10b) are unergative, while *harden* in (10c) and *yellow* in (10d) are unaccusative. (Examples in (9) and (10) are taken from Stevenson and Merlo, 1997:365.)

(9) a. #The candy caramelised in an hour burned.
b. #The wax solidified into abstract shapes melted.
c. #The paper yellowed in the sun shrank.

(10) a. #The chain-smoker yellowed the papers.
b. #The sculptor solidified the wax.
c. The sculptor hardened the wax.
d. The sun yellowed the paper.

The problem with this test is that unergative verbs, including agentive manner of motion verbs, when used transitively *require* their subject argument to be an Agent: cp. **The explosion jumped the horse* vs. *The jockey jumped the horse.* (This observation was made by Cruse, 1972; Jackendoff, 1972; Levin and Rappaport Hovav, 1995; see also Stevenson and Merlo, 1997:357 and footnote 4 below.) This inconsistency clearly indicates that a test based on the possibility of the overt expression of an Agent argument cannot be the right diagnostic for deciding the membership of verbs in the unaccusative and unergative class. The main source of confusion stems here from correlating 'external causation' and 'possibility of an overt expression of an external agent', on the one hand, and 'internal causation' and 'prohibition against an overt expression of an external agent', on the other hand. What is lacking is a precise characterization of the notions 'internal causation' and 'external causation', introduced by Levin and Rappaport Hovav (1995), and the motivation for the correlation of these semantic notions with the syntactic structures associated with unergative and unaccusative verbs. Moreover, (10a) is claimed to be less acceptable than (10d), because its subject referent may be intentionally involved in the denoted event, while in (10d) the denoted change of state is "indirectly brought about by some natural force" (p. 365). However, it is not shown how such a fine-grained distinction between '(volitional) Agent' and 'natural force', and the suggested difference in acceptability judgments, can be viewed as being correlated with the external subject argument in the case of unergative verbs, and with the internal object argument in the case of unaccusative verbs.

The fact that Stevenson and Merlo do resort to rather subtle semantic criteria in order to account for difficult cases is instructive, because it shows that explanations in terms of categorical differences between syntactic configurations in the lexicon are insufficient. Indeed, one may ask to what extent syntactic factors are necessary in addition to semantic ones in order to account for the garden-path phenomenon. If we focus on the differential semantics of the verbs in the material discussed here, we can begin to acount for the overlapping distribution of sentences with reduced relatives as well as the great deal of variability with respect to how good or bad they are judged to be, leaving open the question of what role, if any, a word-internal syntactic differences are left to play. We now turn to characterizing those semantic constraints more precisely.

4.1 Thematic Proto-Roles

The idea that argument positions of verbs are associated with certain "thematic roles" (Case Roles, Case Relations) such as Agent, Patient, Instrument, and so forth, has received varying characterizations in the linguistic literature. Here, however, we follow the analysis of David Dowty (1988, 1991), who proposes that the only thematic roles are two cluster concepts, Proto-Agent and Proto-Patient, each characterized by a set of verbal entailments, given in (11) (see Dowty, 1991:572). "[A]n argument of a verb may bear either of the two proto-roles (or both) to varying degrees, according to the number of entailments of each kind the verb gives it" (Dowty, 1991:547).

(11) Contributing properties for the Agent Proto-Role:

a. volitional involvement in the event or state
b. sentience (and/or perception)
c. causing an event or change of state in another participant
d. movement (relative to the position of another participant)
(e. referent exists independent of action of verb)

Contributing properties for the Patient Proto-Role:

a. undergoes change of state
b. incremental theme
c. causally affected by another participant
d. stationary relative to movement of another participant
(e. does not exist independently of the event, or not at all)

The Argument Selection Principle determines the direct association of clusters of Proto-Agent and Proto-Patient properties with grammatical relations in a many-to-one fashion:

(12) Argument Selection Principle (Dowty 1991:576)

In predicates with grammatical subject and object, the argument for which the predicate entails the greatest number of Proto-Agent properties will be lexicalized as the subject of the predicate; the argument having the greatest number of Proto-Patient properties will be lexicalized as the direct object.

4.2 Compatibility between subjects in sentences with reduced relative clauses

In reviewing the contrasts found in examples, such as (5)–(8), it appears that the following is a reasonable description of one effect of the main verb on a reduced relative clause:

(13) Hypothesis

The acceptability of sentences with reduced relative clauses, headed by passive participles derived from unergative and unaccusative verbs, increases when the passive participle and the main verb of a matrix clause assign their subject-NPs more Proto-Patient, and fewer Proto-Agent, properties.

