Binding in Finnish and the language-cognition interface[1]

Pauli Brattico

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Abstract. Binding conditions are usually modelled as a mapping from syntactic structures into sets of coreference relations expressed and represented by narrow syntactic devices such as indices and/or formal operations such as Agree. Here we consider an alternative based on binding data from Finnish and English in which the mappings are generated dynamically during left-to-right comprehension of an arbitrary number of sentences ("conversations") at the language-cognition interface. The model assumes that binding regulates semantic assignment management at the language-cognition interface by blanking out portions of the transient discourse available for coreference computations at the hearer's end. The hypothesis is tested by using the computational generative grammar methodology.

Keywords: Binding; Finnish; comprehension; computational linguistics; computational generative grammar; picture nouns

Running title: Binding in Finnish

1 Introduction

1.1 Language comprehension and binding

Successful linguistic communication presupposes that both the speaker and hearer can construct mutually consistent inventories of semantic objects corresponding to the subject matter under discussion. This allows the interlocutors to position themselves into a common discourse space and share an implicit notion of what the conversation "is about." This framework presupposes a cognitive mechanism at the hearer's end for deciding whether an incoming expression denotes an object that already exists in the shared discourse space or if the speaker requested a new object to be assumed into existence. For example, the first use of a proper name or an indefinite article invites the hearer to assume a new object, whereas an

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unstressed pronoun or the use of a definite article signals that the reference should be assumed to be discourse old.

Some coreference restrictions are structure-dependent. Sentences (1−3) illustrate structure-dependent coreference patterns for reflexives (1), regular pronouns (2) and proper names (3) in English.

(1) a. John$_a$ admires himself$_{a,*b}$.
    b. *John's$_a$ sister admires himself$_a$.

(2) a. John$_a$ admires him$_{*a,b}$.
    b. John's$_a$ sister admires him$_{a,b}$.

(3) a. He$_a$ admires John$_{*a,b}$.
    b. His$_{a,b}$ sister hates John$_a$.

As a first approximation we can say that the reflexive *himself* must denote the same thing as the subject of its own clause (1); *him* cannot denote the same object as the subject of its own clause (2); and a proper name must introduce a new semantic object (3). These rules, which restrict the discourse material available for interpretation during language comprehension, are known as the *binding conditions* (Chomsky 1981). Their nature is controversial, although the phenomenon has received considerable attention in linguistics (e.g., Büring 2005; Chomsky 1980, 1981, 1982; Helke 1971; Chomsky & Lasnik 1977; Lebeaux 2009; Lees & Klima 1963; Reinhart 1983; Postal 1971; Reinhart & Reuland 1993; Reuland 2001, 2010) as well as in psycholinguistics (Aoshima et al. 2009; Cunnings & Felser 2013; Cunnings & Sturt 2014; Sturt 2003)(for a general introduction, see Büring 2005; Huang 2000a; Safir 2004 and Fischer 2015).

Here we examine binding from the point of view of comprehension. It is argued that binding takes place at the language-cognition interface. Specifically, binding effects emerge when a language-external cognitive module responds to lexical assignment management features that hijack the system for linguistic purposes and "blanks out large portions of the discourse" (Hankamer & Sag, 1976: 425), making comprehension more efficient.

This article is organized as follows. Section 1.2 elucidates the main hypothesis after working through the necessary background. Section 2 describes the methods and data used to test the hypothesis. Section 3 reports the results, while Section 4 attempts to position the proposed hypothesis into a broader context. Section 5 concludes the article.

1.2 The hypothesis

The human language faculty maps linguistic inputs into syntactic parses that are interpreted semantically (e.g., Nicol & Swinney 2003). For example, the input string *the* + *horse* + *ran* + *past* + *the* + *barn* could be mapped into a syntactic parse [$_{S}$[$_{DP}$ *the horse*] [$_{VP}$ *ran* [$_{PP}$ *past* [$_{DP}$ *the barn*]]]] that feeds semantic interpretation and generates the reading 'the horse ran past the barn'. The sequence of operations between the sensory input and the syntactic parsed output will be called the *syntactic processing pathway*.[2] The endpoint of the syntactic processing pathway will be called the *syntax-semantics interface* (also *LF interface*). The syntax-semantics interface is followed by *semantic interpretation*. Semantic interpretation connects the language-specific processing pathway(s) with the rest of the cognition that is not specific to language and linguistic processing. We call the latter *general* or *global cognition*.

To establish a connection between referential expressions in the parsed input and their meanings in the semantic component, we posit a *global discourse inventory* that holds a record of all semantic objects and their known properties that have been mentioned during the ongoing conversation (e.g., Heim 1982; Kamp 1981). In the case of *the horse ran past the barn*, the inventory holds (representations of) at least two spatiotemporal objects, the horse and the barn – the two spatiotemporal objects the sentence "talks about." The global discourse inventory is a language-external representational system accessed by global cognitive processes. It allows the speaker and hearer to retrieve past memories of the objects, perform inferences concerning them, plan further action, and decide what to say next.

Several sentences can share the global discourse inventory and thus "talk about" the same things. If the first sentence introduces objects into the discourse inventory, processing of subsequent sentences can take those objects into account when evaluating assignments. Suppose *the horse ran past the barn* is followed by *it was very fast*. The most likely interpretation for this continuation is one in which *it* refers to the horse, but it could also refer

[2] This definition of "syntactic processing pathway" includes also low-level sensory processing together with phonetic, phonological and morphological aspects of the linguistic information processing. Morphological processing was included into the present study, phonetic and phonological processing were not.

to the barn, a third unmentioned entity, or to the whole event. When all referential expressions are provided with a denotation, we say that the sentence is provided with an *assignment*. Thus, under any particular assignment all referential expressions are assigned some denotation. Because expressions can denote several semantic objects, each sentence will typically have several possible assignments. An example of a legitimate assignment would be *the horse*$_1$ *ran past the barn*$_2$*; it*$_1$ *was very fast*, where the subscripts map into objects in the global discourse inventory.

When two referential expressions point to the same object (or more generally share their extensions) under some assignment, they stand in a *coreference* relation under that interpretation (e.g., *the horse* and *it* in the example just mentioned). If they point towards different semantic objects, we say that they are *disjoint* in reference. Expressions which are coreferential under all assignments are *necessarily coreferential*, and those which are disjoint under all assignments are *necessarily disjoint*. When the denotation of some expression must be coreferential with the denotation of some other expression under all assignments (notice the asymmetry in the description), we say that the latter constitutes an *antecedent* for the former.

Given these preliminaries we develop a hypothesis according to which binding restricts the way global discourse inventory is harvested for assignment generation.

