Research Article

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On the computational modeling of English relative clauses

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Abstract: Even in this era of parameter-heavy statistical modeling requiring large training datasets, we believe explicit symbolic models of grammar have much to offer, especially when it comes to modeling complex syntactic phenomena using a minimal number of parameters. It is the goal of explanatory symbolic models to make explicit a minimal set of features that license phrase structure, and thus, they should be of interest to engineers seeking parameter-efficient language models. Relative clauses have been much studied and have a long history in linguistics. We contribute a feature-driven account of the formation of a variety of basic English relative clauses in the Minimalist Program framework that is precisely defined, descriptively adequate, and computationally feasible in the sense that we have not observed an exponential scaling with the number of heads in the Lexical Array. Following previous work, we assume an analysis involving a uT feature and uRel feature, possibly simultaneously valued. In this article, we show a detailed mechanical implementation of this analysis and describe the structures computed for *that*, *which*, and *who/whom* relatives for standard English.

Keywords: English relative clauses, Minimalist Program, computational modeling

1 Introduction

Relative clauses have been the subject of much research in modern Generative Grammar.[1] These constructions are of particular interest because the head noun of the relative clause appears to be doubly licensed. In (1)a, resp. (1)b, the relative clause head noun *man* appears to obtain both grammatical case and a theta-role in two distinct positions (assuming that there is only one head noun *man*); i.e., as an object (resp. subject) of the relative clause verb *saw* (resp. *loves*) and as an object of the matrix verb *like*.

(1) (a) I don't like [the man who John saw ~~man~~]
(b) I don't like [the man who ~~man~~ loves Mary]

Analyses of relative clauses in the Generative Grammar tradition have attempted to explain the structure of relative clauses and clarify how a relative N is licensed. Analyses can be loosely categorized into *matching* analyses, in which there are two separate relative nouns that have the same reference, and *head promotion/raising* analyses in which there is only one relative noun that undergoes movement. In an operator movement

1 See Brame (1968), Schachter (1973), Carlson (1977), Chomsky (1977), Vergnaud (1974), Kayne (1994), Borsley (1997), Bianchi (1999, 2000), Citko (2001), Chomsky (1995), Gallego (2006), de Vries (2002), Schachter (1973), Salzmann (2017), Radford (2016), Radford (2019), *inter alia*.

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analysis, like that in (2)a (Chomsky 1977, Chomsky and Lasnik 1995), a relative operator is base generated in the relative clause and raises to the specifier of the CP. It then gets its interpretation by being associated with an external noun, expressed through coindexation here. In another account, shown in (2)b, there are two separate relative nouns that have the same reference, and the lower noun is deleted under identity (cf. Citko 2001). Both of these types of analyses in (2)a–b have been referred to as matching analyses, as there are two separate relative nouns. In a head promotion/raising account, the nominal head of a relative clause undergoes movement outside of the clause, as in (2)c (Brame 1968, Schachter 1973, Vergnaud 1974, Kayne 1994, Borsley 1997, Bianchi 2000, etc.). Unlike a matching analysis, there is only one relative noun which undergoes movement, and it is basically licensed in two positions.

(2) a) I don't like the man$_1$ [who/OP$_1$ C John saw ~~who/Op$_1$~~]
b) I don't like the man$_2$ [[who/OP ~~man$_2$~~]$_1$ John saw [~~who/Op man$_2$]$_1$~~]
c) I don't like the [man$_2$ [[who/D ~~man$_2$~~]$_1$ John saw [~~who/D man]$_1$~~]]

The matching analysis does not face the problem of a single noun receiving case and a theta-role in two positions, as it makes use of separate but co-indexed nouns. On the other hand, a raising analysis does not require a separate matching/coindexation operation. A thorough comparison of the various approaches, and their variants, is beyond the scope of this article,[2] but we adopt a version of the raising/promotion account in which new NPs with the same core noun lexeme can be formed through Internal Merge (IM), obviating the need for a separate matching operation. At the same time, we avoid the problem of a single noun receiving multiple theta-role and case assignments, through the use of separate D heads.

English relative clauses pose a non-trivial problem as they vary with respect to the content of the head and edge of the CP, as summarized in Table 1. None of the standard English relative clauses permit *which*/*who that*;[3] there being a well-known ban on doubly filled COMP (cf. Chomsky and Lasnik 1977, among others). Object relatives permit an empty COMP (indicated by Ø), but subject-relative clauses do not.

This article presents a computational model of relative clauses based on linguistic proposals in the Minimalist Program (MP) framework (Chomsky 1995, 2001).[5] We have a full computer implementation of the theory, verified across all core examples presented in this article.[6] The detailed step-by-step derivations computed by the program are too lengthy for inclusion in the body of this article; they may be found in the online Appendix, thus permitting the reader to verify the accuracy of our claims.[7] These derivations should also prove helpful to both linguists and engineers who wish to understand how the components of the theory interact in full detail. To our knowledge, this is the first computer implementation in the MP framework to accurately generate the complete set of basic subject and object English relative clause constructions, while also accounting for the usage of *which*, *that*, and *who(m)* in relative clauses.

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2 See Aoun and Li (2003), Radford (2016), and Salzmann (2017), among others for comparisons of the head raising and matching analyses, as well as arguments for and against each approach. Salzmann favors a matching analysis, whereas Radford and Aoun and Li argue that both approaches are necessary (depending on the type of relative clause).

3 The use of *who* vs *which* is dependent on whether or not the head noun is human/animate and is subject to minor stylistic variation. In particular, *who* appears to require a human head noun (although it is sometimes used for animals with names; e.g., see https://erinwrightwriting.com/refer-animals), whereas *which* can be non-human and animate, but it can also be inanimate.

4 Most of these examples are from Gallego (2006), who has taken some of these examples from other works such as Kayne (1994) and Bianchi (1999).

5 Implemented in Prolog and in Python independently, nearly identical results were obtained, thus providing verification of correct implementation, as well as verification for the consistency of the theory. This involves checking for intended derivations, for the absence of unintended derivations, as well as crashes in cases of ungrammatical input.

6 Our model makes logical consistency checks with respect to feature valuation. The model also implements disjunctive logic; i.e., multiple derivations are, in principle, possible. Any logical inconsistencies will result in non-convergence for a particular derivation, but other derivations may proceed independently. However, we also use the notion of economy of feature-checking to compare and dis-prefer other successful derivations.

7 Complete derivations, implemented independently by each author, are available in the online Appendix.

Table 1: Examples of core relative clauses[4]

	Type of relative	Restrictions	Examples
a)	Object relative	which/that/Ø	(i) the book which/that/Ø I read
		*which that	(ii) *the book which that I read
		who(m)/Ø	(iii) the man who/Ø John saw
		*who that	(iv) *the man who that John saw
b)	Subject relative	who	(i) the man who loves Mary
		that	(ii) the boy that called Mary
		*who that	(iii) *the boy who that loves Mary
		* Ø	(iv) *the boy Ø called Mary
c)	Object headless relative	what	(i) what I read
		*what that	(ii) *what that I read
d)	Subject headless relative	what	(i) what annoys John
		*what that	(ii) *what that annoys John

1.1 Computational modeling of linguistic theory

The computational implementation of linguistic theory requires overcoming substantial barriers including (1) the careful selection of compatible sub-theories of grammar, a particularly important aspect as relative clauses involve both theories of the noun phrase (NP) and sentential structure (CP); and (2) theory mechanization, as linguistic theories are not specified with a mechanical architecture in mind. We take a *linguistically-faithful* automatic computer program to be one that autonomously assembles syntactic derivations (beginning with a list of primitive lexical items). The MP continues a long line of inquiry into the nature of the language faculty; this being a theory of competence, and our implementation concretely realizes the generative procedure. The problems of externalization, e.g., the mapping of linguistic representation into instructions to the sensory-motor system, and the problem of (efficient) parsing are important ones for which scientifically motivated answers are still limited. In this article, we limit our attention to the modeling of the generative procedure. We emphasize that the generative procedure does not automatically imply a psychologically realistic parser; it generates structures and sentences starting from a list of (user-supplied) lexical heads.[8]

Let us consider the general problem of concrete modeling. First, the theory should be precise and substantial enough to withstand scrutiny. It must be possible to algorithmically specify details down to the level of the linguistic primitives assumed in the MP framework, i.e., Merge (combing syntactic objects [SOs]) and probe-goal feature checking (agreement relations between features on two SOs). This is a non-trivial requirement as theoretical development in the MP framework proceeds apace and in a radical fashion.[9] Suppose we are able to select a sufficiently precise and broad theory. We also need to provide a computationally tractable implementation. For example, the implementation should not exhibit combinatorial characteristics, such as in terms of temporary syntactic ambiguity or lexical ambiguity, that require exponentially scaled resources, e.g., as the list of initial heads grows. Finally, in line with broader MP goals, we submit that an implementation of a particular phenomenon should be succinct in terms of the number of construction-specific theoretical devices required, ideally none. Every grammatical feature or data structure we specifically introduce to limit or

8 Simply by selecting a correct list of lexical items, our model implies a semi-decidable parsing procedure in the sense that we can explore a finite number of possible options, e.g., with respect to movement and possible empty categories. The problem of convergence for ungrammatical input leaves us with only semi-decidability. An efficient parser would require additional constraints to effectively limit the search space. A cognitively plausible model would also have to account for psycholinguistic data, i.e., express ranked preferences. We note attempts to account for this, e.g., the surprisal theory of Hale (2001), have been made, but not within the MP framework. We leave this important topic for future work.

9 For instance, a simple glance at the theoretical apparatus and structural descriptions suffices to confirm that the MP framework described in the study by Chomsky (1995) differs substantially from that of Chomsky (2001), which, in turn, differs substantially from that of Chomsky (2013).

control derivations is an additional burden, not only to acquisition and evolution but also with respect to the goal of simplifying core syntax. As we will show, our system is *parameter-efficient* in this sense. Since relative clauses embed sentential structure, any model of relativization must also include substantial modeling of sentential structure and therefore will be of broad relevance to general modeling of grammar.

We need to also motivate the MP framework itself. For theoretical linguistics, this requires little justification: the goal of a universal theory built around binary Merge has resulted in a large body of work (since Government-Binding theories of the late seventies) that has contributed greatly to the understanding of language. However, there remains a substantial gap from theoretical to computer models. Müller (2015, 35) writes that there are no “large-scale computer implementations that incorporate insights from Mainstream Generative Grammar.” We believe we have substantially narrowed that gap by clearly demonstrating that theoretical achievements can be implemented. Furthermore, Müller (2015, 37) writes that the system presented in Fong and Ginsburg (2012), which is similar to the system presented in this article, “neither parses nor generates a single sentence from any natural language”. We wish to clarify that we compute linguistic derivations which are spelled out as phrases and sentences of English.

We do not employ a phrase structure grammar-based formalism in this article, choosing instead to implement devices described by theory directly. We are aware that there is a substantial body of work centered around the Minimalist Grammar formalism, e.g., Stabler (1997, 2011), including computational implementations such as Hale (2003), Harkema (2001), and Torr et al. (2019), and Indurkya (2021). A detailed comparison of our work with an equivalent Minimalist Grammar is a topic that is beyond the scope of this article.[10] There are also proposals for relative clauses in other linguistic frameworks such as Head-Driven Phrase Structure Grammar (HPSG), e.g., Sag (1997), that lend themselves to computational implementation, e.g., Müller (2015). Sag (1997) takes a construction-specific approach to relative clauses, slicing them up into a sort hierarchy.[11] In Chomsky's MP, construction-specific rules are frowned upon: the goal being to reduce constructions to universal primitives. We also include key examples from Sag (1997) and show how they are handled in the MP framework.[12]

1.2 The Minimalist Program

It is important to note that the MP is a program of research inviting many different theories under the umbrella of eliminating complex operations in favor of the simplest possible operations that can be conceived

10 Minimalist Grammar (MG) is a grammar formalism that embraces strict feature checking to drive displacement (movement), i.e., Internal Merge, and selection (External Merge). Lexical entries embed a sequence of (possible arbitrary) formal features to be applied in sequence to fix the correct word and hierarchical order (at the cost of requiring multiple lexical entries to account for different derivation paths). We limit the discussion here to the major points of departure from MG, including that displacement is not always feature-driven, the null hypothesis being that it is free (to take place or not). It is generally accepted that Merge is concerned only with hierarchy, i.e., encodes nothing about word order, e.g., Chomsky (2013). A MG account adds formal features and Merge-operations to encode the correct word order. Each additional formal feature requires extraordinary justification due to evolutionary and acquisition burdens, criteria relevant to the notion of *Genuine Explanation* (Chomsky 2021). We finally note that theoretical linguistics has not adopted MG, and MG has not tracked the trajectory of recent theory, e.g., Labeling theory, and the fact that Internal Merge does not create copies.

11 HPSG uses feature structure inheritance and typing to factor out commonalities between sub-constructions. For example, subject relatives with overt wh-relatives are specified as wh–subj–rel–cl with constraints inherited from both general clause structure, viz., hd–subj–ph, and relatives in general, viz., wh–rel–cl. Similarly, object relatives, e.g., fin–wh–fill–rel–cl, inherit constraints from wh–rel–cl and general gap structures, viz., hd–fill–ph.

12 English relative clauses are a complex construction in the sense that there are many exceptions and restrictions, e.g., between subject and object relatives. Simplicity of theory and the elimination of redundancy are what both HPSG and Chomsky's MP aim for. Despite these common goals, it is perhaps telling that both frameworks are quite complicated. In fact, Sag (1997, 453–4) mentions “every constraint … is playing some role in this representation, making the combined effect … a rather intricate theorem.”

(thereby contributing to evolutionary plausibility). Our model follows much of the theory outlined by Chomsky (2000, 2001, 2008). We review the core assumptions and mechanisms.

At the heart of the theory is binary set-Merge, the simplest possible operation is taking two objects that, when iterated, create a hierarchical structure. Merge can result in either a symmetric structure, resulting from set-Merge, or an asymmetric structure, resulting from pair-Merge (Chomsky 2000, 2004). Pair-Merge is asymmetric in that one of the two merged objects in Pair-Merge is rendered inaccessible to further operations (not so in set-Merge). Set-Merge can be internal or external. IM encodes displacement from within an SO, and External Merge (EM) combines two distinct SOs, encoding argument structure. As a concrete example, EM applies to an object DP and a transitive verbal root V forming the set {V, DP}, followed by EM twice to form the theta configuration {DP, {v*, {V, DP}}}. v* is a verbalizer that licenses the outer DP subject. For unergatives, e.g., *sleep*, the equivalent configuration is {DP, {v, V}}, and v is the corresponding verbalizer.

In Chomsky (2000), agreement is implemented using (mostly) local c-command between a *probe* and a *goal.* A probe searches top–down into its c-command domain. T (tense), a probe, has *unvalued* phi-features (person, number, gender) that must match *valued* phi-features on the goal. For example, in {T, {DP, {v*, {V, DP}}}}, T finds the first DP, the subject. Similarly, unvalued phi-features on v*, a probe, match corresponding valued features on the DP object. Implicit in this model is that features that remain unvalued will crash a derivation. In this article, we use uF to represent unvalued F, F a feature: e.g., uT will be an unvalued T feature that needs to be valued in the course of a syntactic derivation.[13]

In our model, movement is generally considered to be feature-driven.[14] Heads may have an Edge Feature (EF) that permits movement to the edge of a phrase. For example, in (3)a, the EF on T results in the movement of a subject from a v*P internal position to the edge of TP, and an EF on an interrogative complementizer, C_Q, forces the movement of a *wh*-phrase to C in (3)b (for visible *wh*-movement).

(3) a) I $T_{[EF]}$ read ~~I~~ v* the book
b) What $C_{Q[EF]}$ did you read ~~what~~?

We assume that theta-roles are associated with a determiner head D (rather than N).[15] For example, when V merges with an object DP, V assigns a theta-role to the DP, which lands on the D head of the object.

We also adopt Chomsky's Phase Theory (Chomsky 2001). Assuming the Phase Impenetrability Condition (PIC), once a phase is complete, constituents inside the complement of a phase head are invisible to operations (highlighted by <u>underlining</u>). However, constituents displaced to the edge of a phase may be accessed outside of the phase. Phase heads are usually assumed to be transitive v* and C (possibly, also D). Thus, v*P and CP (highlighted by boldface {…}) are the phases in (4)a. Cyclic movement must involve iterated displacement through the edge of each phase, as in (4)b.