The intuition behind the hypothesis (13) is that sentences are easier to interpret when there is an internal coherence among the interpretations of their constituents. One way this coherence can be achieved is in terms of compatible assignments of thematic properties to different NP arguments that are associated with one and the same participant in the domain of discourse. In sentences with a reduced relative clause the internal coherence depends in part on how well the thematic make up of the subject NP in the matrix clause matches the thematic make up of the PRO-subject of the reduced relative clause: namely, the passive participle in the reduced relative requires that its PRO subject be a "very good" Patient. Let us take (1a) *#The horse raced past the barn fell.* At the point when *raced* is processed, the preferred syntactic-semantic pattern is that of the main clause with an agentive subject-NP. However, when *fell* is processed, *raced* must be understood instead as a passive participle. Passive participles typically presuppose the existence of corresponding active transitive verbs whose subjects correspond to active direct objects (see Sag and Wasow, 1997:164, for example; however, passive subjects do not always correspond to active direct objects, see Zwicky, 1987; Postal, 1986, and others). Let

us now look at the assignment of thematic properties by the verb *raced* in its intransitive (unergative) and transitive (lexical causative) use. ('PA' stands for Proto-Agent properties and 'PP' for Proto-Patient ones.)

(14) *The horse RACED past the barn. The rider RACED the horse past the barn.*

PA	PA	PA and	PP
(+ volition)	+ volition	(+ volition)	+ causally
+ sentience	+ sentience	+ sentience	affected
+ movement	+ causing change	+ movement	

A causative form of an unergative is not a "usual" transitive in that it semantically departs from prototypical transitives. Intuitively, prototypical transitives can be understood in terms of a 'billiard ball model', as Langacker (1986) calls it, which involves two participants that interact in an asymmetric and unidirectional way, whereby one of them is directly affected by some action (possibly involving movement, contact, effect, and the like) instigated or caused by the other participant. In Dowty's terms, this means that the direct object has many Proto-Patient (and a few Proto-Agent) properties, and the subject has many Proto-Agent (and a few Proto-Patient) properties. A typical unergative verb used transitively does not fit the semantics of a transitive prototype, because its direct object has a thematic make up of a "good" Agent: in our example (14) the subject *the horse* of the intransitive *raced* corresponds to the object of the transitive *raced* and they share three Proto-Agent properties. At the same, *the horse* is assigned one Proto-Patient property 'causally affected' by the transitive *raced*. The awkwardness often related to the transitive use of unergative verbs may be seen as stemming from having to reconcile these two different roles or two different perspectives (an Agent-like and a Patient-like) on one and the same participant in the denoted complex eventuality. This carries over to passive participles derived from inherently unergative verbs. The reason is that a prototypical passive construction requires its subject to have a high number of Proto-Patient properties, yet a passive participle of an unergative verb supplies a subject argument that carries a number of Proto-Agent properties, given that it corresponds to the direct object of an active transitive verb (*The rider raced the horse*), which in turn corresponds to the subject of the active intransitive verb (*The horse raced*). To return to our lead example, in (15) we see that the PRO subject of the passive participle has the same thematic properties as the corresponding active object in (14), hence it is not a "good" Patient. The main verb *fell* assigns the property 'movement' to its subject *the horse*. In so far as this can be interpreted in terms of 'movement relative to the position of another participant', and given that *the horse* in (15) is a sentient being with a (potentially) certain volitional involvement in the racing event, 'movement' can be here taken as the Proto-Agent property. (This is not uncontroversial. However, *fell* does not assign clear Proto-Patient properties to its subject either. A candidate might be 'undergoes a change of state', but here it would not mean a permanent change, rather just a change in bodily posture, and hence ultimately 'movement'.) Hence, the thematic make up of the subject NP in the matrix clause does not match the thematic constraint of the reduced relative clause which requires that its PRO subject be a "very good" Patient.

(15) **The horse$_i$ [< PRO$_i$ > RACED past the barn] fell.**

PA	PA	and	PP
+ movement	(+ volition)		+ causally affected
	+ sentience		
	+ movement		

If, on the other hand, the main verb of a matrix clause assigns Proto-Patient, rather than Proto-Agent, property (or properties) to its subject, the magnitude of the garden path effect is diminished, as (16) shows: the subject of *died* is clearly a "better" Patient then the subject of *fell*, as it is entailed to undergo a permanent change of state. Hence, (16) is somewhat easier to interpret than (15).