Let us first assume that when processing incoming sentences the hearer allocates attentional resources to a set of semantic objects (semantic object = object in the global discourse inventory, to be distinguished from objects in the real world). We assume that the selected semantic objects are held in a temporary semantic working memory. It could contain mental representations of the horse, the barn and indeed anything mentioned in the ongoing conversation. Semantic objects that are under active processing are a subset of all objects in the global discourse inventory. When the conversation proceeds, some objects fade into background, others raise to the forefront.

Because language can modulate the contents of the semantic working memory, its contents must depend at least in part on the parsed output delivered by the syntactic processing pathway.[3] Intuitively we can think of linguistic communication as modulating or guiding the

[3] This process can be modulated by nonlinguistic processes and events, such as ostension, unanticipated external events or visual perception, ignored here. They play a major role in

allocation of attentional resources. Let us assume that at the time of processing some referential expression E the contents of the semantic working memory are constructed on the basis of (4) and (5).

(4) *Construction of the semantic working memory for expression E*

The semantic working memory contains a set of semantic objects accessed at the syntax-semantics interface from E by an *upward path* (5).

(5) *Upward path*

The *upward path* from E contains the nodes dominating E plus (the heads of) their immediate daughters.

A few clarifications concerning these assumptions are in order before proceeding. First, the semantic working memory is constructed on the basis of the syntax-semantics interface that has hierarchical structure; there is evidence that structure-dependent mechanisms limit antecedent search during language comprehension (e.g., Aoshima et al. 2009; Asher & Wada 1988; Clifton et al. 1997; Cunnings & Felser 2013; Cunnings & Sturt 2014; Dillon et al. 2013; Fedele & Kaiser 2014; Hankamer & Sag 1976; Kazanina et al. 2007; Koorneef & Reuland 2016; Nicol & Swinney 1989; Sturt 2003). Moreover, it does not matter for (4) what the syntax-semantic interface representations are, all that is required is that we have the notions of 'dominance' and 'immediate daughter' available. Finally, (5) posits a modular architecture in which syntax-internal representations and processes are prohibited from contributing directly to the construction of the semantic working memory.

The above principles contain an undefined term "referential expression." The assumption that all DPs belong to this class would be too broad, since DPs can also function in adverbial and predicate roles. We could also decide that other categories, such as CPs and NPs, can function as referential expressions. I assume that referential expressions are distinguished from the nonreferential ones by a lexical feature [Ref] (for 'referential') that must be located at the head of the referential phrase.

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psycholinguistic experimentation, however, and should on such grounds be included into some future model to better match the model with experimental observations.

Given (4−5) as background, we assume that any referential expression can be defined in the lexicon as denoting an object that is either included in or excluded from the semantic working memory.[4] The technical details are provided below, but to illustrate consider (6).

(6) a. He_{a} admires $\text{himself}_{a,*b}$.
    b. He_{a} admires $\text{John}_{*a,b}$.

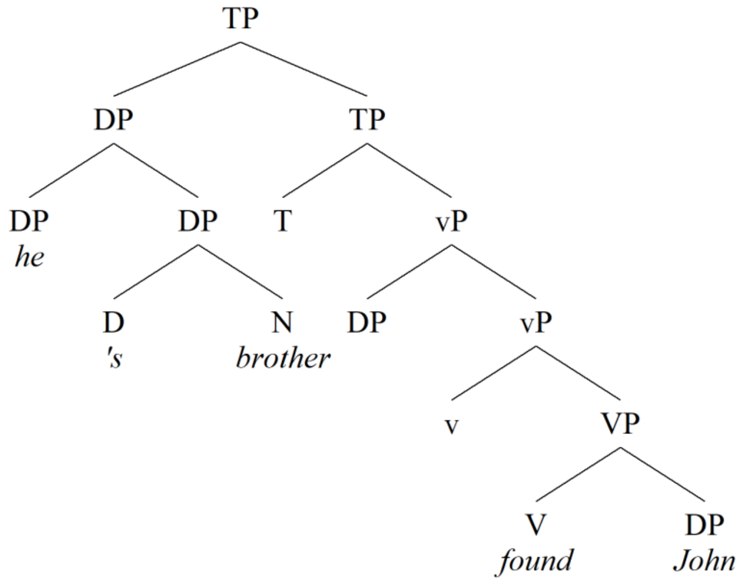
Let us assume that reflexive pronouns such as *himself* (6a) by definition require that their assignment is picked from the active semantic working memory. The upward path from the reflexive in (6a) contains only one referential expression *he*. It follows from (4−5) that under all assignments they must denote the same thing. Proper names and other r-expressions have the opposite property: they cannot denote anything in the active semantic working memory. This replicates the coreference relations marked in (6b). Consider then (7).

(7) $[\text{His}_{a}$ $\text{brother}]_{b}$ found $\text{John}_{a,*b,c}$.

The denotation of *his* is not included in the semantic working memory at the time when the language-cognition interface constructs assignments involving *John*. To see this, consider the syntactic analysis (8) of (7)(most of the details of this analysis are irrelevant to the main point).

[4] A slightly more general definition will be required to handle plurals and quantifiers, but they were excluded from the present study (and hence, from the dataset) since the focus was on binding. The topic is discussed briefly at the end of this article.

(8)



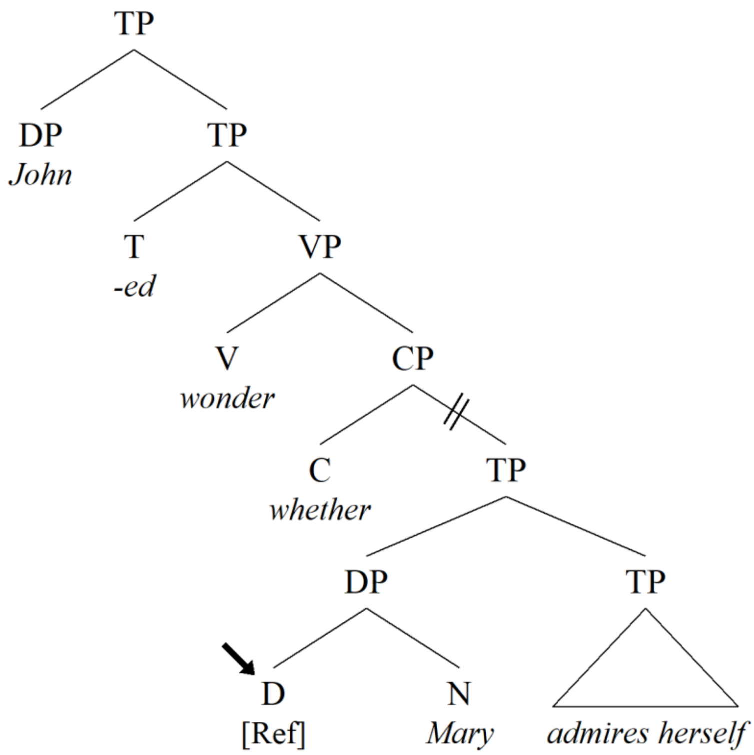
The upward path from *John* contains V, v, T and the D of the subject DP (independent of whether it is at SpecTP or SpecvP) but not the possessor *his*. According to (5), only the heads of the immediate constituents of the dominating nodes are included. *John* can therefore be assigned the same denotation as *he*. The facts for the reflexive are the opposite: [*his brother*] *found himself* can only mean that *his brother* and *himself* denote the same semantic object under all assignments.[5] Examples such as (9) are problematic, however.