(4) a) **{**C, <u>{DP, {T, **{**DP, {v*, {V, DP}**}}**}}</u>**}**
b) {DP_{wh}, {C_Q, {DP, {T, {~~DP_{wh}~~, {DP, {v*, {V, DP_{wh}}}}}}}}}

13 Approaches exist that rely on the idea that features are *interpretable* or *uninterpretable*, and *valued* or *unvalued*, so you can have *unvalued interpretable* features (cf. Pesetsky and Torrego 2007). However, since this notion of interpretability/valuation is not crucial to our analysis, we will simply assume that features can be either unvalued or valued, where unvalued features need to be checked and valued via agreement with matching valued features.

14 In more recent work, e.g., (Chomsky 2013, 2015), IM is considered to be free, i.e., not feature-driven. In our system, we implement a small amount of free Merge in that a single input stream of lexical items can produce multiple structures.

15 Here, we assume the DP hypothesis (Abney 1987), which is relatively standard in syntactic theory. However, in some theories, theta-roles are associated with nouns and not determiners. In this case, the theta-role would be assigned to the N head and an argument would not be a DP, but rather an NP. See Bruening et al. (2018) and Bruening (2020) for arguments that N, not D, is the head of a nominal argument.

Given the variety of possible feature mechanisms, one should seek to constrain the grammatical feature system that shapes syntactic derivations as much as possible, as suggested by Chomsky's MP.[16] Formal language theory tells us that Turing-computability, i.e., arbitrarily powerful devices, can be built on formal features (Black (1986) and Johnson (1988)). The use of formal features should be kept to a minimum, and conceptually unnecessary ones should be eliminated from the theory.[17] Narrow syntax may make use of other features relevant to the interfaces. For example, we assume Q (question) and *wh* will be read at the semantic interface, and inflectional Case and phi-features will be read at Spell-Out. However, formal features, e.g., Edge, or its earlier incarnation, the EPP (Extended Projection Principle)[18] or ECM (Exceptional Case Marking), are arguably fundamentally limited to Merge syntax, and therefore should be deleted prior to Interpretation and Externalization.[19] The introduction of new features during the course of a derivation is also not permitted. Examples of such devices from the past include indices, as used in Binding theory, or the γ-feature, from the Barriers framework (Chomsky 1986).[20]

We posit, following fundamental MP assumptions, that there is a one-time selection of heads into a Lexical Array (LA) from the lexicon for Merge, but no explicit staging of features (as in MG, see note 10). In our implementation, the LA is ordered as a queue of heads (for input to Merge) purely for computational convenience.[21]

2 The basic model

In this section, we briefly summarize the theoretical aspects underlying our account.

We implement a revised version of Gallego's (2006) relative clause analysis, which builds on work by Pesetsky and Torrego (2001) (henceforth P&T). P&T propose that nominative case results from a checked uT feature (uT = uninterpretable T) on a head D. The head T locally c-commands the subject DP and checks the DP's uT feature, resulting in nominative Case. Embedded C also possesses a uT feature, which can be checked in two ways. One way is by raising T to the edge of C and T checks the uT on C. An alternative way is by raising the subject DP to the edge of CP, in which case the already checked uT on D of the subject checks uT on C. When checked by T, the uT feature on embedded C is pronounced as *that* (e.g., *Mary thinks that Sue will buy the book;* P&T 2001, 373). When a nominative subject raises to the edge of CP to check the uT feature on C (e.g., *Mary thinks Sue will buy the book*), there is no pronunciation of *that*.

Although in principle, two methods for checking the uT feature on C are available, P&T utilize economy to account for *that*-trace effects and the English subject/object wh-movement asymmetry.[22] In principle, multiple Agree operations are possible in this system. Abstractly, in (5)a, uF1 and uF2 on X are checked by Y and W, respectively. In (5)b, Z checks both uF1 and uF2 at once instead. Economy dictates that we prefer a single operation (over multiple operations) and, therefore, (5)b over (5)a.

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16 Chomsky (2011, 2013) suggests that narrow syntax be reduced to general Merge, plus residual probe-goal for Agreement. Formal labeling of phrases is carried out at the interface, and therefore, phrasal categories have no formal role in Merge. We note that in some other accounts, e.g., Epstein et al. (2014), Merge may be conditioned on whether labeling obtains for a phrase.

17 We make substantial use of an Edge Feature (EF) in this article. In MP development subsequent to our model, features such as Edge, which regulates the possibility of Merge to the periphery of a phrase, are no longer permitted (or relevant). Instead, movement, i.e., internal Merge, must be unrestricted, and therefore freely available, e.g., see Chomsky (2008) and much work thereafter.

18 This is basically the requirement that a clause have a subject (Chomsky 1981).

19 If present, any remaining unvalued formal features will crash the derivation.

20 Also, in some accounts, e.g., Müller (2011, 122), an Edge Feature (made optionally present) may trigger movement, e.g., for scrambling. Such a device would be ruled out on conceptual (not empirical) grounds.

21 For example, simplifying somewhat with respect to functional elements, in the case of a simple transitive sentence, the LA encodes object < verb < subject. In principle if the LA is unordered we can form from this LA sentences schematized as "subject verb object" and "object verb subject." The ordering is for convenience as we seek convergence on our intended sentence only.

22 This is the requirement for *do* in an object wh-question (e.g., *What did John buy?)* compared to no *do* in a subject wh-question (e.g., *Who bought the book?).*

(5) a) Agree($X_{[\cancel{uF1},uF2]}$,$Y_{[F1]}$) & Agree($X_{[\cancel{uF1},\cancel{uF2}]}$,$W_{[F2]}$)
b) Agree($X_{[\cancel{uF1},\cancel{uF2}]}$,$Z_{[F1,F2]}$)

Note that the preference for a single Agree relation over a multiple Agree relation does not make any predictions about the presence of *that* in cases where both are possible, as in (6)a. Note that P&T assume that in constructions in which there is wh-movement out of an embedded clause, there is a uWh feature in a non-interrogative C that hosts a wh-phrase. The uT feature on C can be checked by T, (6)b, in which case *that* is pronounced. The uT feature can also be checked by the subject, (6)c in which case *that* is not pronounced. Therefore, *that* is optional, and there is no preference for or against *that*.

(6) a) What did John say (that) Mary will buy? (P&T 2001:370)
b) What$_i$ did John say [$_{CP}$ ~~**what$_i$**~~ [$_T$**that**]$_k$ + $C_{[\cancel{uT},\ \cancel{uWh}]}$ Mary$_j$ ~~T$_k$~~ will ~~Mary$_j$~~ buy ~~**what$_i$**~~]?
c) **What$_i$** did John say [$_{CP}$ ~~**what$_i$**~~ **Mary$_j$** $C_{[\cancel{uT},\ \cancel{uWh}]}$ ~~**Mary$_j$**~~ T ~~**Mary$_j$**~~ will buy ~~**what$_i$**~~]?

Gallego extends P&T's proposal to relative clauses, i.e., that *that* is the pronunciation of uT in C. In addition, Gallego assumes that a relative clause C has a uRel feature that is checked by a relative DP containing a corresponding iRel (i = interpretable) feature. Economy, following P&T, comes into play if both uT and uRel on C can be checked by a single goal. Gallego's analysis is noteworthy in that it attempts to provide a unified account of relative clause formation and the distribution of *which/who(m)/that/Ø*.

According to Gallego, in (7)a, *who man* originates in the subject position of the clause, from where it moves to the relative CP edge, followed by further movement of *man* to a higher position in the CP. Assume the subject relative D *who* contains both an iRel feature and nominative case. Applying economy, *who* checks both uT and uRel on C via a single Agree relation, as shown in (7)b. There is no pronunciation of *that* crucially because *who*, not T, checks uT on C. Gallego proposes that uT and uRel have EPP subfeatures, a complication that we do not adopt and that forces *who man* to raise to the edge of the CP. Gallego also proposes that there is an extra projection, referred to as cP, in the left periphery that 'introduces a subject of predication (Gallego 2006, 157)'. This c has uPhi features with EPP subfeatures. The uPhi probe for matching phi-features that are interpretable and the uPhi find iPhi on *man* in (7)a–b. The EPP sub-feature of uPhi forces *man* to raise to the edge of the cP. Example (7)a with *that* is blocked by economy: pronunciation of *that* would require uT on C to be checked by T, and uRel on C to be checked by *who*, separately. However, economy dictates *who man* checks both uT and uRel features on C simultaneously.

(7) a) the man who loves Mary/*the man who **that** loves Mary
b) [$_{DP}$ the [$_{cP}$ **man$_j$** $c_{[u\text{Phi,EPP}]}$ [$_{CP}$ [$_{DP}$ **who man$_j$**]$_i$ $C_{[u\text{T,EPP}]\ [u\text{Rel,EPP}]}$ [$_{DP}$ **who man$_j$**]$_i$ T [$_{DP}$ **who man$_j$**]$_i$ loves Mary]]]]] (Adapted from Gallego 2006, 156)

An issue is that Gallego's analysis requires an extra cP projection in the left periphery. It is also not entirely clear why *c* can attract N from inside of a relative D and not the head of the DP itself, viz. D.

In (8)a, Gallego assumes the subject *boy* contains a null D and, following Chomsky (2001), that a null D must remain *in situ*. Furthermore, the uRel on C (conveniently) lacks an EPP sub-feature so that uRel on C is checked by iRel on null D without triggering movement. The uT's EPP sub-feature then causes T to raise to C and be pronounced as *that*. (Note that this analysis also implies that the relative DP *boy* does not move to Spec-T either, as it has a null D.)

(8) a) the boy that called Mary
b) [$_{DP}$ the [$_{cP}$ **boy$_j$** $c_{[u\text{Phi,EPP}]}$ [$_{CP}$ **that$_i$** + $C_{[u\text{T,EPP}][u\text{Rel}]}$ T$_i$ [$_{DP}$**D$_{REL}$ boy$_j$**] called Mary]]] (Adapted from Gallego 2006, 158)

This analysis has two potential problems. First, it requires a stipulation that a relative DP with a null D cannot move. Furthermore, there is lexical proliferation for C containing uRel. As uRel typically has an EPP sub-feature, this must be modified for relatives containing a null D, as they do not move in Gallego's account.

Therefore, C with uRel must come in two versions: one with an EPP subfeature (as in (7)b) and one without an EPP sub-feature (as in (8)b).

Gallego's analysis is also unable to account for the ill-formedness of (9)a; it has difficulty accounting for doubly filled Comp effects. As the structure (9)b indicates, T should be able to check uT on C, resulting in the pronunciation of *that*. Because the relative DP is an object, it does not have nominative case, and thus, it is unable to check uT on C. Hence, *that* must be pronounced, as in (9)a. But (9)a is ungrammatical in standard English.

(9) a) *The car which that John sold. (Gallego 2006, 160)
b) $[_{\mathrm{DP}}$ the $[_{\mathrm{cP}}$ car_j $\mathrm{c}_{[u\mathrm{Phi,EPP}]}$ $[_{\mathrm{CP}}[_{\mathrm{DP}}$ which $\mathrm{car}_j]_i$ that_k + $\mathrm{C}_{[u\mathrm{T,EPP}][u\mathrm{Rel,EPP}]}$ John_z T_k John_z sold $[_{\mathrm{DP}}$which $\mathrm{car}_j]_i]]]$

We adopt a modified version of Gallego's core proposals about uT feature checking on a relative C and about economy. While we follow Gallego's insights regarding uT and uRel feature checking, we omit the extra cP projection and we do not utilize EPP subfeatures. We are able to account for the distribution of the relative D and a noun in the examples above, including the ban on **who that* in (7). Also contrary to Gallego, we have no stipulation that a DP with a null D is unable to move. Our analysis, to be discussed below, is able to account for the ill-formedness of (9)a, and we also extend this analysis to account for headless relatives (which Gallego does not investigate) and genitive relatives, as well as other related relative clause types. Note that we assume the judgments of standard English about relative clauses; in particular, no doubly filled COMP. However, there are varieties of English that permit a doubly filled Comp, suggesting there may be some dialectical variation in whether or not a relative D can check a uT feature. We discuss this in detail in Section 5.

Suppose all relative D heads check a uRel feature. We assume there is variation in whether or not a relative D may also check a uT feature on C. When relative D can check both a uRel and uT feature, pronunciation of *that* (only when uT on C is checked by T) is blocked due to economy. Only when relative D is unable to check uT on C, then T can (raise and) check uT on C and *that* can be pronounced. Finally, we use an unvalued D feature to trigger extraction of the relative noun, termed "relabeling" in the study by Cecchetto and Donati (2015).

Consider sentence (10)a and its subject relative counterpart in (10)b.

(10) a) the boy told the story
b) the boy who told the story (Keenan and Hawkins 1987, 63)

(10)a has the core structure shown in Figure 1, typically assumed in Minimalist syntax.[23] Root *tell* selects for an internal argument, *the story*, and transitive v* combines with the phrase headed by *tell* to form a basic verb phrase. Case-Agreement proceeds by minimal c-command. For example, v* c-commands and values accusative Case on the internal argument. v* also provides for an external argument (EA) position in its specifier, occupied by *the boy*. $\mathrm{T}_{\mathrm{past}}$ selects for v*P and c-commands the EA, valuing nominative Case. In English, $\mathrm{T}_{\mathrm{past}}$ also provides for a surface subject position that must be filled, the so-called EPP property. In Figure 1b, *the boy* raises to the edge of TP. Only the highest copy is pronounced, and unpronounced copies are indicated by strikethrough. As part of Case-Agreement, $\mathrm{T}_{\mathrm{past}}$ picks up number and person feature values associated with the EA, resulting in English subject–verb agreement. The heads $\mathrm{T}_{\mathrm{past}}$, v*, and the root *tell* combine at Spellout to form *told*. (Note that we indicate C as c, $\mathrm{C}_{\mathrm{rel}}$ as $\mathrm{c}_{\mathrm{rel}}$, and the relative determiner $\mathrm{D}_{\mathrm{rel}}$ as $\mathrm{d}_{\mathrm{rel}}$ in our diagrams.)

23 This can be interpreted as a reduced form of *the boy who was told the story*, as pointed out by a reviewer. In our implementation, the full passive would be constructed, and rules of ellipsis (not implemented) would have to apply. An anonymous reviewer points out that in non-standard varieties of English this could also be interpreted as a subject relative (*the boy ~~who~~ told the story*). See Section 5 for further discussion.

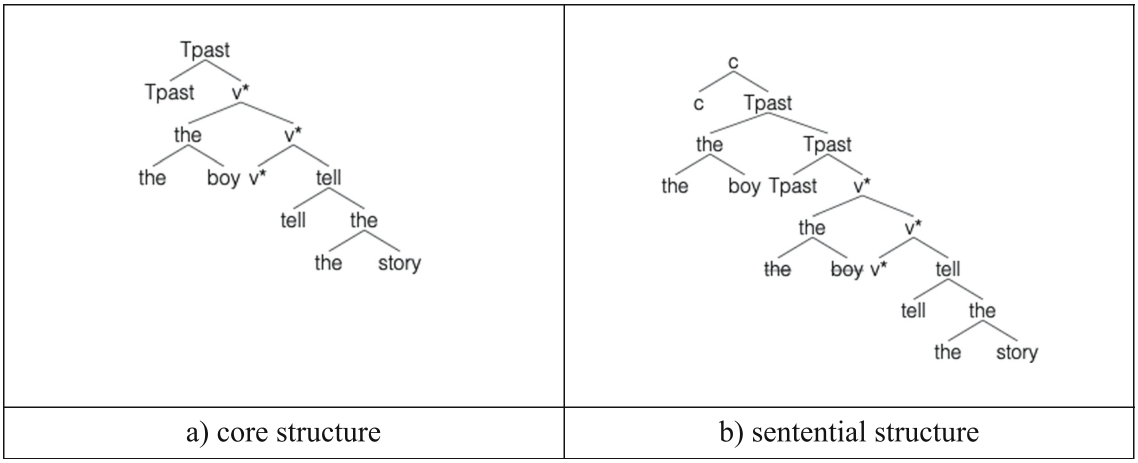

Figure 1: Example of syntactic structure for *the boy told the story*.