(16) **The horse$_i$ [<PRO$_i$ > RACED past the barn] died.**

PP	PA	and	PP
+ undergoes change	(+ volition)		+ causally affected
of state	+ sentience		
	+ movement		

Of course, not all transitive and passive uses of inherently unergative verbs are odd. Other factors, such as expectations related to the occurrence of highly conventionalized combinations of words and general world knowledge, may come into play and override the semantic mismatch described above. For example, *John walked his dog* and *Fido was walked by John tonight* sound highly natural.

Let us now look at sentences with reduced relatives headed by passive participles derived from unaccusative verbs. In (17a) the subject of the unaccusative *melted, the butter*, corresponds to the object of the active transitive *melted* in (17b), they are both entailed to have at least two Proto-Patient prop-

erties: 'change of state' and 'Incremental Theme'. Hence, they are "very good" Patients, and we can expect that both the transitive and passive uses of *melted* are perfectly acceptable.

(17) a. The butter MELTED in the pan.
b. The cook MELTED the butter in the pan.

(18) a. The butter MELTED in the pan was fresh.
b. #The butter MELTED on the stove dripped onto the kitchen floor.

As is predicted by the hypothesis in (13), (18a) is judged easier to process than (18b). (18b) contains the matrix verb *dripped* that entails that the referent of its subject argument moves relative to the position of another participant, and hence can be viewed as entailing one Proto-Agent property in its subject argument. This, however, is inconsistent with the requirement stated in our hypothesis (13) that the subject NP in the matrix clause matches in its Proto-Patient properties the thematic make up of the PRO-subject of the reduced relative clause. (18a) contains the stative predicate *be fresh* in the matrix clause, which entails no Proto-Agent properties in its subject argument, and hence (18a) is more acceptable than (18b).

4.3 An HPSG approach

In the past ten years or so there has been a growing convergence of results and methodological assumptions coming from psycholinguistics and theoretical linguistics in the domain of constraint-based approaches to natural language description (e.g., Pollard and Sag, 1987; Pollard and Sag, 1994; Sag, 1998, for example; see Tanenhaus and Trueswell, 1995 and MacDonald, 1997 for a review of constraint-based approaches in psycholinguistics). They share two main assumptions: First, a sentence's interpretation requires satisfaction of multiple (possibly differentially weighted) constraints from various domains of linguistic and non-linguistic knowledge. Second, the integration of such diverse constraints is facilitated by the information contained in lexical entries. Verb-based syntactic and semantic patterns provide a guide for interpreting key aspects of the sentence's structure and meaning, whereby semantic constraints often have a privileged status.

The lexical constraint-based approach proposed here has all the main hallmarks of recent versions of HPSG (see Sag, 1998, for example). Assumptions about lexical semantics of verbs and linguistic information directly associated with extra-linguistic context and general world knowledge are influenced by Fillmore's work and Construction Grammar (see Fillmore and Kay, in press). The grammar assumed here is monostratal, non-derivational and non-modular. It is characterized declaratively by specifying types of well-formed linguistic expressions (e.g., words, phrases, part of speech classes, argument structure classes, and traditional morphological classes, for example) and constraints on those types. All properties of linguistic expressions are represented as feature structures. Language-particular rules and universal principles are characterized as systems of constraints on feature structures. The main explanatory mechanism is unification in the narrow sense of structure sharing of token-identical feature structures (cf. Pollard and Sag, 1994).

Since lexical entries constitute the key ingredient for interpreting the main aspects of the sentence's structure and meaning, and facilitate integration of diverse types of knowledge, let us introduce their main features using a simplified lexical entry for the transitive active *raced* in (19):

(19)
$$\begin{bmatrix} \text{PHON} & \textit{raced} \\ \text{SYN} & \begin{bmatrix} \text{HEAD} & \textit{verb} \\ \text{CAT} & \langle [1]\text{NP}, [2]\text{NP} \rangle \end{bmatrix} \\ \text{SEM} & \begin{bmatrix} \theta & \langle e, [1]_i, [2]_j \rangle \\ \text{CONTENT} & \begin{bmatrix} \text{psoa} \\ \text{PRED} & \begin{bmatrix} \text{REL} & \text{race} \\ \text{racer} & \text{i} \\ \text{racee} & \text{j} \end{bmatrix} \end{bmatrix} \end{bmatrix} \\ \text{CONTEXT} & [\ \ldots\ ] \end{bmatrix}$$