(9) *John$_a$ wondered if Mary$_b$ admires only himself$_a$.

Both *John* and *Mary* are inside the upward path from the reflexive pronoun, which should be able to denote what *John* denotes. It is well-known that some binding restrictions are governed by locality. To incorporate locality into the model we assume that the semantic working memory construction can be limited by an *intervention feature*. For Finnish and English, [Ref] as defined above suffices for this role. As a consequence, the semantic working memory for the reflexive in (9) contains the representation of Mary but not John, since the lower DP (*Mary*) is headed by a D with an intervention feature [Ref](10).

[5] It should be clear from these examples that I intend to substitute the notion of c-command, a key concept defining the relevant notion of syntactic scope in many syntactic theories of binding, with the notion of upward path (5).

(10)



The idea that locality is defined in terms of a relativized intervention feature is not new. Several possible intervention features have been proposed in the literature (e.g., Manzini & Wexler 1987; Raposo 1986). Manzini and Wexler (1987) mention subject, Infl, tense, referential tense and root tense and propose that the matter is subject to crosslinguistic parametrization.[6] In addition, it will later be possible to model crosslinguistic variation by assuming a different feature, though all the data included into the present study, with only one possible exception discussed separately in Section 3.2.7, follow from the one intervention feature [Ref]. Let us coin the term *complete semantic working memory* to denote the whole semantic working memory, and the notion of *limited semantic working memory* to denote all semantic objects accessed by the upward path until an intervening head is encountered.

[6] Manzini & Wexler (1987) define locality by lexical features of the bound elements (e.g., r-expressions, reflexives, pronouns) which are in turn (i) drawn from a predefined set of features determined by the UG and (ii) organized hierarchically according to the Subset Principle (see Section 2 in their article). Property (i) is implemented in the present study by the assumption that the algorithm which interprets the said features is hardwired into the UG; questions of learnability that have to do with (ii) did not arise since the dataset required only one feature [Ref].

The above assumptions yield four possible binding configurations shown in Table 1, depending on whether (i) the denotation must be new or old with respect to the semantic working memory and whether (ii) the working memory is restricted by intervention.

Table 1. Four binding configurations created by whether (i) intervention is active and whether (ii) the semantic object must be present in the semantic working memory.

		Denotation in relation to semantic working memory	
		New	Old
Intervention	No	Antecedent cannot be in complete semantic working memory, Condition C (r-expressions)	Antecedent must be in complete semantic working memory (long distance reflexives?)
	Yes	Antecedent cannot be in limited semantic working memory, Condition B (pronouns)	Antecedent must be in limited semantic working memory Condition A (reflexives)

These four possibilities cover the standard binding conditions and one extra condition corresponding to long-distance reflexives (not attested in our dataset, but see below).

Some further assumptions are as follows. *Conversations* (which will be understood here in a special technical sense) are implemented by leaving the global discourse inventory intact between sentences. Contexts can therefore provide sentences with meanings (here, assignments) that they would not have had they occurred in isolation. Possible denotations are restricted further by phi-features: *he* can only denote male persons, *she* female persons. As a consequence, *John*$_1$ *met Mary*$_2$*; he*$_2$ *admires her*$_1$ is not a possible assignment. Gender, number, person and class (human, nonhuman) were used in this way in this study.

Let us consider some alternatives before testing the hypothesis. The main alternative is an analysis in which all/some coreference dependencies are calculated inside syntax (e.g., Chomsky 1977, 1980, 1981, 1982; Fiengo & May 1994; Hicks 2008, 2009; Hornstein 2001; Murphy and Meyase 2022; Reuland 2001, 2006, 2011; Rooryck & Wyngaerd 2011). Accordingly to these hypotheses, formal devices such as indices generated inside the syntactic processing pathway and/or syntactic operations such as Agree restrict assignments at the language-cognition interface and replace at least some (or all) of the lexical features and their effects defined in Table 1. The present analysis, in turn, is more in line with Levinson (1991), Jackendoff (1992), Chomsky (1995), Culicover & Jackendoff (1995), Schlenker (2005), Safir (2008) and Bruening (2021) who assume that binding regulates semantic interpretation at the "outer edge" of language. Syntax-internal theories of binding cannot, however, deny that assignments are calculated at the language-cognition interface: linguistic expressions must be able to "talk about" things that exist outside of language independent of how coreference relations are calculated.[7] What they can claim, however, is that the assignments are *constrained* by calculations inside syntax. The question then becomes what empirical data could distinguish between the two hypotheses. Several authors (e.g., Hicks 2008, 2009; Hornstein 2001; Reuland 2001) have argued that the syntactic theories can be motivated by the fact that binding follows syntactic constraints such as c-command and locality. Reuland (2001) observes that "since locality cannot be a characteristic of interpretive dependencies per se," delegating the conditions to an interpretative component "would only state the problem, rather than solve it" (p. 441). Hicks (2008) notes, correctly, that it would make sense to search for a theory of binding which relies on syntactic operations and principles that are "independently required in the framework" (p. 256), as this would make the overall theory more elegant. While legitimate concerns, these observations are weakened by the fact that semantic interpretation, while outside of syntax proper, can still see the endpoint of syntax.[8] (4–5) refer to structural, syntactic properties of the LF-interface. Moreover, while the reduction of independent theoretical assumptions constitutes a nonnegotiable goal of any rational inquiry, the unifying principles do not have to be restricted to syntax. I will return to this issue in Section 4.

[7] It might be a matter of some historical interest to note that while Chomsky (1981) assumed that the syntax-internal binding module regulates coreference – coreference being represented in that study by formal indices constrained by binding, among other factors – today most researchers who advocate for the syntax-internal view separate coreference as a broader semantic-pragmatic phenomenon from syntactic binding. The present model follows Chomsky (1981) in that binding is part of the larger coreference system, but adopts the view that it operates at the language-cognition interface and not inside syntax.