Example (10)b has the same underlying core as (10)a, with two crucial featural differences that will drive relativization. We assume rel to be a formal feature marking the DP that undergoes relativization, which is the EA headed by who$_{rel}$ in Figure 2. The clausal head C$_{rel}$ attracts this EA (containing rel) to its edge. We crucially assume the noun *boy* has an unchecked D feature (uD), indicated by !D, normally checked through Merge with a determiner D. We assume all (and only) relative Ds lack the ability to check uD. Thus, *boy* may subsequently emerge from sentential structure to head a new NP, and its unchecked D-feature will be checked by the (regular) determiner *the*, as shown in Figure 3.[24] As only the highest copy may be pronounced, vertical lines in Figure 3 are used to pick out possible pronounced elements of the frontier of the structure.[25]

To summarize, uD on N, if left unchecked, enables N to (raise and) relabel a relative clause. N then gets its uD feature checked by a higher D in a regular sentence. The feature-checking details regarding uD, uT, and uRel are summarized in Table 2.

A reviewer asks how examples such as (11) in which the relative *book on syntax*, not a simple head, can be accounted for under this relabeling proposal. As the PP *on syntax* is an adjunct, the relevant structure is ⟨book, {on, syntax}⟩, where *book* and the PP *on syntax* are pair-Merged, as indicated by the angle brackets. Since pair-Merge is asymmetric, the adjunct *on syntax* is essentially invisible, and *book on syntax* is treated exactly the same as the single-head *book*; thus, it can relabel.[26]

(11) the [book on syntax] that I read

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24 A reviewer points out that the following examples require lexical substitution when the head noun is raised out of sentential structure.
(i) *He rode twenty miles to see her picture in the house of a stranger, which stranger politely insisted on his acceptance of it* (Radford 2019, 9)
(ii) *He had hired a vessel to convey him to Constantinople, for which city he should sail in a few hours* (Mary Shelley, *Frankenstein*).
We put aside implementation of a theory of inserting lexical items into a lexical array for future work.

25 We assume C$_{rel}$ has no spellout in English. *That* as in the object relative construction *the story that the boy told* is derived via T to C movement, following P&T. See the following sections for details.

26 We suggest the entire pair-Merged structure raises like a head; we cannot have **book that on syntax I read*. A reviewer asks about how labeling occurs in an example such as *the destruction of the city that led to the collapse of the empire surprised the traders*. Just as with the VP *destroy the city*, *destroy* cannot separate (by raising) from its argument to form an entirely new phrase. The same applies to the derived nominal form *destruction*, we cannot *form *the destruction that of the city led to the collapse of the empire*. The entire head with the object *the city* must raise and relabel. (In terms of labeling theory, left to future work, both *book on syntax* and *destruction of the city* must be labeled as N.)

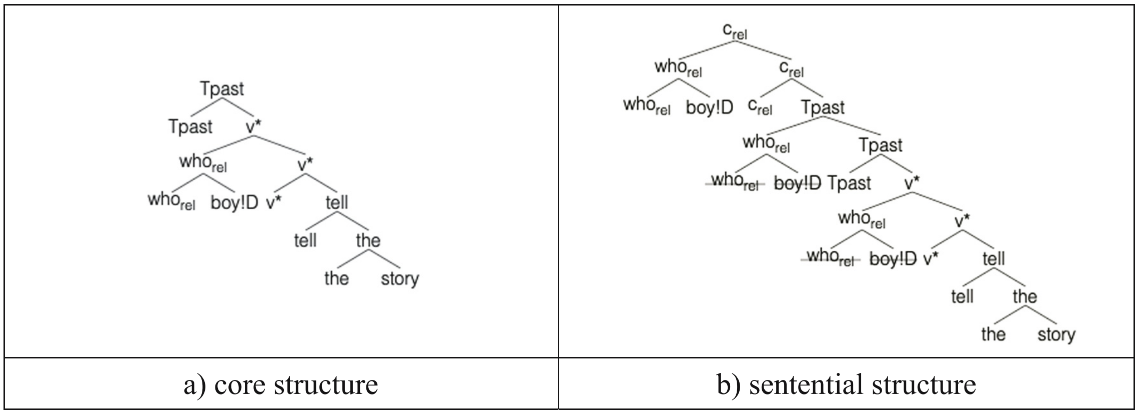

Figure 2: Relative clause structure for *the boy who told the story*.

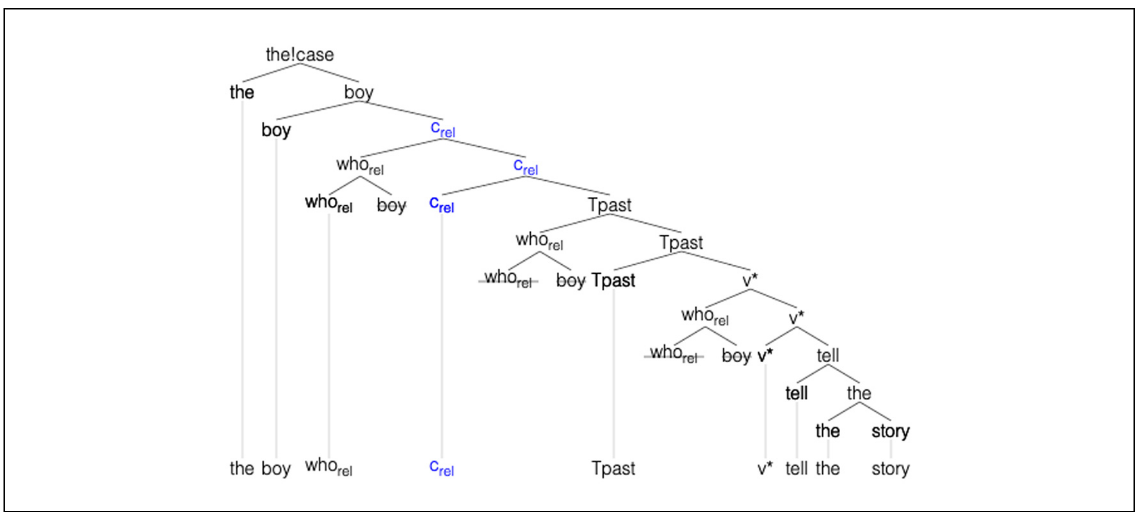

Figure 3: DP structure for *the boy who told the story*.

Table 2: Feature checking

Feature	Checked by
uD on N	iD of D (D_{rel} is unable to check uD)
uT	T (pronounced as *that*), by nominative case (which is a form of T), or by certain relative Ds
uRel on C_{rel}	iRel of D_{rel}

Relativization productively occurs with external and internal arguments, and even oblique, i.e., non-core, arguments, as will be illustrated in the following sections. In each case, the mechanism is the same, i.e., a relative determiner (D_{rel}) heading the argument to be relativized is attracted by a relative complementizer (C_{rel}). There is no theta role clash (or theta criterion violation) with this movement-based account as we assume theta roles are hosted in D.[27] In Figure 3, external *the* (not *boy*) bears the theta role assigned to the

27 Alternatively, assume that a nominal consists of a root R that is categorized by a N categorizer, i.e. {N, R} (cf. Marantz 1997, Chomsky 2013, 2015 among others), and that R can raise independently and be categorized anew. In *the boy who told the story*, the root *boy* alone can raise and relabel the clause, as shown in (i). With two Ns, theta-roles can be assigned independently, without violating the Theta Criterion. (i) [N_2 boy [C_{rel} [who_{rel} N_1 ~~boy~~]...]]

entire DP when it is Merged as an argument in a higher clause, and the lowest copy of who_{rel} (not *boy*) bears the theta role assigned to the EA of *tell*. As *the* and who_{rel} are distinct, there is no theta problem.

We next summarize the algorithm used to derive the structure in Figure 1. Assume all sentences involve a selection of heads from the Lexicon to feed Merge. A head may bear both formal features, e.g., D and Case on nominals (discussed previously), and unvalued phi-features (person, number in English) on T and v*. Unvalued formal features must be valued in the course of a derivation (or else the derivation will not converge). Heads may also bear interpretable features, e.g., Q on *wh*-words and intrinsic phi-features on nominals, e.g., first-person-singular on *I*/*me*. A head that probes for matching values gets only one opportunity to value its unvalued formal features, viz. when it is first Merged. If a head H merges with a phrase YP, as in HP = {H, YP}, YP is the c-command search domain for H's formal features. Once HP is merged with another head or phrase, H is inactivated as a probe and cannot search again. As this policy is strict, leftover unvalued features on H will crash the computation, and no convergent structure will be produced.

As the algorithm selects only the first head of a sequence for Merge, heads selected from the Lexicon are sequenced precisely for proper assembly.[28] For (10)a, the sequence of heads that derives the structure shown in Figure 1 is given in (12)a.

(12) a) [story, the, tell, v*, [the, boy], T_{past}, C]
b) [story, the, tell, v*, [who_{rel}, boy], T_{past}, C_{rel}, the]

Sequence (12)a is read from left to right with the algorithm selecting the appropriate Merge action based on the current state, i.e., the SO constructed so far and the first input head.[29] In most cases, there will be only one possible Merge action per state. Non-determinism, i.e., more than one possible Merge action, is limited solely to linguistic choice points; e.g., the option to pied-pipe a preposition with a DP in English or the T-to-C option described in this article, both producing derivations that separately converge.[30] Let us sketch the steps for Figure 1: step (i) Merge combines *story* and *the*, forming a DP; (ii) *tell*, the next head in the list, merges with the DP formed in (i), we obtain {tell, {the, story}} (a VP); (iii) the next head, v*, merges with the VP from (ii), forming {v*, VP}; (iv) the sub-list [the, boy] initiates a sub-computation producing {the, boy}, which replaces [the, boy] in the list of heads, (v) the v* phrase in (iii) Merges with {the, boy}, the EA, forming {EA, {v*, VP}} (a v*P); (vi) the head T_{past} Merges with the v*P from (v), forming {T_{past}, v*P}; (vii) English T has an EF which triggers IM for {T_{past}, v*P}. By minimal search, EA, being the highest accessible DP, is raised, forming {EA, {T_{past}, v*P}}. In step (viii), the last head, C, Merges to head the clause. Note there is no ambiguity as to which sub-phrase must label the merged structure at each step. Therefore, the derivation is deterministic (and efficient in this sense). Minimal search itself is implemented using a stack to maximize the efficiency of the search. Phrases with unvalued features (or *rel*) are placed onto a stack when merged initially. When IM is triggered or a head probes to value unvalued features, generally only the top stack element is consulted. For IM, the top stack element is extracted, i.e., raised. As a goal, the top stack element features must be used (to satisfy the probe). Hence, minimal search typically involves no search at all, and minimal c-command naturally results.[31] The derivation of Figure 3 proceeds similarly with the sequence of heads in (12)b. One crucial

28 We must be careful to distinguish this from feature sequencing. In MG, lexical features must be sequenced in strict order for checking. In our implementation, this is not required.

29 For example, if we merge a D to a N, our algorithm specifies that a DP must result. Similarly, a verbal root and existing DP forms a VP. In each case, we generally know which Merge item must project. For internal Merge, a sub-phrase must be extracted, but the original phrase will generally continue to project, e.g., as in the case {EA, {T, {EA, {v*, VP}}}}, where EA is an external argument.

30 Another case involves temporary structural ambiguity in the case of adjunct phrases, which may or may not front, e.g., as in *Yesterday, I went home* vs *I went home yesterday*. In such cases, the algorithm considers both possibilities for Merge of the adjunct phrase in turn, but as they are mutually exclusive options, only one of them will be licit (the other will crash). See the derivation for (24)b "the letter which Dick wrote yesterday" in the Appendix.

31 We state "typically" as there are a few situations in which the top stack item does not possess the feature needed to match a probe; e.g., C_{rel} could potentially match with any stacked argument. In such cases, the first matching stack item is used. Should no such item exist, the derivation must crash.

difference between (12)a and (12)b is that C_{rel} in (12)b possesses EF, triggering IM after the equivalent of step (viii), and the EA {who_{rel}, boy} raises (in a similar fashion to *wh*-phrase fronting triggered by C_Q).

The system that we implemented is based on the feature-driven Merge model of Chomsky (2000, 2001, 2008, and other work).[32] In this work, Chomsky assumes there is a one-time selection of items from the Lexicon to form an LA. Merge of Lexical Items is recursively applied to form an aggregate SO. An SO can be selected and Merged from the LA (EM), or it can be Merged from within the current SO; this is the process of movement (IM). The term Workspace refers to the LA and SO at any given stage. For a convergent derivation, the Workspace must consist solely of a single SO, with formal features eliminated. Any remaining uninterpretable features in the SO, or leftover LA items, will crash the derivation.

Multiple threads of derivation are in principle possible if there are multiple possible operations, i.e., choice points, at any given point in the derivation. An example of a theoretical choice point that we use is the possibility of uT on C being checked either by movement of T (resulting in pronunciation of *that*) or by nominative case on the subject (in which *that* is not pronounced). In such cases, e.g., "*the man* (*that*) *John saw,*" the model correctly generates two different structures starting from the same LA. Another linguistic choice point will permit the option of pied-piping for cases like "*the man to who/whom I talked*" and "*the man who/whom I talked to.*" Note that we assume that *who* and *whom* are inflectional variants of the same word *who*. Again, two different structures will be generated from the same LA. The model we describe has only linguistic choice points predicted by the theory; there are no temporary ambiguities attributable solely to the algorithm or data structures required. In this sense, our model is maximally efficient with respect to the theory.

Assuming we begin, as does Chomsky, with a one-time LA, our LA is selected in order, purely for computational efficiency.[33] As the LA is ordered as a queue, the current SO has the choice of EM with the first item in the sequence, or ignoring the LA, the choice of IM, i.e., selecting a sub-SO from within itself. Based on the current SO and the head currently first in line in the LA, our machine will correctly select the right operation one step at a time to converge on the intended SO. (In the case of non-convergence, the machine will end up in a state with no possible continuation, call this a *crash*.) Lexical items selected from the LA may have unvalued and valued features. In the case of an LA head with an unvalued feature, when it is first Merged to the current SO, it must probe the existing SO for a matching valued feature. For efficiency, we assume all required probing for valued features can be accomplished during this first Merge time; i.e., no second chances are permitted nor needed.[34]

Our model also incorporates an operation of Last Resort that enables an unlicensed relative head to move to the edge of a phase. If heads with remaining unvalued features are not to crash the derivation, the phrases they head must move to the edge of the Phase to save and keep the derivation going. This Last Resort operation happens automatically. A general remark about feature-driven movement is in order at this point: a head with an EF licenses movement to its phrase edge. Without it, movement is not permitted. Hence, for Last Resort to operate, either we must assume all Phases have an optional EF, or movement is generally licensed to all Phase edges.[35]

The model that we created is *complete* in the sense that all convergent derivations are grammatical and all grammatical sentences in this article are generated. For a summary of the basic operations of our model, please see the Appendix.

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32 See Collins and Stabler (2016) for a formal account of various important notions in the MP that also attempts to make a connection between MGs and the MP.

33 With respect to LA ordering, see also Note 21.

34 Heads may probe just once, when the head is first merged with an existing SO. Heads are not revisited for probing once Merged. As probes cannot retry searching for goals in this theory, once an SO has been built, no probe operations can take place inside the SO. Single-probing is efficient because there is never any need to search the SO for probes.

35 An issue is whether the model should require movement to always be triggered by a feature or whether movement should be freely available (without reference to features) in limited cases. The latter option may result in needless overgeneration, i.e., be less efficient, but conceptually it is simpler (and evolutionarily more plausible).

3 Derivations of basic relative clauses

Our model crucially accounts for the (im)possibility of *that* in a variety of relative clauses. Consider (13), in which *that* can be either pronounced or unpronounced.

(13) the book t**hat/Ø** I read (Gallego 2006, 151)

Snapshots of the derivation of (13) with *that* are shown in Figure 4. In Figure 4a, TP is the current SO, and C_{rel} is about to be Merged from the LA. In Figure 4b, C_{rel} has been Merged, and its unvalued features uRel and uT have been checked by D_{rel} and T, respectively. uT on C_{rel}, checked by T, results in pronunciation of *that*. As C_{rel} possesses an EF, the DP {D_{rel}, book} raises to the edge of CP. We assume D_{rel} cannot check the D feature on the noun (in this case, *book*), freeing *book* to raise as shown in Figure 4c. *Book* is a head and therefore labels {*book*, CP}. Finally, the external D is merged, checking uD on *book*. Note that the diagram correctly indicates Case (shown as !case) is currently unvalued on the external D head *the*. Its Case will be valued via probe-goal agreement when the relative clause is integrated into a larger environment, as in "They like *the book that I read*."