(19) contains phonological, syntactic, semantic and pragmatic information, encoded as values of the feature attributes PHON, SYN, SEM and CONTEXT, respectively. The value of SYN encodes syntactic information required for constructing syntactic projections headed by *raced*. The linking between the syntactic (SYN) and semantic (SEM) structure in the lexicon is mediated via co-indexation of syntactic arguments and thematic argument slots, and motivated by Dowty's Argument Selection Principle (here given in (12)). Each argument slot in the thematic structure of a verb corresponds to a cluster of Proto-Agent and/or Proto-Patient properties (cf. Dowty, 1991). Thematic argument slots in turn are co-indexed with individuals in the predication feature structure PRED, which together with 'psoa' (parametrized state of affairs) constitutes the value of CONTENT. The feature structure PRED captures the assumption that verbs semantically express relations between individuals. The attributes 'racer' and 'racee', which correspond to 'frame-specific participants' in Fillmore (1986) or 'individual thematic roles' in Dowty (1989), include properties that we associate with the individuals 'i' and 'j' on the basis of knowing that the statement

'i raced j' is true. In a given single-clause predication, further semantic restrictions on participants are imposed by the interpretation of noun phrases. For example, '[racer i]' will be constrained by the content of the NP filling the '[1]NP' place. PRED does not provide an exhaustive account of all that we know about the meaning of a given verb. What role an individual plays in a given situation depends on a number of other factors, including world knowledge, which is encoded under 'psoa'. (For a related, though not identical, use of 'psoa' see Pollard and Sag, 1994; Sag and Wasow, 1997.) Lexical entries of verbs also include frequency information about the occurrence of a given verb form in the language, about its argument structures, and the like.

Apart from the lexicon, the grammar will minimally include the level of verb forms and the syntactic level with phrasal templates. This is illustrated in a highly simplified Figure 2.

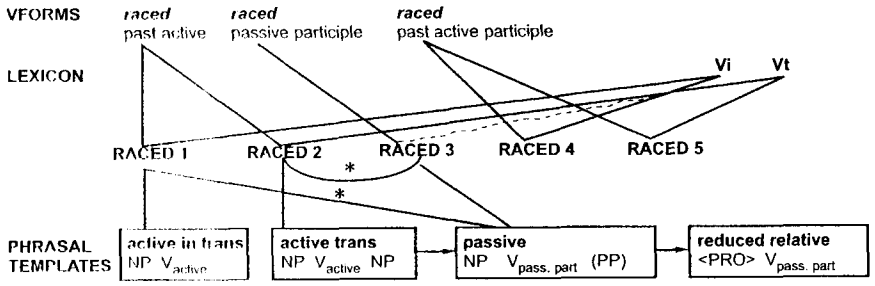


Figure 2. A simplified outline of a constraint-based model.

In general, types at each level of representation are cross-classified in multiple inheritance hierarchies according to their shared information. (Due to the limitation of space, this is not represented in Figure 2.) The information shared by a given class of objects is associated with a general type and is automatically passed down from the general type to specific members of the class. For example, RACED2 and RACED5 inherit information from the generic lexical entry for transitive verbs, here represented by the node Vt. Types directly subsumed under the same supertype represent mutually inhibitory alternatives, which often represent multiple interpretation alternatives and differ in frequency of occurrence in the language. For example, RACED2 (active past tense) and RACED3 (passive participle) are mutually exclusive, here indicated by the thick starred line between RACED2 and RACED3. The active intransitive use of *raced* is more frequent than the active transitive one. We assume that such frequency information is encoded in the lexical entries of verbs.

Unification allows us to represent dependencies and connections within one particular level of representation and also among different levels. Feature structures representing compatible types are unified in a new coherent structure by linking them to a single feature structure, which is shown with straight lines (not all such possible connections are here indicated): e.g., [VFORM PAST.ACTIVE] ∪ [SYN Vi]. Feature structures representing incompatible types cannot be unified: for example, active verbs cannot be projected into a passive clause. One advantage of this system is that it allows us to capture the observation that different types of information that characterize the use of a given word are dependent on each other so that accessing one type of information during sentence processing results in accessing others compatible with it. For example, if the sequence *The horse raced...* is understood as the main clause, the information associated with the verb *raced* will be a complex feature structure comprising the information that this verb shares with all active past tense verbs. If the same sequence is understood as the head noun modified by a reduced relative clause, *raced* will be associated with the information shared with all passive participles, and due to its passive argument structure it will also activate the information associated with the active transitive use of *race*.