[8] What constitutes the 'endpoint of syntax' is a theory-dependent matter that will have an effect on the argument discussed in the main text. Questions such as whether the LF-interface (and semantic interpretation more generally) can see copies or other traces of narrow syntactic operations, whether prosodic features are represented as lexical/syntactic features at LF and whether some principles or rules apply both to syntax and to LF/semantic interpretations (as is the case here) have to be taken into account when evaluating the alternatives.

Table 1 predicts the existence of long-distance reflexives whose antecedents must be found from the complete semantic working memory. These elements were not attested in the present dataset. Long-distance reflexives are, however, a well-known phenomenon (e.g., Loss 2011; Pica 1987), so in this regard the proposed features do not seem to overgeneralize. The related notion of logophoricity (e.g., Baker & Ikawa 2024; Charnavel 2020, 2021; Clements 1975; Hellan 1988; Huang 2000a: Ch. 2.3; Sells 1987; Thráinsson 1990, 1991; see the various contributions in Koster & Reuland 1991), on the other hand, seems to require additional resources. Since they were not present in the data selected for investigation in this study, I leave the matter for future research.[9] It is also possible to have a referential expression that does not have either feature listed in Table 1. Such expressions do not impose restrictions on their assignment on the basis of (4–5). For example, *a man* can denote a clause-mate object (*John$_a$ saw a man$_a$ in the mirror*) as well as a third party (*John$_a$ saw a man$_b$*, *John$_a$ investigated if the police saw a man$_{a,b}$ on the crime scene*) while the behavior of quantified expressions (e.g., *every man likes one person/somebody*) does not fall under the categories defined in Table 1.

2 Methods

2.1 Procedure

The hypothesis together with the background assumptions (Section 1.2) were formalized and embedded inside computational infrastructure that determines by deductive calculation if the hypothesis together with its background assumptions suffice to entail the data.[10] The procedure

[9] Logophoricity refers to additional perspective-based semantic attributes such as 'salience', 'source', 'self' and 'point of view' (e.g., Sells 1987) that disambiguate antecedents. We could add such attributes to the global discourse inventory and invoke an additional lexical logophoric feature to guide antecedent selection by the said features. A mechanism of this type seems to be necessary on independent grounds since there is linguistic (Ariel 1990; Givón 1983; Grosz et al. 1995; Huang 2000b; Pollard & Sag 1992; Schlenker 2005; Sperber & Wilson 1995; Thráinsson 1991) and psycholinguistic (Almor 1999; Cunnings & Sturt 2014; Kazanina et al. 2007; Malt 1985; Murphy 1985a, b; Nicol & Swinney 2003; Parker 2019) evidence that assignment management utilizes context.

[10] Rigorous and unambiguous proof techniques constitute a methodological novelty in linguistics at the present writing but are assumed as a minimal requirement for justification in all advanced sciences. What linguists today report as justifications are what natural scientists call "discovery," namely the informal reasoning steps and intellectual debate undertaken by the author(s) and other researchers to arrive at a hypothesis or theory. This is a serious problem that hinders progress in the field by depraving it from one of the most essential features of the 17th century scientific method, the requirement that the data is shown to follow unambiguously (hence by "calculation") from the hypothesis or theory. Formal justifications of this type

examines all expressions in the dataset (described in Section 2.2) one by one and verifies whether they can be derived by the underlying grammar by considering all possible derivations.[11] If an expression can be derived, it is judged *grammatical*. If not, it is judged *ungrammatical*. If the grammaticality judgments predicted by the model match those provided by native speakers, the model is said to be *observationally adequate*. Any serious model has to satisfy the condition of observational adequacy, and there must exist a rigorous demonstration it does so.

Binding dependencies are provided in the input dataset together with the test sentences, which the algorithm matches with its own output. For example:

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John admires Bill
¦-> Binding: John[a] admire Bill[b]

he 's brother admires Bill
¦-> Binding: he[b] brother[a] admire Bill[b,c]

Bill said that John admires Tim
¦-> Binding: Bill[a] say John[b] admire Tim[c]
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The first sentence of each pair is a test sentence whose properties we want to predict, the second sentence describes coreference relations provided by a native speaker. The procedure will compare the predicted binding dependencies as determined by the computationally implemented hypothesis with the target dependencies listed above. If there are no prediction errors, the model is said to be *descriptively adequate*. Any serious candidate hypothesis must satisfy the condition of descriptive adequacy, and there must exist a demonstration that it does so. See Figure 1.

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completely replaced intellectual debate as the primary means for generating knowledge during the 17th century scientific revolution.

[11] This is accomplished technically by a recursive derivational search function which explores systematically all derivations as defined by any grammar and compares the output with a dataset (see Brattico 2024 for how to construct a simple derivational search function for any grammar in Python).

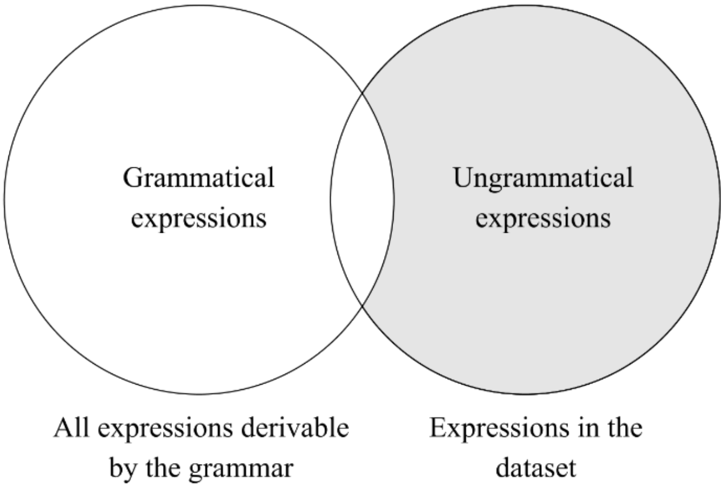

Figure 1. We verify that any expression E in the dataset is derivable from the grammar if and only if E is grammatical. For grammatical expressions, we verify that the binding configuration C for E is derivable from the grammar if and only if C is attested.