The corresponding derivation of (13) without *that* is given in Figure 5 – in this case, the option of uT being checked by the subject (instead of T) is taken, so *that* is not pronounced. The remainder of the derivation, as illustrated in Figure 5a and b, is the same as in the case with *that*, described earlier.

Example (14) contains a covert D_{rel} within a PP headed by *to*. The two licit derivations are shown in Figures 6 and 7. We assume *talk to* is a verb-particle construction, where *to* is a particle and Case is

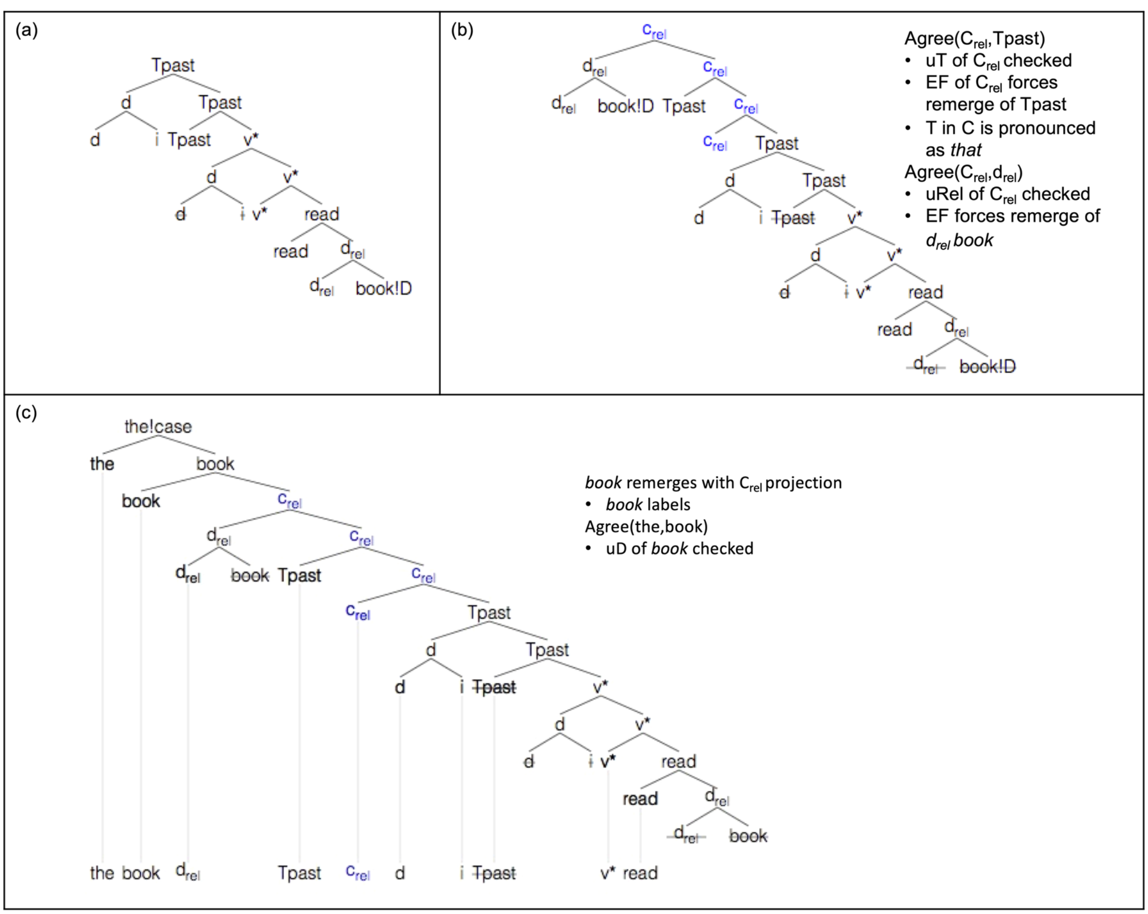

Figure 4: Derivation of *the book that I read*.

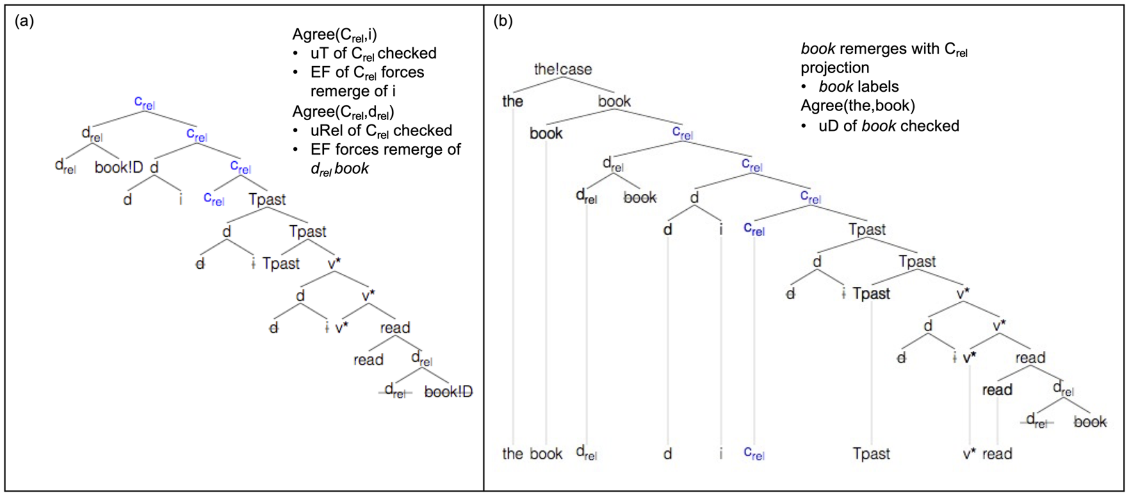

Figure 5: Derivation of *the book Ø I read*.

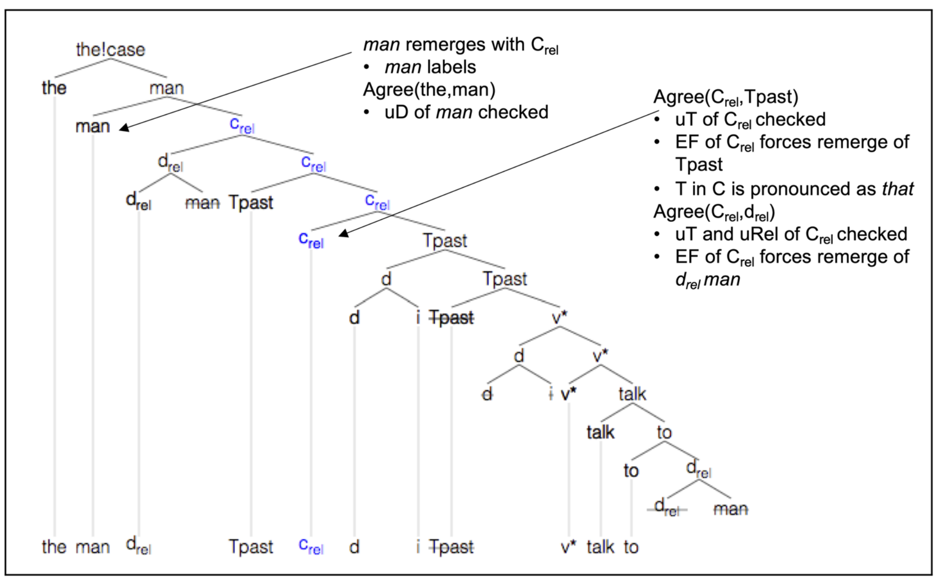

Figure 6: Derivation of *the man that I talked to*.

valued by v*.[36] In this case, pied-piping is generally blocked, as **the man to that I talked* and **the man to I talked* are ill-formed. One explanation for the lack of pied-piping here is that *to* followed by an empty category disallows pied-piping (Chomsky 2001, 28).

(14) the man that/Ø I talked to

Consider the case of the subject relative in (15)a–b.

(15) a) the boy **that/who** called Mary
b) *the boy called Mary (ill-formed as a relative clause)

36 Clearly v* + *to* assigns case. For simplicity of implementation, we assume that v* assigns Case without *to* mediating it.

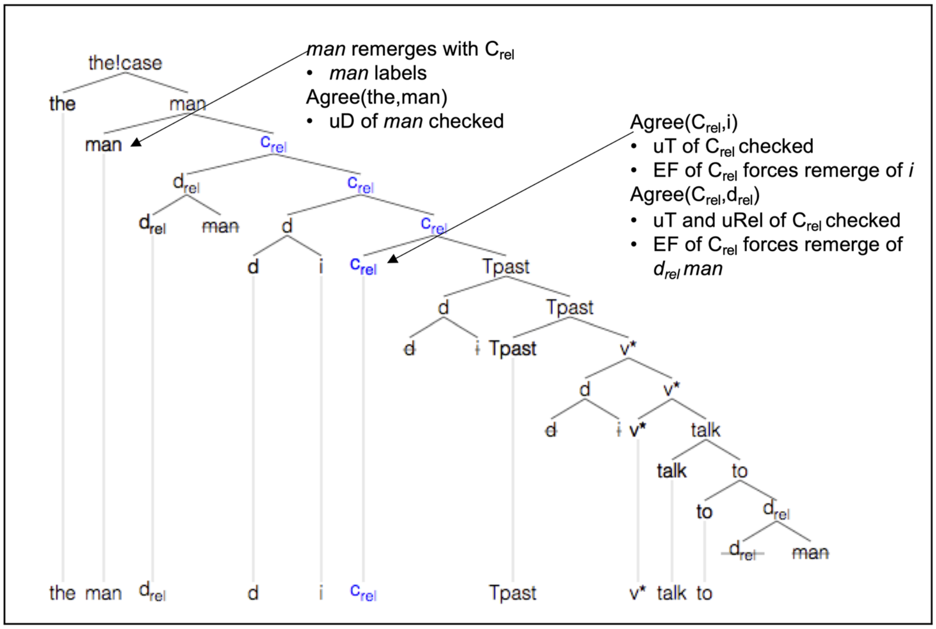

Figure 7: Derivation of *the man Ø I talked to*.

In the previous examples, i.e., (13) and (14), D_{rel} is covert. (15)b can be explained if covert D_{rel} generally cannot check uT on C_{rel}. Then the only available option is for T to raise to check uT on C, obligatorily pronounced as *that* in (15)a, and illustrated in Figure 8.[37] The covert/overt distinction neatly divides uT (on C_{rel}) valuation; in

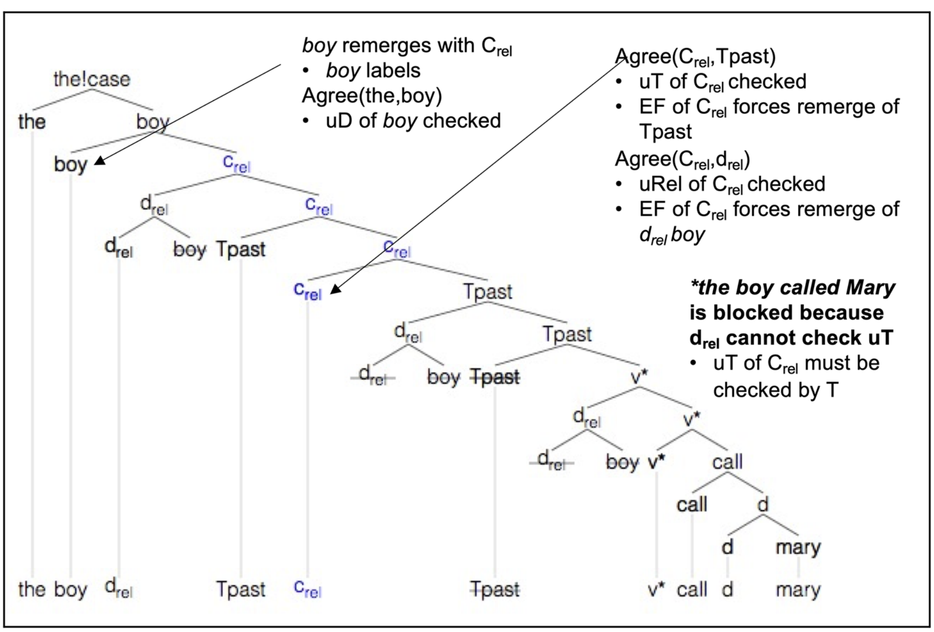

Figure 8: Derivation of *the boy that called Mary*.

37 For P&T, nominative Case is a checked T feature on an argument, and thus an argument with nominative case can check a uT feature. However, if certain relative D heads can check uT, regardless of whether or not they have nominative Case, then the checked T feature is not necessarily associated with just nominative Case. One possibility is that this T feature-checking ability is associated with Case in general, not just nominative Case. We leave this issue for further investigation.

short, covert D_{rel} cannot check uT and overt D_{rel} can. Thus, the *wh*-relative counterpart of (15)b, i.e., *the boy who called Mary*, is available.

Our model can also account for long-distance subject relative clauses such as (16)a.

(16) a) the boy (that) John thinks (that) called Mary (*from an anonymous reviewer*)
b) the boy (that) John thinks called Mary

D_{rel} *boy* raises from the subject of embedded verb *call* out to the matrix CP. Since it passes through the edge of the embedded CP, there is no violation of the PIC. D_{rel} will check the uRel feature on C_{rel} at the matrix CP. However, in our theory, the uT feature on C_{rel} cannot be checked by D_{rel}, leaving it to be checked either by movement of the matrix subject to C, as in Figure 9, without the higher *that*, or by T-to-C, pronounced as the higher *that*, as in Figure 10. In the case of the embedded (non-relative) C, viz., C_e, the lower *that* is predicted to be obligatory because D_{rel} from D_{rel} *boy* cannot check C_e's uT feature as it passes through the edge of the embedded CP. One of the authors of this article finds (16)b, which lacks *that* in the embedded clause, to be ill-formed. The other author finds (16)b perfectly acceptable (both authors are native speakers of English). This suggests for those who find (16)b fine, D_{rel} can check the uT feature of an embedded non-relative C, and for other speakers, D_{rel} can never check a uT feature.

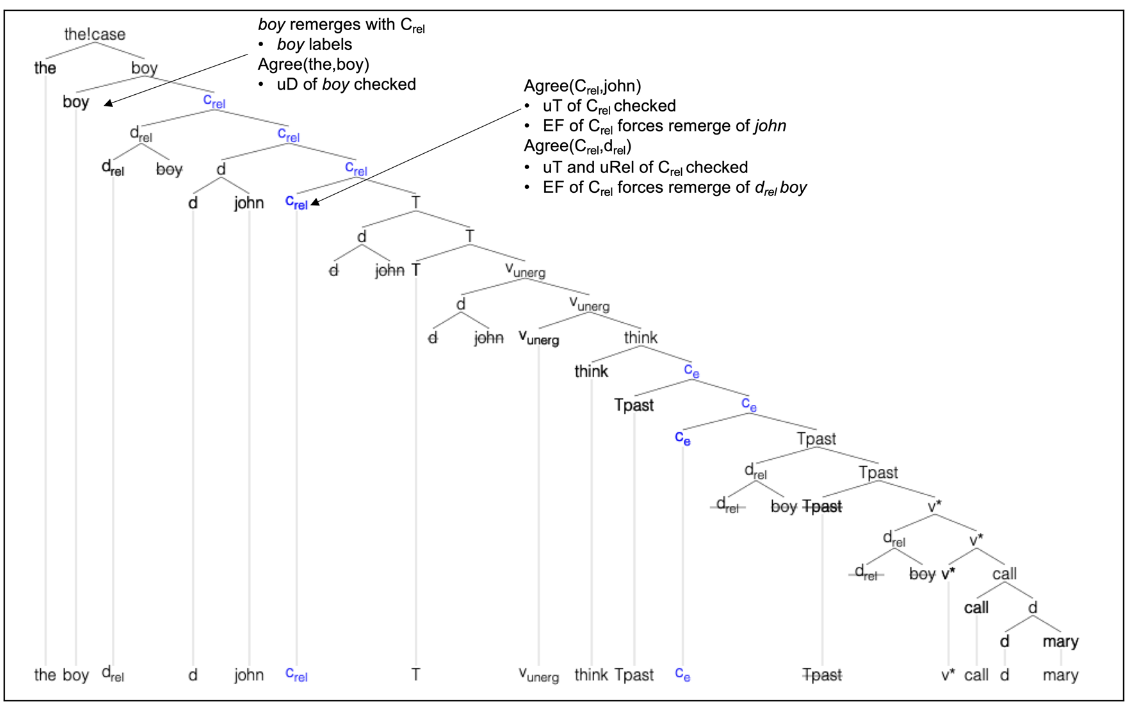

Figure 9: Derivation of *the boy John thinks that called Mary*.