5. Empirical study of effects at the main verb

We conducted a rating study in which we had six subjects complete questionnaires in which they made judgments about four of the dimensions that Dowty identified as being part of the Proto-Agent cluster: 'volition', 'sentience', 'causing an event or change of state', and 'movement'.[5] The questions concerned the subject argument of the main verb in the matrix clause. Thus to obtain ratings for *The horse raced past the barn died*, the subject would rate *The horse died*. Each simple sentence in the latter set of data was associated with four questions designed to illicit judgments about the four main Proto-Agent properties entailed by the verb for its subject argument. Each question was answered by our subjects using a scale from 1 to 5. For example, in the case of 'volition', 1 would indicate a completely non-volitional participation of the individual denoted by the subject argument (e.g., *The horse died*) and 5 would a fully volitional participation (e.g., *The patients complained*). We then averaged these ratings to come up with a composite Proto-Agent rating, with 1.0 being the lowest and 5.0, the highest. Subsequently, we selected matched pairs of reduced relatives with different main verbs, e.g., *The victims rushed to the hospital complained/died*, in which participants assigned different Proto-Agent ratings for the two main

verbs (e.g., *The victims died* vs. *The victims complained.* We were able to identify 21 matched pairs of reduced relatives that met this criterion. We then had another group of subjects rate reduced relatives using these main verbs, e.g., *The victims rushed to the hospital complained/died shortly after arrival.*

Table 3. Rated difficulty for reduced relatives with main verbs differing in the Proto-Agent properties assigned to their subject argument. Numbers in parentheses represent the mean Proto-Agent rating

passive participle derived from	Proto-Agent properties			
	low		high	
unaccusative verbs	2.32	(1.37)	2.50	(2.35)
unergative verbs	2.81	(2.04)	3.31	(3.83)

The data are presented in Table 3. The numbers in brackets indicate the mean ratings for verbs with low Proto-Agent entailments in their subject argument, and the mean ratings for verbs with high Proto-Agent entailments in their subject argument. An ANOVA conducted on the difficulty ratings revealed a main effect of verb class, $F(1,20)=9.50$, $p<.01$, a main effect of the Proto-Agency of the main verb, $F(1,20)=5.02$, $p<.05$ and no interaction, $F(1,20)=1.10$. Overall, then, reduced relatives with main verbs with higher Proto-Agent properties were more difficult than reduced relatives with lower Proto-Agent properties.

To summarize this section, we showed that the unaccusative-unergative distinction that Stevenson and Merlo characterize as a syntactic distinction correlated with difficulty or ease of processing in reduced relative clauses can be re-cast as a distinction that concerns the assignment of thematic roles. One advantage of this novel way of looking at the garden-path phenomenon is that it allows us to understand something that has never been systematically commented on before: namely, the influence of the main predicate in a sentence on the magnitude of the garden-path effect. The analysis in terms of Dowty's thematic roles, formulated in (13), also makes the correct predictions here. These results also support the claim made by Carlson and Tanenhaus (1988), Tanenhaus and Carlson (1989), and in a number of later studies by Tanenhaus and his collaborators, that thematic roles play a central role in language comprehension. We also showed that our thematic analysis is consistent with an independently motivated linguistic model.

Taken together, the current work confirms Stevenson and Merlo's finding that sentences with reduced relatives headed by passive participles derived from unergative verbs pose more processing difficulty than sentences with reduced relatives based on unaccusative verbs. Contrary to Stevenson and

Merlo's claims though, this result is completely consistent with currant constraint-based lexicalist models. We also presented an analysis of the unergative/unaccusative distinction using thematic role properties along with some preliminary supporting evidence. In future research it will be important to combine more sophisticated thematic role representations into a constraint-based processing model.

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Notes

1. '+' Department of Linguistics, '*' Department of Brain and Cognitive Sciences.

2. The unaccusative/unergative distinction (e.g., *melt* vs. *race*) was introduced by Perlmutter (1978), and also noticed by (Hall, 1965).

3. According to semantic characterizations given by Van Valin (1990) and Dowty (1991), for example, unergative verbs tend to entail agentivity in their single argument and to be aspectually atelic. Unaccusative verbs take a patient-like argument and are mostly telic.

4. It might be objected that our examples in (3) are easy to process, because they involve complex unaccusative predicates, rather than unergative verbs. However, for English at least, there seem to be no convincing grammatical tests for the unaccusative status of the combination 'unergative verb + directional PP'. (See Levin and Rappapport-Hovav, 1995: 188 and elsewhere, for a discussion of possible candidate tests, such as the occurrence of unaccusatives in the causative alternation.)

5. One of Dowty's Proto-Agent properties was not included: namely, 'referent exists independent of action of verb'. It does not matter for our analysis, given that the constructions under consideration have the same value for this feature.

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