The algorithm writes all derivations into a *derivational log file*. If the model is observationally and descriptively adequate, the derivational log file can be said to constitute a *justification* for the hypothesis: a permanent storage of the calculations required to show that the data follows from the hypothesis. The study can be replicated by downloading the source code from the source code repository and by executing the master script. Instructions on how to do this, together with links to the original input/output files and to the source code, can be found from the supplementary document attached to this article.[12]

2.2 Data

The hypothesis was tested against a dataset (test corpus) that contains binding constructions, both grammatical and ungrammatical from Finnish and English. Some test sentences formed conversations (sequences of sentences with a shared global discourse inventory), others were isolated. The test sentences were selected to cover the core of the whole binding theory as discussed in the linguistic literature, but also special constructions exhibiting null subjects, DP-internal syntax, picture nouns, noncanonical word orders, filler-gap dependencies (both A- and Ā-chains) and embedded infinitivals. Test sentences were written into a file, normalized, and

[12] PERMANENT LINK

organized hierarchically. No morphosyntactic tagging was used apart from a few cases where the input item was disambiguated to reduce irrelevant derivations and to facilitate the examination of the output. When two or more sentences were assumed to be part of the same conversation, they were separated by a semicolon; otherwise, no special punctuation was used. The most important test constructions will be discussed in the results section of the present article; additional material can be found from the supplementary document. The dataset can be downloaded from the software repository.[13]

Finnish and English were targeted for modelling for several reasons. First, English was used for comparison since its binding properties are well-known, and it and its structure could be assumed to be understood by the majority of readers and hence presupposed when testing, illustrating and discussing the operation of the model. I will not, however, consider any new or otherwise controversial properties of English in this study. There were several reasons why Finnish was chosen as the second target language for modelling. First, at the time of designing the original study the author was not aware of any comprehensive study of Finnish binding, so there was a gap in the literature that the present study was designed to fill. Second, Finnish has several interesting properties when it comes to binding, among them the use of the so-called possessive suffix (a type of infinitival agreement) when creating reflexives and other types of binding or control configurations; use of bare noun phrases instead of obligatory articles in creating referential arguments; a partial pro-drop profile leading into a type of finite control that interacts with binding; and a discourse-configurational profile which leads into extensive use of scrambling (or an equivalent flexible displacement operation) and hence also to interesting issues that have to do with reconstruction. The proposed analysis provides an analytic solution for each of these issues. Finally, the baseline computational model has already been applied to Finnish by the present author, so I was able to build on an existing body of work.

[13]https://github.com/pajubrat/parser-grammar/blob/master/language%20data%20working%20directory/study-10-binding-theory/binding_theory_corpus.txt

2.3 Algorithm

2.3.1 Introduction

In this section I elucidate the main properties of the computational model of the human language faculty used in the testing. The section on baseline algorithm (Section 2.3.2) describes the model as it existed prior to this study, and is followed by a section (Section 2.3.3) describing how the hypothesis was implemented.

2.3.2 Baseline algorithm

The hypothesis described in Section 1.2 was added to an existing Python-based LPG ("linear phase grammar")(Brattico, 2019) which uses a left-to-right comprehension cycle to find derivations for input sentences and is consistent with the background assumptions elucidated in Section 1.1. LPG models language comprehension by extracting items from input sentences provided by the sensory systems in a (temporal) left-to-right order. Real life language comprehension as well as production – thus, almost all real linguistic processing – proceeds temporally from left to right ("left to right" referring to the temporal sequence). See Phillips (1996). The sentences are represented as linear sequences of phonological words and are picked automatically from the dataset (Section 2.2) for the computational experiment.

The algorithm maps the input sentences from the dataset (approximating and representing sensorimotoric items) into sets of PF-interface representations (*SM-PF mapping*) and then maps the latter into syntax-semantics interface representations (LF-interface representations) by utilizing what could be characterized as reverse-engineered transformations (*PF-LF mapping*). Both cyclic and noncyclic transformations are used.[14] PF-interface representations are considered shallow surface parses of the sensory inputs, while LF-interface representations correspond to "deep parses" cleaned and optimized after the application of several noise-tolerance operations, including reverse transformations. These mappings provide the input sentences with structural analyses (several if the input is ambiguous) and implement the syntactic processing pathway introduced in Section 1.2. PF- and LF-representations are based on the minimalist bare phrase structure. The LF-interface representations are mapped further

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[14] Cyclic transformation refers to a transformational mapping that is implemented incrementally as the input expression is being processed; noncyclic operations are applied to complete solutions (complete solutions in the sense of "phases" in the current model).

into semantic interpretations (*LF-SEM mapping*), which include the assignment mechanisms posited in Section 1.2. The mappings are summarized in (11).

(11) Sentence ~ PF-interface ~ LF-interface ~ Meaning ~ Cognition

——— Assignments ———

Mappings from the LF-interface into meanings into cognition (global discourse inventory) comprise the *language-cognition interface*. The PF-LF mapping is also called *transfer*. Notice that although the underlying implementation algorithm creates these mappings by reconstructing syntactic structures and meanings from derivatives of sensory inputs, hence it mimics language comprehension, the same mappings could be created by an inverse algorithm which maps meanings and syntactic structures into linear output strings. Mappings, unlike implementations, are directionless.

2.3.3 Implementation of the hypothesis

The global discourse inventory, which contains a set of semantic objects projected into existence during the conversation, was added to the model. The semantic objects were defined as "file-cards" (technically Python dictionaries) that may contain an arbitrary amount of information of any type concerning each object. Thus, when processing an input sentence *the horse ran past the barn* the algorithm creates file-cards for the horse and for the barn. The file-cards are filled with information as the conversation proceeds. In the current study only phi-features were used. Phi-features like [3rd person] and [singular] were translated into semantic attributes such as 'person: third' and 'number: singular'. These features play a role in the assignment mechanism by blocking coreference relations such as **John*$_a$ *admires herself*$_a$ (gender mismatch). The idea is based on the general style of analysis proposed by Heim (1982) and Kamp (1981) and then developed further by many others.[15]

Expressions such as *every man*, *nobody* or *two women* do not denote individual objects; rather, they denote sets of objects defined by further semantic criteria (e.g., 'being man/woman', 'every/two/no'). In addition, the assignment algorithm described in Section 1.2 presupposes that we have some way of constructing and storing the notion of 'possible denotation'. I

[15] Both approaches were preceded by Lauri Karttunen's work on discourse referents (Karttunen 1976).

therefore assumed that linguistic expressions at the LF-interface have abstract context-independent meanings and it is these meanings, rather than the expressions themselves, that are linked with the actual objects in the global discourse inventory. The intermediate layer hosting the linguistic meanings is called *narrow semantics*. We can think of narrow semantics as defining the intensions ('characteristics of objects') while the global discourse inventory defines the extensions ('actual objects, referents, extensions'). If we consider an expression like *he* as an example, it exists at the three levels as follows: at the level of syntax as a phrasal constituent [$_{DP}$ D N]; at the level of narrow semantics as a cluster of semantic attributes such as 'human', 'third person', 'singular', 'masculine' and possibly others, as determined by its formal lexical features; at the level of global discourse inventory as a (representation of a) particular person as provided by any given assignment, and which must have properties consistent with its narrow semantic attributes together with encyclopedic properties if any.