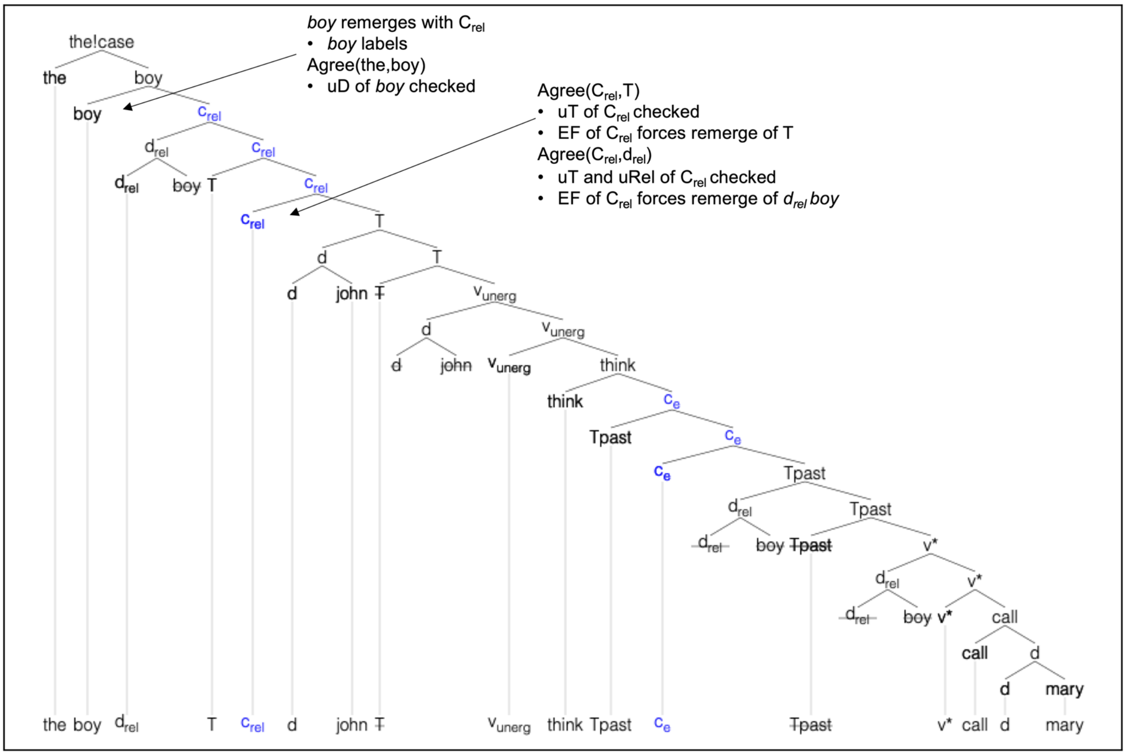

Figure 10: Derivation of *the boy that John thinks that called Mary*.

We next consider why a wh-relativizer (e.g., *which* and *who*) cannot co-occur with *that* in an object relative clause (17)a–d, nor in a subject relative clause (17)e–f.

(17) a) the book which I read
b) *the book **which that** I read (Gallego 2006, 151)
c) The man who John saw
d) *the man **who that** John saw (Gallego 2006, 154)
e) the man who loves Mary
f) *the man **who that** loves Mary (Gallego 2006, 151)

Our proposal is that $which_{rel}$ and who_{rel} are relative Ds that may value uT on C_{rel}.[38] Economy then forces uT on C_{rel} to always be checked by a relative *wh*-determiner when present. This is summarized in Table 3, which states that it is more economical for a single goal to value multiple uFs on a probe than it is for multiple goals to value the uFs. Basically, the fewer Agree operations required, the better.

38 Consider (i)–(iii). P&T account for (i) and (ii) by economy. They assume that a non-interrogative embedded C has a uWh feature when there is a wh-phrase contained within. A subject *wh*-phrase will check both the uT and uWh features on embedded C (resulting in (i)). Economy therefore blocks T from checking just one feature, viz., uT on embedded C, and *that* is not permitted; i.e., (ii) is ruled out. We have argued that the relative *which* can check a uT feature on relative C. Suppose *which book* could also check the uT on embedded C, then by economy, *that* should not be possible in (iii), contrary to fact. We propose, however, that the *which* in *which person* does not have the properties of a relative D in that it cannot check a uT feature. Thus, the uT on the embedded C must be checked either by movement of a subject, in which case *that* is not pronounced, or by movement of T, in which case *that* is pronounced.
(i) Which person did Mary say bought the book?
(ii) *Which person did Mary say that bought the book?
(iii) Which book did Mary say (that) John bought?

Table 3: Economy

Economy (of feature checking)	Given a head $X_{[uF1,..uFn]}$, $n > 1$, all uF_i ($1 \le i \le n$) probe for a matching goal. Suppose distinct goals $G_1,\ldots,G_m$ ($m \le n$) suffice to value F_1 through F_n. A derivation with m_{min}, the fewest number of goals required, blocks all derivations with $m > m_{min}$ goals[39]

In the derivation of (17)a shown in Figure 11, a single Agree relation between C_{rel} and *which*$_{rel}$ results in simultaneous valuation of both uT and uRel on C_{rel}. Economy blocks the option in which uRel and uT are

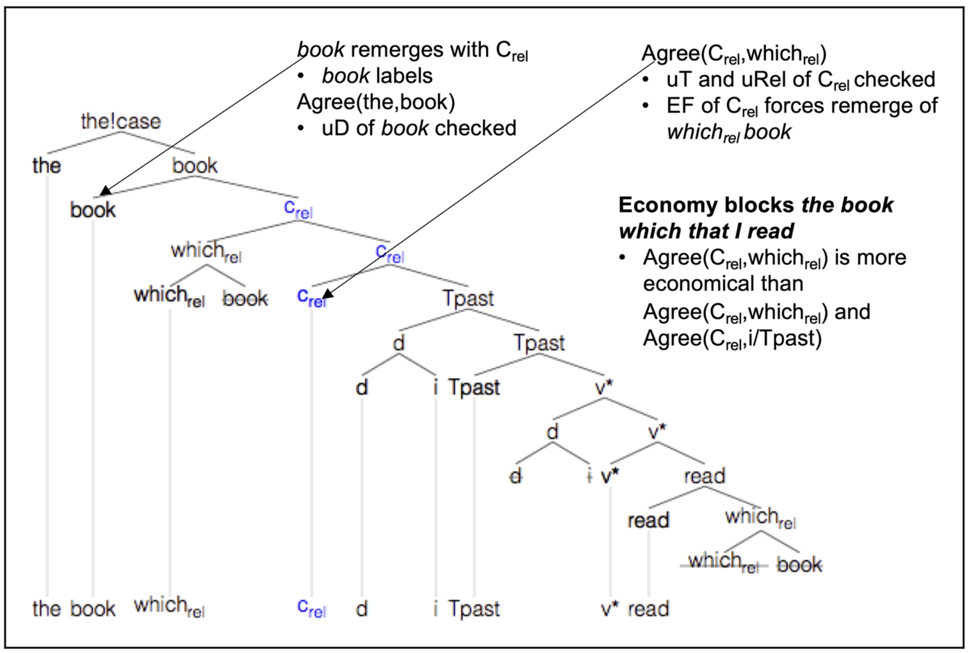

Figure 11: Derivation of *the book which I read*.

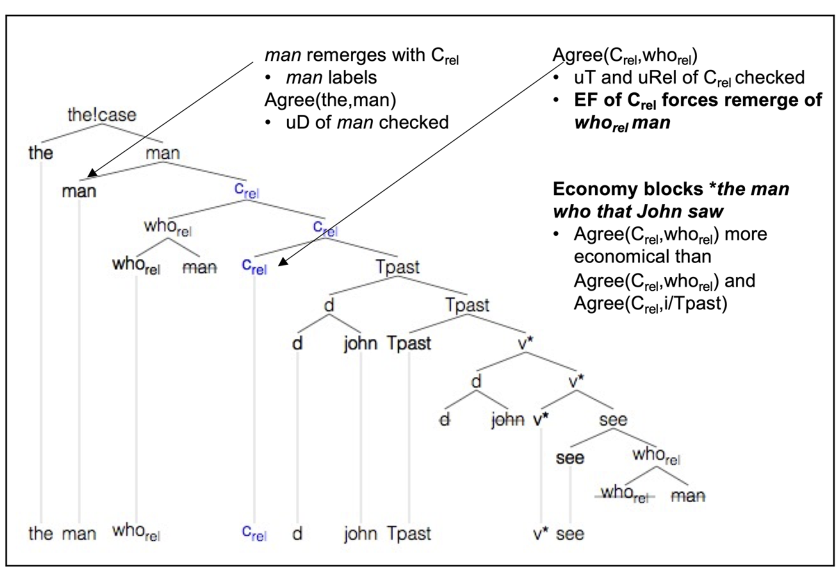

Figure 12: Derivation of *the man who(m) John saw*.

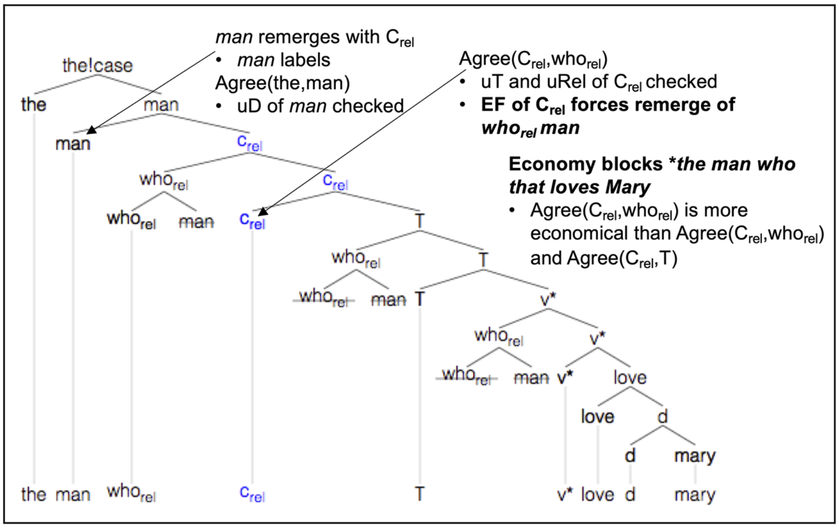

Figure 13: Derivation of *the man who loves Mary*.

separately checked (by *which*$_{\text{rel}}$ (or *who*$_{rel}$) and nominative Case on the subject, respectively). Hence, (17)b, which would require checking of uT on C_{rel} by T, is blocked. Similarly, the derivation of (17)c, shown in Figure 12, results from a single Agree relation between C_{rel} and *who*$_{\text{rel}}$, and likewise, (17)d is blocked by economy.

Next, consider the case of *who*$_{\text{rel}}$ in subject relative clauses as shown in (17)e-f. Again, a single Agree relation between C_{rel} and *who*$_{\text{rel}}$ licenses (17)e, as depicted in Figure 13, and (17)f is blocked by economy.

Related constructions with pied-piping can also be accounted for. Notably, pied-piping of P is optional as shown in (18)a–b, which contain *whom*$_{rel}$, the object equivalent of *who*$_{rel}$. To account for this, we assume that C_{rel} may Agree with a relative DP contained within a PP, and the EF on C_{rel} can attract either the relative DP itself or the containing PP. Pied-piping obtains in the latter case.[40]

(18) a) the man whom I talked to (Gallego 2006, 152)
b) the man to whom I talked
c) *the man **whom that** I talked to
d) *the man to **whom that** I talked

The derivation of (18)a is given in Figure 14. Note we assume *who*$_{rel}$ may also be pronounced as *whom* at Spell-Out. For some speakers, the form of *who*$_{rel}$ can be sensitive to Case. For example, *whom* = who + Accusative. C_{rel} agrees with the relative DP headed by *who*$_{rel}$., and uT and uRel on C_{rel} are simultaneously valued. Economy blocks the option of T separately checking uT on C_{rel}, and (18)c is ruled out. The EF of C_{rel} attracts the relative DP to the edge of CP, leaving *to* stranded. Example (18)b is analyzed in Figure 15. This is identical to Figure 14 except that the entire containing PP is raised to the edge of CP. Similarly, (18)d with *that* is ruled out by economy.

Wh-adverbials such as *when* can also be relativized, as in (19)a–b, from an anonymous reviewer. Note that *when* and *where* are adverbials, not determiners. We must extend the rel feature to wh-adverbials, i.e., *when*$_{\text{rel}}$

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39 This leaves open, in principle, the possibility of there being simultaneous derivations with m_{min}. In the cases of uT valuation explored in this article, this theoretical possibility does not occur.

40 A reviewer points out a contrast between the use of *who* versus *whom*, from Radford (1997: 141–2).
(i) a) *Whom were you talking to?
b) To whom where you talking?
Note that one of the authors finds (i)a to be better than (i)b and the other author finds (i)b to be better. (Both authors are native speakers of English.) As this is clearly a property of dialect, externalization is involved, and Spellout may be sensitive to pied-piping (especially as the pied-piped preposition will be adjacent to *who*/*whom*). The pronunciation of *who*/*whom* is not a property of Narrow Syntax.

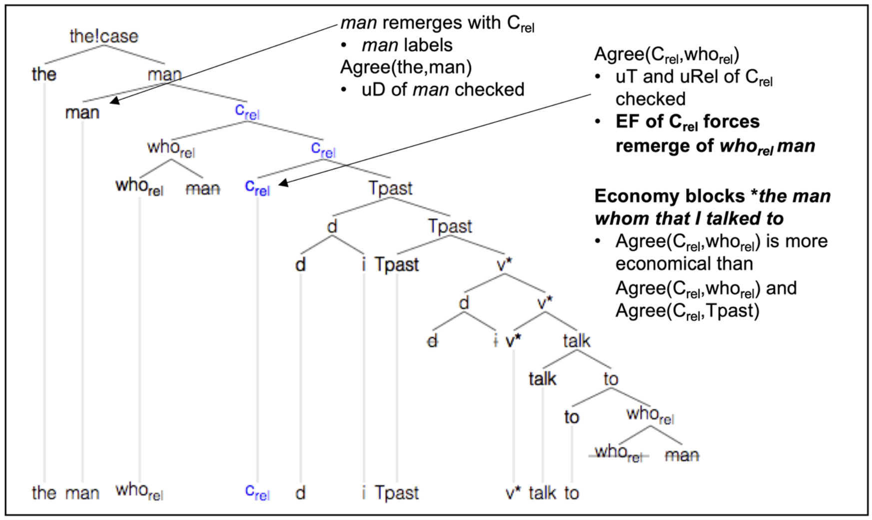

Figure 14: Derivation of *the man who(m) I talked to*.