A function was then added for the construction of possible denotations for referential expressions in the context of the global discourse inventory, and another which generates all assignments from the denotations. These functions determine all possible ways all referential expressions in the input sentence can denote language-external things. Possible denotations were restricted by the phi-features. The upward path mechanism (5) already existed in the baseline algorithm; the semantic working memory mechanism was added by relying on the upward path (called *external search* at the level of implementation code). All possible assignments are generated, after which their plausibility is assessed by weighing them. Weights of assignments violating the binding principles were set to zero; the rest are weighted according to their pragmatic plausibility by drawing information from multiple sources (e.g., Asher & Wada 1988; Badecker & Straub 2002; Garrod & Sanford 1994; Kaiser 2011)(not modelled in this study).[16]

With these components at hand, the instructions described in Table 1 were added to the model: interpretation of each incoming referential expression may (i) require a new or old semantic object in relation to the contents of the SWM and (ii) have an optional intervention feature in

[16] The assumption that illegitimate assignments have zero weights instead of being deleted from the assignment stack was motivated by the existence of a variety of exempt anaphors in which (it seems to the present author) zero-weighted assignments are resurrected due to pragmatic reasons (see, for example, Pollard & Sag 1992). The same mechanism could apply to the reference shifting phenomenon discussed by Jackendoff (1992).

the construction of the relevant semantic working memory. The two options were represented by lexical features. If the features are absent, binding did not limit assignment generation.

3 Results

3.1 Observational adequacy

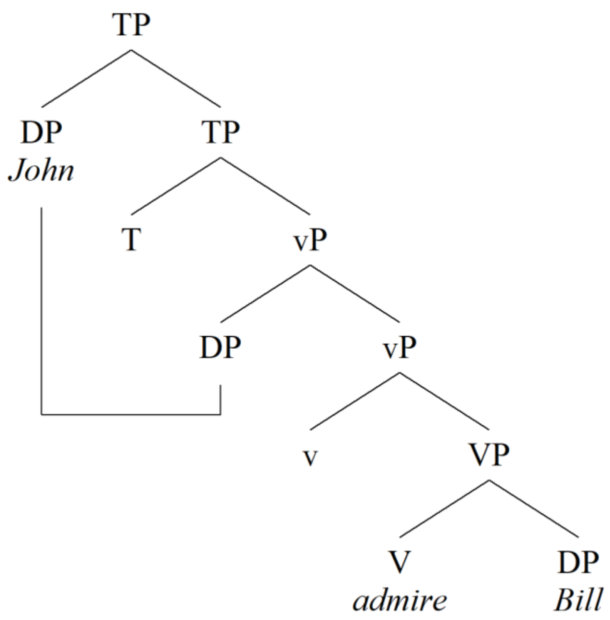
Testing the computational model against the dataset returned no errors in grammatical judgments. The model is therefore observationally adequate.

3.2 Descriptive adequacy

3.2.1 Deducing the binding conditions (English)

First we examine the formal deduction of the three binding conditions A, B and C (#items 1–9 in the dataset) by using examples from English.[17] Sentence *John admires Bill* (sentence #1 in the dataset) is mapped to the LF-interface representation (12) by the syntactic processing pathway, which, as assumed in Section 1.2, feeds assignment calculations.

(12)



[17] Notation #X–Y refers to the relevant examples in the dataset. The derivational log file, which contains the complete proof, will be referred to by using line numbers. Notation "lines 5780–5900" refers to the segment in the derivational log file beginning from line 5780 and ending with line 5900.

Notice that the phrasal chain (SpecTP, SpecvP) is implemented by reconstruction, not movement, as the algorithm produces LF-interface representations from the PF-interface representations (and, ultimately, from a linear sequence of words)(lines 59–60 in the derivational log file)(Section 2.3.2). Head chains are not visible in the phrase structure image, but they were recorded into the derivational log file. We ignore the syntactic left-to-right derivation, since binding works with (12)(the derivation is on lines 9–143 in the derivational log file). The semantic system executes the following calculations per the hypothesis defined in Section 1.2 (from the derivational log file). First, the following semantic objects corresponding to *John* and *Bill* are projected into existence:

```
149         Project object (1, QND) for [D John]
150         Project object (1, GLOBAL) for [D John]
151         Project object (2, QND) for [D Bill]
152         Project object (2, GLOBAL) for [D Bill]
```

QND refers to narrow semantics (Section 2.3.3), GLOBAL to the global discourse inventory (Section 1.2); for most purposes we can focus on the latter. *John* is linked with its semantic interpretation inside narrow semantics (QND object) and to an object – a person – in the global discourse inventory (GLOBAL object). It is indexed by [1] as shown by lines 149–150. That object has properties such as 'singular', 'male' and 'human'. The same thing is done for *Bill* (lines 151–152, index [2]).[18] As a consequence, the global discourse inventory contains two spatiotemporal objects John and Bill (i.e., the corresponding file-cards; it does not matter if any actual persons assumed to correspond to these representations exist):

[18] The hearer also assumes that the sentence denotates an event, but we ignore events in this study; they are visible in the derivational log file as additional semantic objects.

```
        Object [D John](1) ['$Thing'] in GLOBAL
            Class: human
            Constituent: D
            Gender: m
            Number: singular
            Person: third
            Reference: [D John]
            Referring constituent: D
            Semantic space: GLOBAL
            Semantic type: $Thing
        Object [D Bill](2) ['$Thing'] in GLOBAL
            Class: human
            Constituent: D
            Gender: m
            Number: singular
            Person: third
            Reference: [D Bill]
            Referring constituent: D
            Semantic space: GLOBAL
            Semantic type: $Thing
```

`$Thing` refers to the semantic type (persons are 'spatiotemporal things'). Both referential expressions *John* and *Bill* are then provided with a set of possible assignments in relation to what is in the global discourse inventory. Since there are two objects, both expressions can denote two objects (lines 165–166).[19] Numbers [1] and [2] refer to the indices of the corresponding objects which identify them. Next, both expressions are provided with a set of possible denotations

```
164    Denotations:
165        [D John]~['1', '2']
166        [D Bill]~['1', '2']
```

where the numbers refer to the indices of the objects in the global discourse inventory. Based on this input the model generates the set of possible assignments:

```
    Assignments:
        Assignment [D John] ~ 1, [D Bill] ~ 1 -
        Assignment [D John] ~ 1, [D Bill] ~ 2 +
        Assignment [D John] ~ 2, [D Bill] ~ 1 +
        Assignment [D John] ~ 2, [D Bill] ~ 2 -
        Summary:  John[a] admire Bill[b]
```

[19] Why would *John* denote Bill and vice versa? While 'having the name *John*' could be a property of semantic objects and real world entities, that object can be denoted in principle by any referential expression, even by *Bill*. For example, John's nickname could be *Bill*. Proper names of persons can also be used to denote the statues of the said persons and other related entities (Jackendoff 1992).