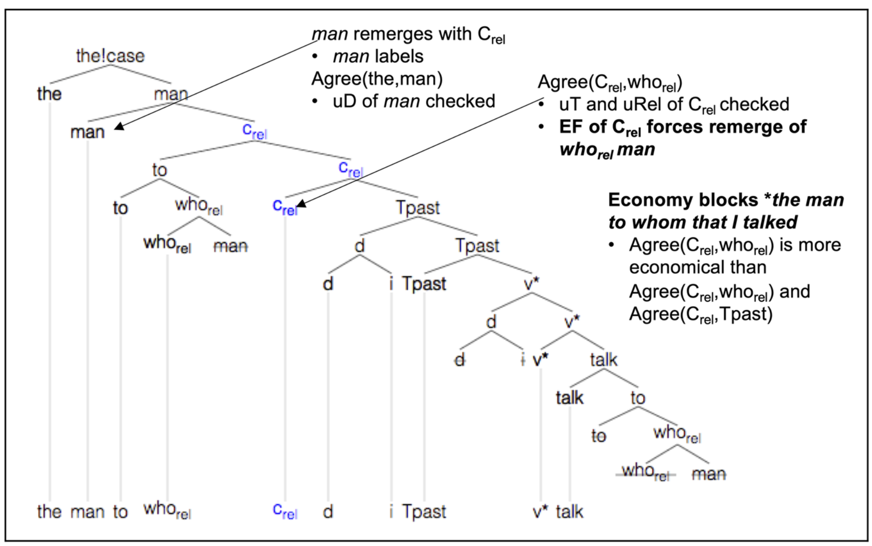

Figure 15: Derivation of *the man to who(m) I talked*.

and $where_{\text{rel}}$ exist in the Lexicon. This raises a possible acquisition question as not all determiners have a relative counterpart.[41]

(19) a) the time when I got drunk
b) *the time when that I got drunk

As $when_{\text{rel}}$ has an iRel feature and can check uT on C_{rel}, our model straightforwardly accounts for (19)a, as shown in Figure 16. We assume that *$when_{rel}$ time* initially adjoins at the TP level (as it is a temporal modifier).[42]

41 For example, although there is no *the_{rel}* in modern English, the Old English demonstrative *se* (sometimes translated as *the*, cf. van Gelderen 2014, 64, 128) can function as a relative determiner (cf. Ringe and Taylor 2014, 444, 447).

42 A reviewer wonders if adverbs can generally take NP complements. We assume all wh-adverbs may take an unpronounced *in situ* NP complement. Radford (2016, 423) observes that "*when/where/why* have the property that they cannot have an overt nominal complement at PF."

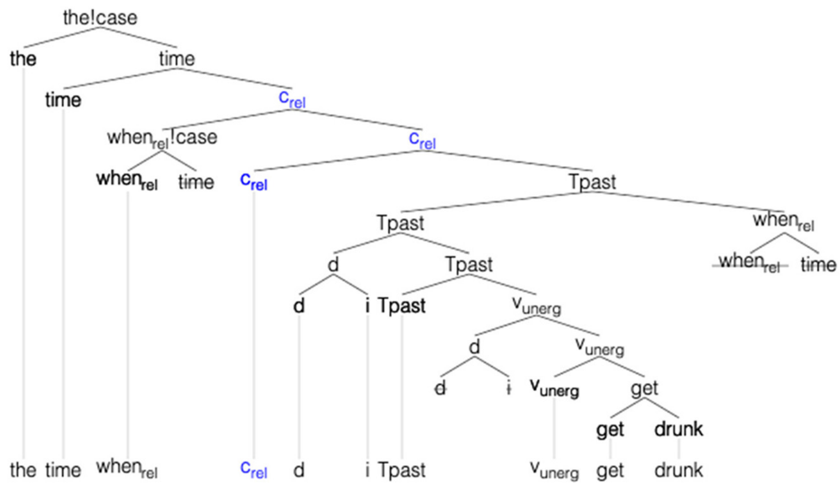

Figure 16: Derivation of *the time when I got drunk*.

Furthermore, we assume that $when_{rel}$ checks both uT and uRel simultaneously on C_{rel}, so economy blocks (19)b with *that*. Finally, the relative *wh*-adverbial $when_{rel}$ cannot value the uD of *time* (as is the case with all relative Ds); hence, *time* raises and its uD is valued via Merge with external *the*.[43,44]

Relatives can also occur in non-finite clauses, as in (20)a–b.[45] Note that Sag (1997) indicates (20)b as being ill-formed; however, we find it grammatical. Pied-piping seems subject to dialectal variation.[46]

(20) a) the baker in whom to place your trust (Sag 1997, 461)
b) the baker whom to place your trust in (Sag 1997, 461 – marked as * by Sag)

Relevant structures for (20)a–b are given in Figure 17. Note that we employ a non-finite T (Tinf) and a null subject (PRO). We assume a dyadic *in* that takes complement and specifier arguments.

Another type of non-finite relative clause can occur with an optional *for* as in (21)a–b.

(21) a) the person to visit
b) the person for us to visit (Sag 1997, 464)

Assume that Tinf (as with tensed T) and *for* are both capable of checking the uT feature on C_{rel}. For (21)a, as shown in Figure 18, Tinf raises and checks the uT on C_{rel}. The noun *person* raises and relabels the clause as a nominal. For (21)b, as shown in Figure 19, we assume that the complementizer *for* raises and checks the uT feature on C_{rel}. Since *for* is closer to C_{rel} than Tinf, Tinf does not raise given minimal search. The relative DP raises to the edge of CP, and then, *person* raises to relabel.

Our analysis also extends to the case of headless relatives, examples shown in (22)a–b. Headless relatives appear not to support *that* for C_{rel}.

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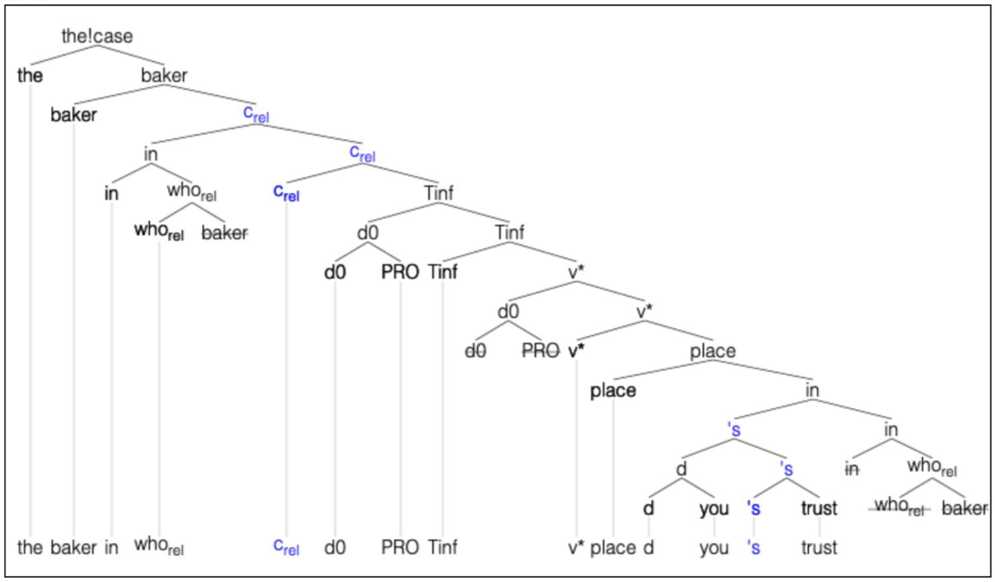
43 For further details of this derivation, see the Appendix (Example 11). Note that our model tries Merging the adverbial $when_{rel}$ *time* using both pair-Merge and set-Merge. Normally, an adjunct would be Merged via pair-Merge only. However, pair-Merge fails because extraction is impossible, assuming that a pair-Merged element is invisible to extraction. As a result, the set-Merge option is required.

44 A reviewer wonders how we can account for adjectival relatives such as the following:
(i) John will be [however helpful you are willing to be].
Notably, the head of the relative is an adjective, so this could involve relabeling by the adjective *helpful* which then Merges with the adverbial *however*. This is an interesting type of example, which we must leave for future work.

45 We thank a reviewer for questioning how our model can account for this type of example.

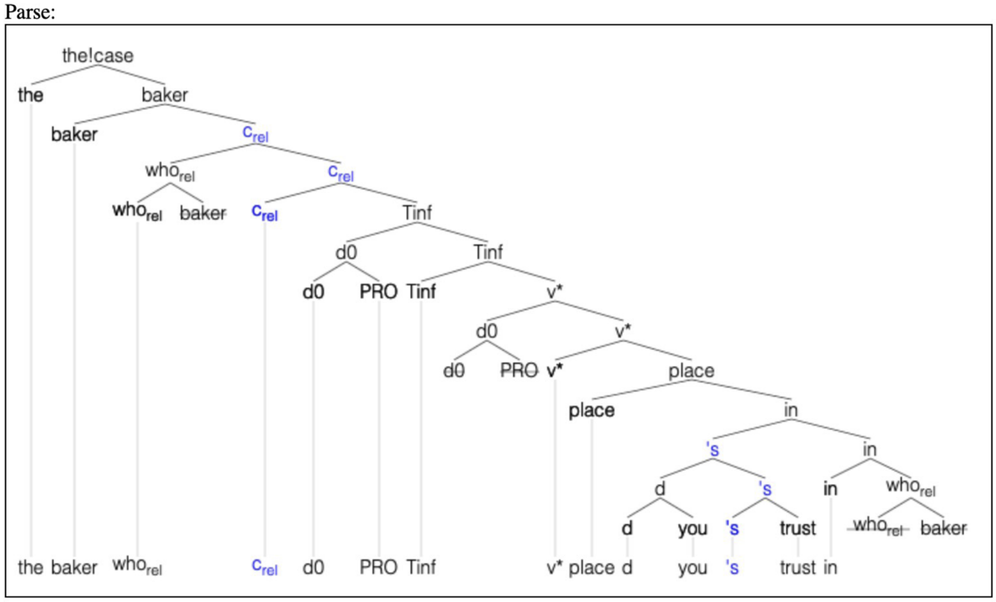
46 A reviewer notes that, in British English, some prefer stranding with *who* and not *whom*.

a) Parse:



Spell-out:
the baker in who to place -gen your trust (after morpheme realization)
the baker in who to place your -gen trust (after affix-hop)
the baker in who to place your -gen trust (after morpheme realization, stage 2)
the baker in who to place your trust

b) Parse:



Spell-out:
the baker who to place -gen your trust in (after morpheme realization)
the baker who to place your -gen trust in (after affix-hop)
the baker who to place your -gen trust in (after morpheme realization, stage 2)
the baker who to place your trust in

Figure 17: Derivation of *the baker in who to place your trust/the baker who to place your trust in*.

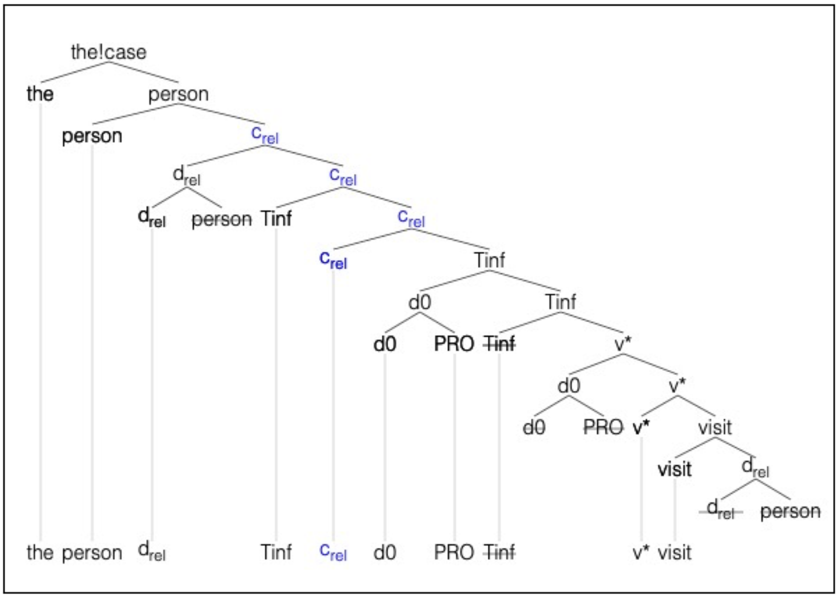


Figure 18: Derivation of *the person to visit*.

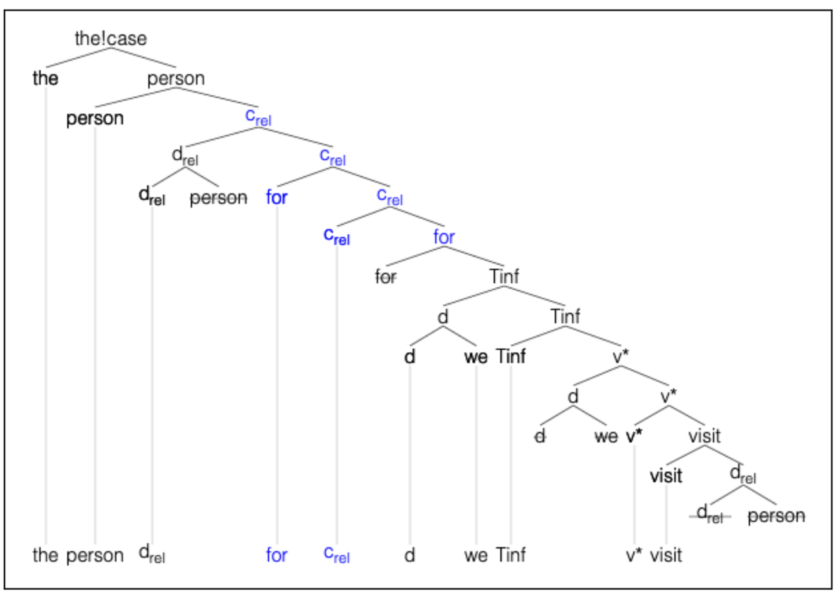


Figure 19: Derivation of *the person for us to visit*.

(22) a) what I read
b) *what that I read

Assume that headless relatives contain pro_n, a form of *pro* occurring in relative clauses. We can co-opt our uRel and uT on C_{rel} analysis by assuming that pro_n also has a uD feature, just as with the overt Ns so far.[47]

47 pro_n must have extremely restricted distribution as wh-determiners generally do not occur by themselves. Its use is much more constrained than *pro* in *pro*-drop languages. As a reviewer noted, it's possible to extend this analysis to interrogatives with non-relative *who* and *what* decomposed as *who* + pro and *what* + pro, respectively, implications of which are not explored here for lack of space.

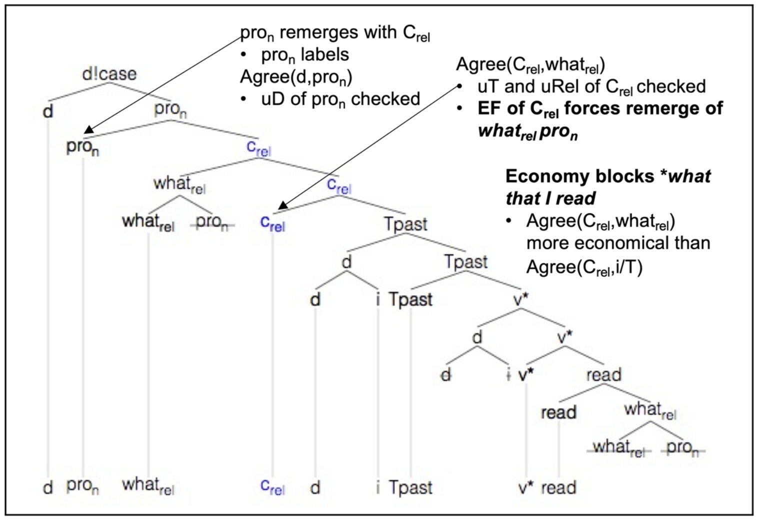


Figure 20: Derivation of *what I read*.

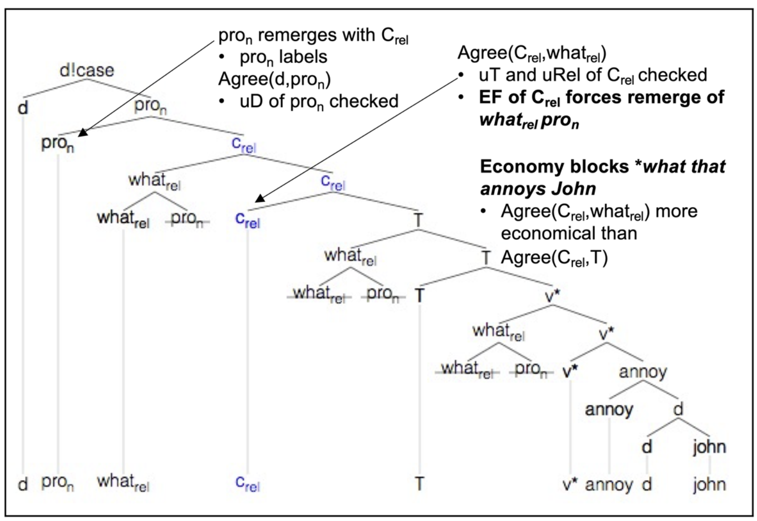


Figure 21: Derivation of *what annoys John*.

Figure 20 illustrates the derivation of (22)a. Suppose a relative determiner *what*$_{\text{rel}}$, like *who*$_{\text{rel}}$ and *which*$_{\text{rel}}$ previously, agrees with C_{rel}. In particular, permit *what*$_{\text{rel}}$ to simultaneously value uT and uRel on C_{rel}. By economy, the option of checking uT on C_{rel} separately via T is blocked, and (22)b is ruled out. Note that we permit pro_{n} to undergo movement before Merging with an external null D. (We do not need to stipulate a difference between covert and overt relative N with respect to movement.) This null D values uD on pro_{n}, cf. null D_{rel}, which cannot value uD. Finally, we must also assume that pro_{n} is limited in distribution to co-occur with relative determiners only, as **the what I read* is ill-formed.

We next turn to subject headless relative clauses, accounted for in parallel fashion.

(23) a) what annoys John
b) *what that annoys John

This is similar to the case of (22)a–b, except that the relative DP originates in the subject position here. The derivation of (23)a is shown in Figure 21.

We have developed an analysis of the distribution of *who*/*whom*/*which*/*what* and a null D_{rel} in English. The relative determiner *who* occurs with human nouns, with the object variant *whom* occasionally used in some varieties of English.[48] Relative D *which* can be used with non-human NPs. A reviewer notes nothing in our syntactic analysis blocks **the man which arrived*. We assume semantic feature matching for determiner-noun combinations is also involved, e.g., -human for *which* and +human for *who*. We assume that the appropriate relative pronoun is selected from the lexicon, so $which_{rel}$ occurs with a non-human relative noun and who_{rel} occurs with a human relative noun. (But see also Note 3.) Otherwise, these relative Ds are identical. We have also seen that *what* can be used with a null NP complement.

4 Comparative and genitive relatives

Hale (2003) implemented a Minimalist Grammar that covers a variety of relative clauses from Keenan and Hawkins (1987) involving subject and object relatives, passivization, comparatives, and genitives. Although Hale covers a wide range of relative clause constructions, the reasons for the uses of the relative determiners *which*, *who*, *what*, and for restrictions on their use with *that* are not accounted for. Our model also accounts for all of the relative clause examples from Keenan and Hawkins (1987, 63), notably genitive relatives, as well as other related constructions.

The examples in (24) from Keenan and Hawkins (1987, 63) are essentially identical to examples that we have discussed earlier (Hale models (24)a, b, c, and a version of d).[49] (24)a is a subject relative (Figure 8), (24)b–c are object relatives (Figures 11 and 12). (24)d–e contain relative nouns that originate as the object of a preposition (as in Figures 14 and 15).[50] See the Appendix for complete derivations of these particular examples.[51]

(24) a) the boy who told the story – Subject relative
b) the letter which Dick wrote yesterday – Object relative
c) the man who Ann gave the present to – Relative object of P
d) the box which Pat brought the apples in – Relative object of P
e) the dog which was taught by John – Passivized object relative (Keenan and Hawkins 1987, 63)

48 Radford (2019, 32) writes that “relative *whom/whose* have largely fallen out of use in contemporary colloquial English.” But we note that this does not mean that *whom* is never used. See Radford (2019, 32–3) and references cited therein for discussion of use of *whom* in modern English.

49 Instead of (24)d, Hale (2003, 98) lists “the box which Pat brought with apples in,” which differs from the original Keenan and Hawkins example in that *apples* is contained within a PP. Some find these examples marginal or unacceptable. We modeled the original example on the assumption it is broadly acceptable.

50 Although not important for our analysis of relative clauses, in (24)b we assume that the adverbial *yesterday* is a DP that is Merged at the TP level. Note that *yesterday* can behave as a nominal, as in (i)–(ii). We adopt Larson’s (1985) view that the adverbial *yesterday* is really an NP with inherent case (Larson’s proposal is that if Case isn’t checked, a default Case can be assigned to certain temporal NPs).
(i) yesterday’s refusal (Larson 1985, 598)
(ii) Yesterday was a great day.
We also follow Haumann’s (2007) view that temporal adverbials like *yesterday* are outside the vP. The ill-formedness of (iii), in which y*esterday* occurs in a TP-internal position, can be accounted for if *yesterday* is Merged at the TP level.
(iii) *Illicit smokers were yesterday fined for taking a puff (Haumann 2007, 265).
Similarly, in the following examples adapted from van Gelderen (2013, 127), *yesterday* (van Gelderen uses *last week* instead of *yesterday*), is ill-formed in a TP-internal position, but fine in other positions, that are not necessarily TP-internal.
(iv) a) They were happy yesterday.
b) Yesterday, they were very happy.
c) *They were yesterday very happy.
See the Appendix for the complete derivation of (24)b.

51 The passive (24)e, as shown in the Appendix, is formed with a v~ and a participle Prt. The v~ is a verbalizing head (Deal 2009, Sobin 2014). Both Prt and v~ have EF subfeatures that force remerge of the relative DP.

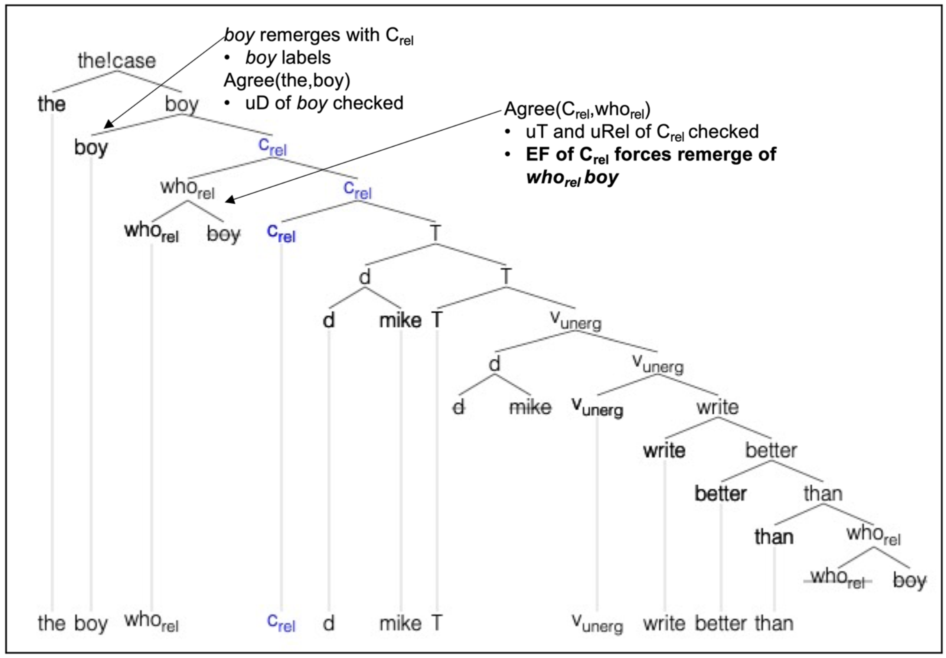


Figure 22: Derivation of *the boy who Mike writes better than*.

We next discuss some examples from Keenan and Hawkins that require some revisions to our core model.[52]

In example (25), *boy* originates from a relative DP object of the comparative *than*.[53]

(25) the boy who Mike writes better than (Keenan and Hawkins 1987, 63) – relative object of comparative *than*

As shown in Figure 22, the relative *who*$_{rel}$ *boy* raises and remerges with C_{rel}, checking uRel on C_{rel}. The head *boy* with unvalued uD raises out of C_{rel}*P*, then relabels and Merges with external *the* (which checks unvalued uD on *boy*).

Next, we consider (26), from Keenan and Hawkins, which contains a genitive subject relative.

(26) the girl whose friends bought the cake – Genitive subject relative (Keenan and Hawkins 1987, 63)

Figure 23 analyzes (26) as follows: the possessive subject DP *who*$_{rel}$ *girl 's friend* raises from the edge of v*P to the surface subject position at the edge of TP. This is followed by raising to the edge of C_{rel}P (*who*$_{rel}$ checks uRel on C_{rel}). The head *girl* raises and relabels the structure. We need to assume that although *who*$_{rel}$ is embedded in the specifier of the possessive DP, its Rel feature is visible to C_{rel} and Agree (*who*$_{rel}$, C_{rel}) results in raising of the entire DP.[54]

Example (27) is similar to (26) except that the genitive relative originates as an object. As shown in Figure 24, the genitive relative raises to the edge of C_{rel}*P*, and the head *man* then further raises and relabels.[55]

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52 Of the following examples, to the best of our knowledge, Hale (2003) modeled (26) and (27), but not the other types of examples.

53 It is crucial for our analysis that *than* has a relative clause DP complement (or that a relative DP occurs within the complement of *than*) in this example. Our analysis may not extend further to other constructions with *than*. One possibility is that *than* can be a P, following Hankamer (1973) and Chomsky (1977).

54 A reviewer asked about the impossibility of *that*-relatives and zero relatives in this case. The derivation for *the girl whose friends* is currently is based on: [[who$_{rel}$ girl] ['s friends]]. This raises the question of why [[d$_{rel}$ girl] ['s friends] can't be substituted. We assume 0_{rel} + 's is not a possible English word because *'s* is an affix, and it has to affix to an overt word (see Radford 2016, 405–6). We assume that affixation happens at Spell-Out and is not a syntactic process. It requires an adjacent host with phonological content, so d$_{rel}$ does not qualify as a host. In this case, *that* is not permitted because *that*-relative formation requires separate raising of T to C (to check uT on C) and is blocked by economy (following P&T).

55 Our model also predicts that T can check a uT feature on C_{rel}, resulting in *the man whose house that Patrick bought*, an example that seems well-formed to us. See the Appendix for the complete derivation.

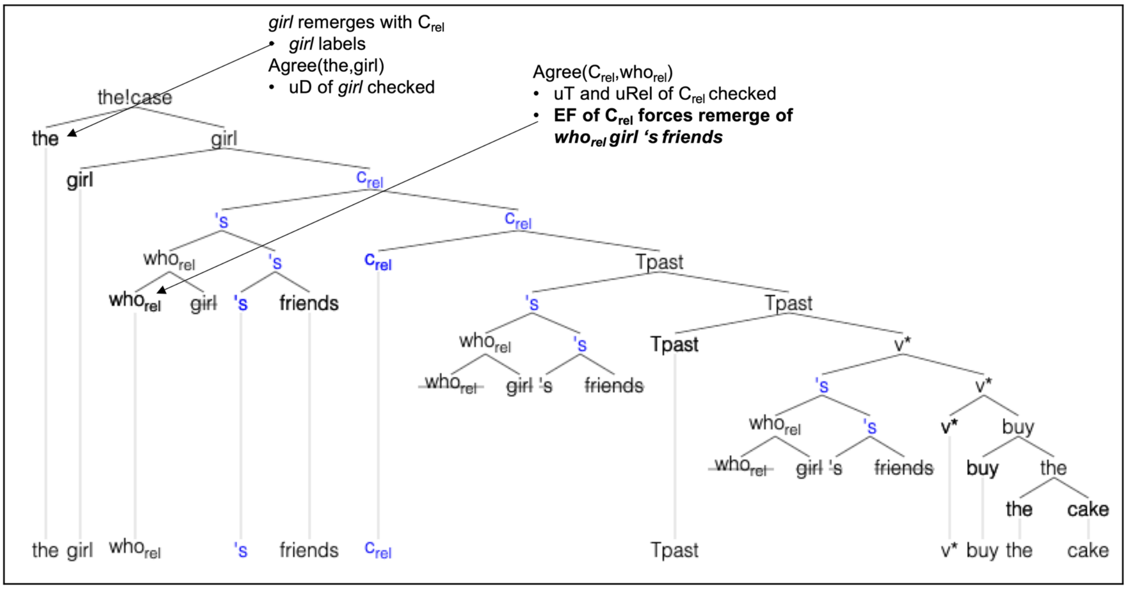

Figure 23: Derivation of *the girl whose friends bought the cake*.

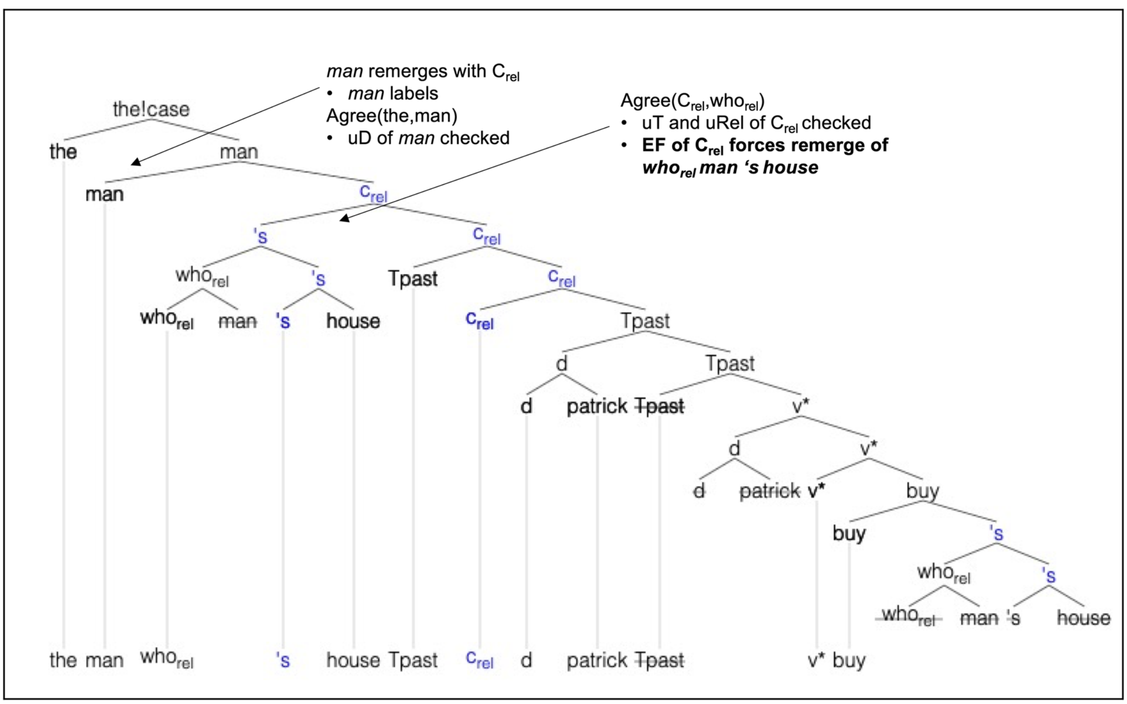

Figure 24: Derivation of *the man whose house Patrick bought*.

(27) the man whose house Patrick bought – Genitive object relative (Keenan and Hawkins 1987, 63)

Example (28) is similar to those shown previously in Figures 22 and 23 except that it is a passive construction (see the Appendix for the complete derivation).

(28) the boy whose brother was taught by Sandra – Genitive subject of passivized object relative (Keenan and Hawkins 1987, 63)

Note that in addition to these examples from Keenan and Hawkins, our model is also able to generate related relative clause constructions with the relative contained within a PP complement headed by *of*. Examples (29)–(31)a correspond to the genitive relatives (26)–(28) except that the relative pronoun originates in a PP complement headed by *of*.[56]

(29) a) the girl who friends of bought the cake[57]
b) friend of *who$_{rel}$ girl*

(30) a) the man who Patrick bought the house of
b) house of *who$_{rel}$ man*

(31) a) the boy who the brother of was taught by Sandra
b) brother of *who$_{rel}$ boy*

The structure of (29)a is shown in Figure 25. The relative DP *who$_{rel}$ girl* originates in a PP *of*-phrase that is the complement of *friends*, embedded within the subject. After the subject moves to the TP edge, the relative DP *who$_{rel}$ girl* moves to the C$_{rel}$*P* edge to check the uRel feature, and head *girl* moves out and relabels. Example (30)a is similar except that it involves a relative object, and (31)a involves a passivized relative object.