After the calculation of possible denotations the algorithm creates assignments and only accepts two in which *John* and *Bill* refer to two different objects (line 172). There are two possible interpretations: one where *John* denotes John and *Bill* denotes Bill, and another where *John* denotes Bill and *Bill* denotes John (+ at the end of the line means that the assignment was accepted; – means it was rejected). This is summarized on line 172, where the subscripts *a* and *b* signal that the denotations are necessarily disjoint (these subscripts are for illustration only; no such formal objects appear anywhere in the syntactic or semantic representations). Specifically, the denotations available for *Bill* do not include objects accessed by semantic working memory, therefore it must be disjoint from any object that *John* denotes under all assignments. All processing steps shown above are external to syntax and created inside the semantic processing pipeline. Based on informal eyeballing we can therefore claim that the model produced the correct output; to produce a proof we define the correct binding dependencies also in the dataset, as shown below,

```
John admires Bill
¦-> Binding: John[a] admire Bill[b]
```

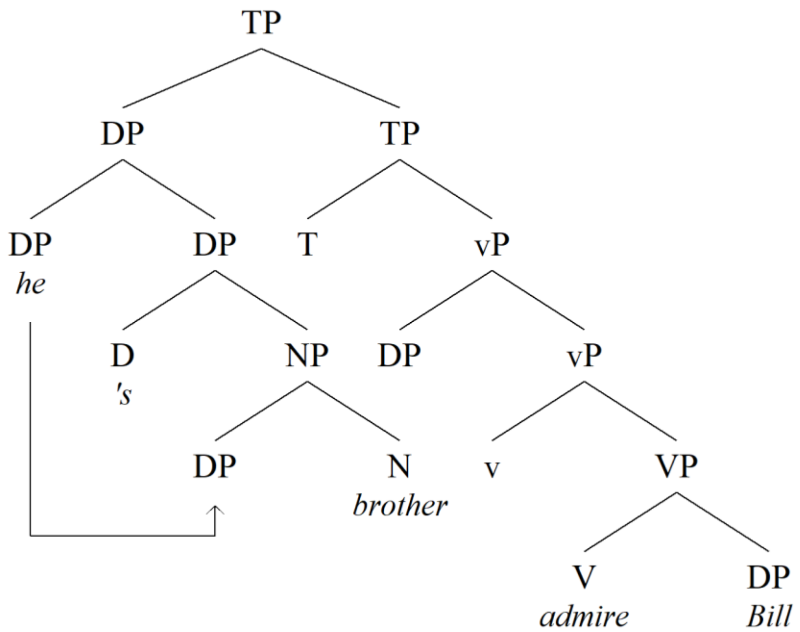
and compare the output mechanically with native speaker output as specified above. This verifies in a rigorous sense that the model predicted the properties of the input expression(s) correctly.

Next we test the model with further examples specifically tailored to bear on the research hypothesis. To this end the dataset contains three expressions which test Condition C-effects that regulate assignment dependencies for r-expressions such as proper names. They are as follows (from the input dataset, # = comment):

```
# Condition C

    John admires Bill
    ¦-> Binding: John[a] admire Bill[b]

    he `s brother admires Bill
    ¦-> Binding: he[b] brother[a] admire Bill[b,c]

    Bill said that John admires Tim
    ¦-> Binding: Bill[a] say John[b] admire Tim[c]
```

The first item, which was already discussed, tests referential disjointness. The second tests the upward mechanism: we expect *Bill* to be coreferential under some assignment with *his* in sentence *his brother admires Bill* because it is not inside SWM when the assignments are generated for *Bill*. These claims presuppose an analysis of *his brother*. The syntactic processing pathway provides it with the analysis (13), where the possessive '*s* represents D (line 1133).

(13)



The pronoun *his* (*he* + '*s*) is reconstructed from SpecDP to SpecNP where it gets an NP-internal thematic role from N. Whether this reconstruction step takes place and whether N is the source of NP-internal thematic roles is inessential; what matters instead is that *his* is not inside the upward path calculated from *Bill*. The model projects three objects corresponding to *he*, *his brother* and *Bill* into the global discourse inventory and finds 12 legitimate assignments:

```
1320        Assignments:
1321            Assignment [[D he] ['s [[D he] brother]]] ~ 1, [D he] ~ 1, [D Bill] ~ 1 -
1322            Assignment [[D he] ['s [[D he] brother]]] ~ 1, [D he] ~ 1, [D Bill] ~ 2 -
1323            Assignment [[D he] ['s [[D he] brother]]] ~ 1, [D he] ~ 1, [D Bill] ~ 3 -
1324            Assignment [[D he] ['s [[D he] brother]]] ~ 1, [D he] ~ 2, [D Bill] ~ 1 -
1325            Assignment [[D he] ['s [[D he] brother]]] ~ 1, [D he] ~ 2, [D Bill] ~ 2 +
1326            Assignment [[D he] ['s [[D he] brother]]] ~ 1, [D he] ~ 2, [D Bill] ~ 3 +
1327            Assignment [[D he] ['s [[D he] brother]]] ~ 1, [D he] ~ 3, [D Bill] ~ 1 -
1328            Assignment [[D he] ['s [[D he] brother]]] ~ 1, [D he] ~ 3, [D Bill] ~ 2 +
1329            Assignment [[D he] ['s [[D he] brother]]] ~ 1, [D he] ~ 3, [D Bill] ~ 3 +
1330            Assignment [[D he] ['s [[D he] brother]]] ~ 2, [D he] ~ 1, [D Bill] ~ 1 +
1331            Assignment [[D he] ['s [[D he] brother]]] ~ 2, [D he] ~ 1, [D Bill] ~ 2 -
1332            Assignment [[D he] ['s [[D he] brother]]] ~ 2, [D he] ~ 1, [D Bill] ~ 3 +
1333            Assignment [[D he] ['s [[D he] brother]]] ~ 2, [D he] ~ 2, [D Bill] ~ 1 -
1334            Assignment [[D he] ['s [[D he] brother]]] ~ 2, [D he] ~ 2, [D Bill] ~ 2 -
1335            Assignment [[D he] ['s [[D he] brother]]] ~ 2, [D he] ~ 2, [D Bill] ~ 3 -
1336            Assignment [[D he] ['s [[D he] brother]]] ~ 2, [D he] ~ 3, [D Bill] ~ 1 +
1337            Assignment [[D he] ['s [[D he] brother]]] ~ 2, [D he] ~ 3, [D Bill] ~ 2 -
1338            Assignment [[D he] ['s [[D he] brother]]] ~ 2, [D he] ~ 3, [D Bill] ~ 3 +
1339            Assignment [[D he] ['s [[D he] brother]]] ~ 3, [D he] ~ 1, [D Bill] ~ 1 +
1340            Assignment [[D he] ['s [[D he] brother]]] ~ 3, [D he] ~ 1, [D Bill] ~ 2 +
1341            Assignment [[D he] ['s [[D he] brother]]] ~ 3, [D he] ~ 1, [D Bill] ~ 3 -
1342            Assignment [[D he] ['s [[D he] brother]]] ~ 3, [D he] ~ 2, [D Bill] ~ 1 +
1343            Assignment [[D he] ['s [[D he] brother]]] ~ 3, [D he] ~ 2, [D Bill] ~ 2 +
1344            Assignment [[D he] ['s [[D he] brother]]] ~ 3, [D he] ~ 2, [D Bill] ~ 3 -
1345            Assignment [[D he] ['s [[D he] brother]]] ~ 3, [D he] ~ 3, [D Bill] ~ 1 -
1346            Assignment [[D he] ['s [[D he] brother]]] ~ 3, [D he] ~ 3, [D Bill] ~ 2 -
1347            Assignment [[D he] ['s [[D he] brother]]] ~ 3, [D he] ~ 3, [D Bill] ~ 3 -
1348            Summary:  he[b] brother[a] admire Bill[b,c]
```