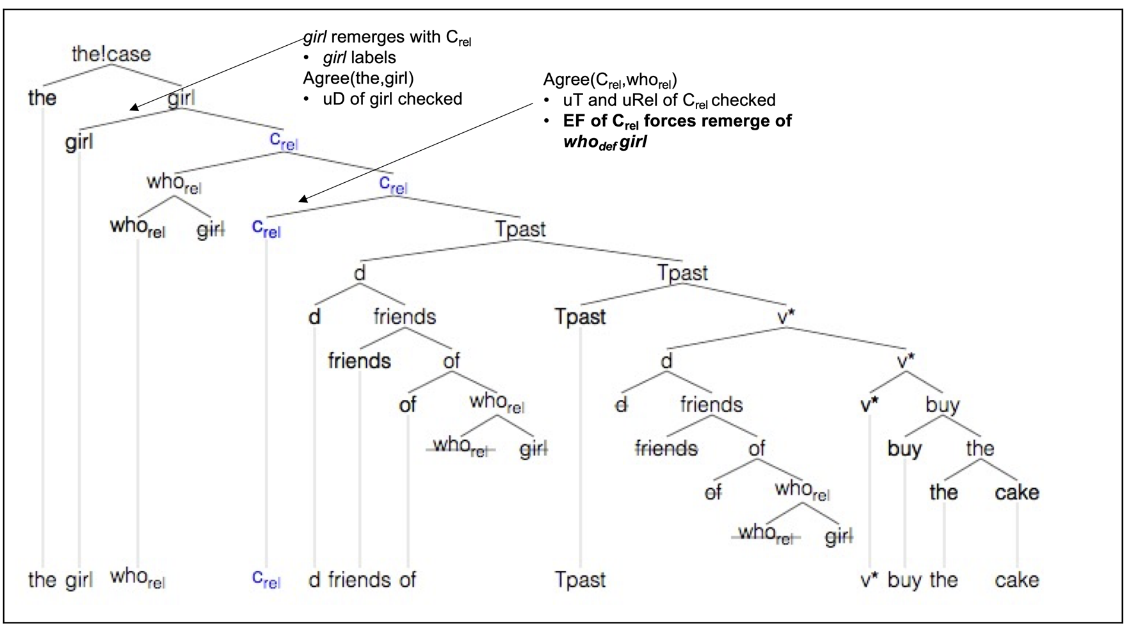

Figure 25: Derivation of *the girl who friends of bought the cake*.

We next turn to deeply embedded genitive relatives, such as in (32).

(32) Give me the phone number of the person whose mother's friend's sister's dog's appearance had offended the audience. (Sag 1997, 450)

The structure of the relative DP *whose person 's mother's friend's sister's dog's appearance* is shown in Figure 26. In our implementation, we must assume that the relative feature of deeply embedded *who$_{rel}$* percolates up onto

56 We note, for some speakers, examples such as these are ill-formed.
57 Culicover (2013, 161) provides the following similar example.
(i) a man who friends of *t* think that enemies of *t* are everywhere.

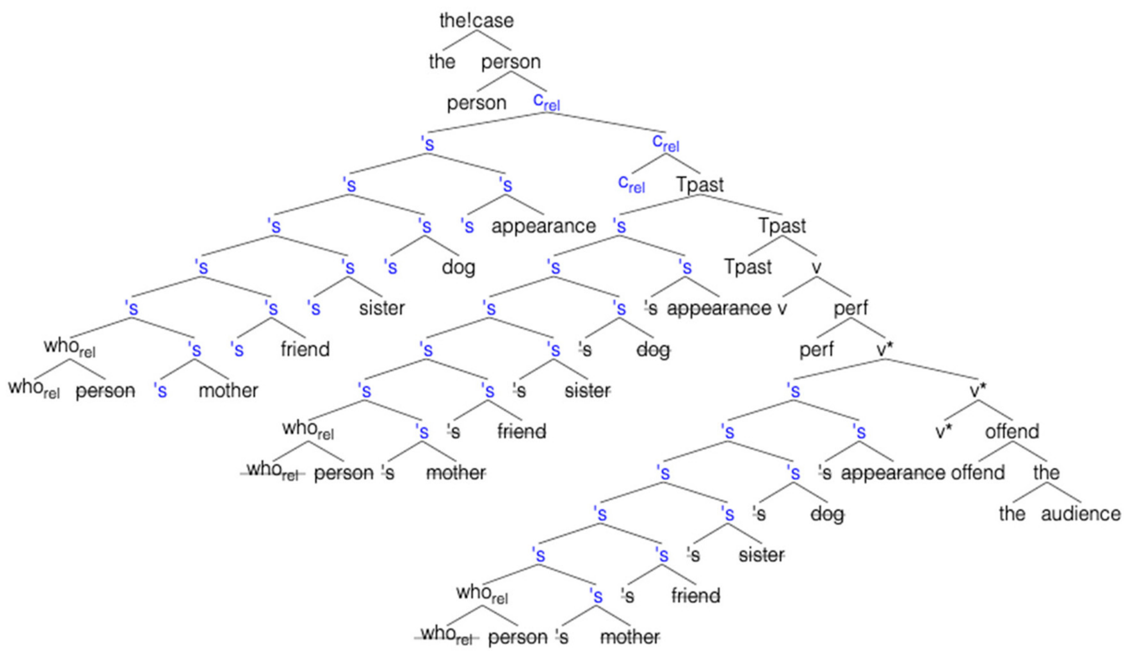

Figure 26: Embedded relative: *the person whose mother's friend's sister's dog's appearance had offended the audience*.

the highest 's, so C_{rel} is able to attract the entire DP to check its uRel feature.[58] See the Appendix for further examples of embedded relatives.

5 Other varieties of English

We have focused on an analysis that accounts for the structures of basic relative clauses in modern standard English. Although the relative clauses' heads in (33)a–c are unavailable in standard modern English, they do occur in older stages of English and in some modern dialects.

(33) a) *which that
b) *who(m) that
c) *Ø in a subject relative (e.g., *the boy called Mary)

Old and Middle English allow a doubly filled CP. Examples (34)a–b are from Old English. *Se* is a demonstrative pronoun, although it is translated as a *wh*-pronoun (Ringe and Taylor 2014, 467).

(34) a) Se [weig **se ðe** læt to heofonrice] is for ði nearu & sticol
the way which C leads to heaven is therefore narrow and steep
'the way which leads to heaven is therefore narrow and steep'
b) Hwæt is god butan Gode anum [**se þe** is healic godnisse]

58 A reviewer asks whether the whole relative clause has to be attracted. The whole relative clause must be attracted, which we can see by examining examples of object relativization, shown below. Compare this with cases of pied-piping, where there can be some variation.
(i) the person [whose mother's friend] the play offended
(ii) *the person whose the play offended [~~whose~~ mother's friend]

What is good except God alone who C is sublime goodness
'what is good except God alone, who is sublime goodness' (Ringe and Taylor 2014, 468–9)

Examples of *which that* are also attested in Middle English, as shown in (35)a–b and (36).

(35) a) they freend **which that** thouh has lorn
'your friend that you have lost'
b) the conseil **which that** was yeven to yow by the men of lawe and the wise folk
'the counsel that was given to you by the men of law and the wise folk' (Penn-Helsinki Parsed Corpus of Middle English - Kroch and Taylor 2000, per Santorini and Kroch 2007, Chapter 11)

(36) the est orisonte, **which that** is clepid commonly the ascendant
the eastern horizon which that is called commonly the ascendant
'The eastern horizon, which is commonly called the ascendant' (Van Gelderen 2014, 128, per Chaucer *Astrolabe* 660, 17–8)

Zero subject relatives may also occur. Examples (37)a–c are cited by Bauer (1994).

(37) a) It was [the city gave us this job]. (Bauer 1994, 77, per Shannon 1978, 15)
b) Even if I found [somebody knew who I was], I won't be them no more. (Bauer 1994, 77, per Wolfe 1977, 151)
c) They used to arrest [people did that kind of thing]. (Bauer 1994, 77, per Higgens 1976, 78–79)

Belfast English also has zero subject relatives, as in (38)a–b.

(38) a) There are [people don't read the books].
b) It's always [me pays the gas bill]. (Henry 1995, 124)

Finally, the following two examples are from Black English Vernacular/African American English.

(39) Ain't [nobody know about no club] (Labov 1972, 188)[59]

(40) The [man saw John] went to the store (Sistrunk 2012, 5)

In our analysis so far, we have assumed the Lexicon contains *who*$_{rel}$, *which*$_{rel}$, *when*$_{rel}$, and *what*$_{rel}$, all of which are able to value uT on C_{rel}. It is certainly plausible that this property could vary over individual lexical items. Thus, certain varieties of English *which*$_{rel}$ and *who*$_{rel}$ may lack this ability, thereby permitting uT on C_{rel} to be checked separately by T or nominative Case on a subject, crucially licensing the pronunciation of *that* in the former case. Another point of variation concerns null D_{rel}; we proposed earlier that null D_{rel}, unlike overt D_{rel}, is unable to value uT on C_{rel}, but it appears that in some dialects null D_{rel} may behave like overt D_{rel}, permitting zero subject relatives, e.g., as in Belfast and African American English. To summarize, a relative D must contain a core Rel feature (by definition). However, the ability to value uT on C_{rel} may vary diachronically and/or synchronically. To summarize, this minor change in lexical feature specification can account for the data described above and is not a problem for our computer implementation in principle.

59 Labov (1972, 188) gives (i), with a zero subject relative, as a possible underlying structure for this example. However, another possible structure given by Labov is (ii) which does not contain a relative clause.
(i) (It) ain't nobody (that) know about no club.
(ii) Nobody ain't know about no club.

6 Conclusion

We have built our theory and verified implementation based on the insights of Gallego's (2006) analysis of relative clauses. Gallego, in turn, has built on the insights of P&T (2001). The fact that this refinement is possible is a sign that the MP is a viable research program. Our account makes use of a relative complementizer (C_{rel}) with separate unvalued Rel (relative) and T (Tense) features. Rel is a construction-specific formal feature, distinguishing relatives from normal clauses. Rel and T together are subject to economic considerations, i.e., simultaneous valuation (where possible). Our verified analyses improve upon Gallego in the following ways: a) there is no need for an extra projection in the left periphery, b) there is no stipulation that a null D cannot move, c) there is no need for two types of C, one with an EPP feature, and one without, and d) we are able to account for the absence of *which that* in standard English. The additional stipulations of our model are that: i) a relative D cannot check a uD feature on N, in order to trigger extraction of the relative noun for relabeling, and ii) the null D_{rel} cannot generally check a uT feature, although other relative Ds, such as *which$_{rel}$/who$_{rel}$/whom$_{rel}$/what$_{rel}$/when$_{rel}$*, can. A natural question arises: is our three-feature system, Rel, T and D, minimal, i.e., *parameter-efficient*? As, in our theory, movement is driven, both EF and something akin to our unvalued D are required to initiate raising and relabeling of the relative clause into a nominal. Finally, a minimum of two features, such as Rel and T, are needed in order to exploit economy. Economy simplifies operational complexity, enabling multiple features to be valued in one operation. More broadly, in the MP framework, the functional category T selects for verbal phrase structure and further projects phrase structure (with a surface subject position).[60] In Chomsky (2008), non-selectional properties of T, e.g., phi-features, the ability to value nominative Case and Tense, do not appear in T's lexical entry, but instead are transmitted from phase head C.

Overall, we have developed a detailed and logically consistent feature-driven theory of English relative clauses in the MP framework. We have also built a computer-implemented derivational system capable of converging on the correct analyses starting from an initial LA queue. The implementation confirms that our theory is both complete and detailed enough to constitute an (automatic) computer program. The interested reader is referred to the Appendix, which contains step-by-step computer-generated derivations, too detailed to be included in the main body of the article. The Appendix includes all the English relative clause examples

Table 4: Summary of relative Ds in English

Relative D		Features	Explanation	Examples
(a)	D_{rel}	Rel	D_{rel} unable to value uT uT on C_{rel} must be checked by T if relative DP is a subject	(14) the man that/Ø I talked to (15)a the boy that called Mary (15)b *the boy called Mary
(b)	which$_{rel}$ who$_{rel}$ whom$_{rel}$ what$_{rel}$ when$_{rel}$	Rel, T	which$_{rel}$/who$_{rel}$/whom$_{rel}$/what$_{rel}$/when$_{rel}$ can value uT. By economy, uRel and uT on C_{rel} must be simultaneously checked by one of the above wh$_{rel}$'s Note: *that* is banned	(17)a the book which I read (17)c the man who John saw (17)e the man who loves Mary (19)a the time when I got drunk (22)a what I read (23)a what annoys John (17)b *the book which that I read (17)d *the man who that John saw (17)f *the man who that loves Mary (19)b *the time when that I got drunk (22)b *what that I read (23)b *what that annoys John

60 It is unclear to us whether the Edge Feature of T (the requirement for subjects in English, also known as the EPP in earlier theories) should also be inherited from C.

discussed in the article (and others). The program is able to correctly select the precise Merge operation at each step (without human intervention), based on the state of the current SO and the first available item in the LA.[61] Moreover, our implementation permits us to verify that the model does not generate spurious analyses – unpredicted by the theory – for all example sentences.

We summarize the core relative D facts in Table 4.

Finally, we believe our analysis can be extended to account for data in other dialects and languages, assuming limited variation in determiner heads with respect to the ability to value uT on C_{rel}. There are also a variety of other relative clause types that remain for future work.[62]

Abbreviations

C	complementizer
COMP	complementizer
cP	(extra) complementizer phrase (above the normal CP)
CP	complementizer phrase
C_Q	interrogative (Question) complementizer
C_{rel}	relative C
$C_{rel}P$	relative CP
D	determiner
DP	determiner phrase
D_{rel}	relative determiner
EA	external argument
ECM	exceptional case marking
EF	edge feature
EM	external merge
EPP	extended projection principle
H	head
HPSG	head-drive phrase structure grammar
IM	internal merge
iPhi	interpretable phi-features (person, number, gender)
LA	lexical array
MG	minimalist grammar
MP	minimalist program
N	noun
NP	noun phrase
Op	operator
phi-features	person, number, and gender features
POSS	possessive head ’s
PP	prepositional phrase

61 We note that a machine learning approach has been taken in predicting the correct stack operation to take in transition-based dependency parsing, Nivre (2003), and in subsequent large-scale models, e.g., Andor et al. (2016). This is reminiscent of selecting the correct Merge operation to perform in our system.

62 For example, stacked relatives such as (i) are not accounted for by the system described here. In principle, if we add the *n*-ary operation FormSet of Chomsky (2021), proposed there for unbounded, unstructured coordination, to apply to the stacked relative clauses (each formed separately in its own sub-Workspace), we can form a set of $C_{rel}P$ phrases. Then, we further require parallel extraction of the nominal head across the members, perhaps justified as the heads are identical inscriptions. In this way, stacked relative clauses can be accommodated. For example, if *student who lives here* and *student who studies English* are constructed in parallel with repetitions of the head noun *student*, (i) can be formed. See the Appendix for detailed derivations of stacked relatives.
(i) the student who lives here who studies English

pro	a pronoun that is not pronounced which is associated with Case positions.
PRO	a pronoun that is not pronounced which is associated with non-Case positions
pro_n	a nominal pro
Q	question
rel	relative feature
SO	syntactic object
T	tense, a feature and a functional head
TP	tense phrase
T_{Past}	past tense
uF	unvalued/uninterpretable feature
uPhi	unvalued/uninterpretable phi-features (person, number, gender)
uRel	unvalued relative feature
iRel	interpretable relative feature
uT	unvalued/uninterpretable T
v	verb
V	verb
v*	transitive verbal head
VP	verb phrase
YP	a phrase with the head Y

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Data availability statement: All of the derivations generated by our computer models are available in the Appendices. The two authors have built separate computational models that generate all of the derivations in this paper. The SWI-Prolog/Javascript implementation is freely available at https://sandiway.arizona.edu/mpp/mm.html for Windows, macOS and Linux. Instructions and all source code are supplied. The Python implementation is also available from the Appendices.

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Appendix

The online Appendices are available at: https://sandiway.arizona.edu/mpp/appendix/.