All 3 x 3 x 3 = 27 possible assignments for referential expressions *he, his brother* and *Bill* appear here. For example, there is a reading '[his$_a$ brother]$_a$ admires Bill$_a$' (line 1321) denoting a man named Bill who is his own brother and admires himself but which is ruled out by two binding principles: neither *Bill* nor *his* can corefer with *his brother*. The final test in the three basic test sentences for Condition C is *Bill*$_a$ *said that John*$_b$ *admires Tim*$_c$ (#3), which establishes that both the local and nonlocal referential expressions are inside the upward path from *Tim*. The proof can be found from lines 1577–2129 in the derivational log file.

Next we verify that the facts for reflexive pronouns are the opposite. The test set contains the following three sentences:

```
# Condition A

    John admires himself
    ¦-> Binding: John[a] admire self[a]

    he `s brother admires himself
    ¦-> Binding: he[b] brother[a] admire self[a]

    Bill said that John admires himself
    ¦-> Binding: Bill[a] say John[b] admire self[b]
```

The model calculates these items without errors (lines 2130–4322). One detail worth mentioning is the syntactic analysis of the English reflexive pronoun. The syntactic processing pipeline parses it as $[_{DP}$ D N] where the reflexive feature, requiring an old object in the context of the semantic working memory, is inside D. Coreference between *Bill* and *himself* is blocked by [Ref] of the subject *John* of the embedded finite clause (14).

(14) Bill_a said that John_b admires himself_{*a}

Condition B-effects are tested in the same way:

```
# Condition B

    John admires him
    ¦-> Binding: John[a] admire he[b]

    he `s brother admires him
    ¦-> Binding: he[b] brother[a] admire he[b,c]

    Bill said that John admires him
    ¦-> Binding: Bill[a] say John[b] admire he[a,c]
```

Their properties are calculated correctly, the proofs are in the derivational log file (lines 4234–6370). In sum, the basic binding properties follow from the hypothesis, and there is a formal proof that this is the case.

3.2.2 Conversations

Conversations are linearly ordered sequences of sentences which share the global discourse inventory. They are created by a semi-colon at the end of the sentence, which causes the next sentence to be interpreted as being part of the same conversation. For example, *John admires Mary*; *he admires her* is an acceptable conversation.[20] To verify that the mechanism works correctly, the nine test sentences above were embedded inside conversations where another person is mentioned in a prior sentence (sentences #10–43 in the dataset). For example:

---

[20] Only the global discourse inventory is shared between the sentences of the same conversation. Syntactically each sentence is an isolated and independent construction. When creating assignments for *he admires her* the model sees the semantic objects John and Mary in the global discourse inventory but does not see the LF-interface representation created for *John admires Mary*. Neither *John* nor *Mary* are in the upward paths calculated for the pronouns *he* and *she*.

```
& 2.1 Condition C

    Tim;
    John admires Bill
    ¦-> Number of assignments: 6

    Tim;
    he `s brother admires Bill
    ¦-> Number of assignments: 36

    Tim;
    Bill said that John admires Tim
    ¦-> Number of assignments: 24
```

A single DP *Tim* was used as a context to make the tests as simple as possible; any number of preceding sentences of any complexity may be used.[21] These data verify that the model generates correct amount of assignments, much more than if the global discourse inventory were empty when processing the second sentence. For example, the processing of *John admires Bill* generates the following assignments if the global discourse inventory contains Tim:

```
Assignments:
    Assignment [D John] ~ 1, [D Bill] ~ 1 -
    Assignment [D John] ~ 1, [D Bill] ~ 3 +
    Assignment [D John] ~ 1, [D Bill] ~ 4 +
    Assignment [D John] ~ 3, [D Bill] ~ 1 +
    Assignment [D John] ~ 3, [D Bill] ~ 3 -
    Assignment [D John] ~ 3, [D Bill] ~ 4 +
    Assignment [D John] ~ 4, [D Bill] ~ 1 +
    Assignment [D John] ~ 4, [D Bill] ~ 3 +
    Assignment [D John] ~ 4, [D Bill] ~ 4 -
    Summary: John[b] admire Bill[c]
```

Both names have three possible interpretations (the numbers in the assignment table refer to the numbers in the global discourse inventory, e.g., [1] = Tim, [3] = John, [4] = Bill, lines 6702–6811). Condition A (#16–22) and Condition B (#23–27) sentences were tested in the same way as pronoun sequences such as *Tim; he admires him* (#28–37).

[21] The outputs of these tests are evaluated against the number of assignments, not the assignments themselves. The subscript notation used in all other items does not take context into account, thus it is not possible to create target bindings such as $John_{a,c}$ *admires* $Bill_{b,c}$ where *c* indexes a contextual entity (e.g., Tim). This output would not even be correct, since it states that *John* and *Bill* could refer to Tim under some assignment. Actual assignments must be verified manually from the derivational log file or they must be listed explicitly in connection with the items in the dataset.

3.2.3 Binding conditions A-C in Finnish

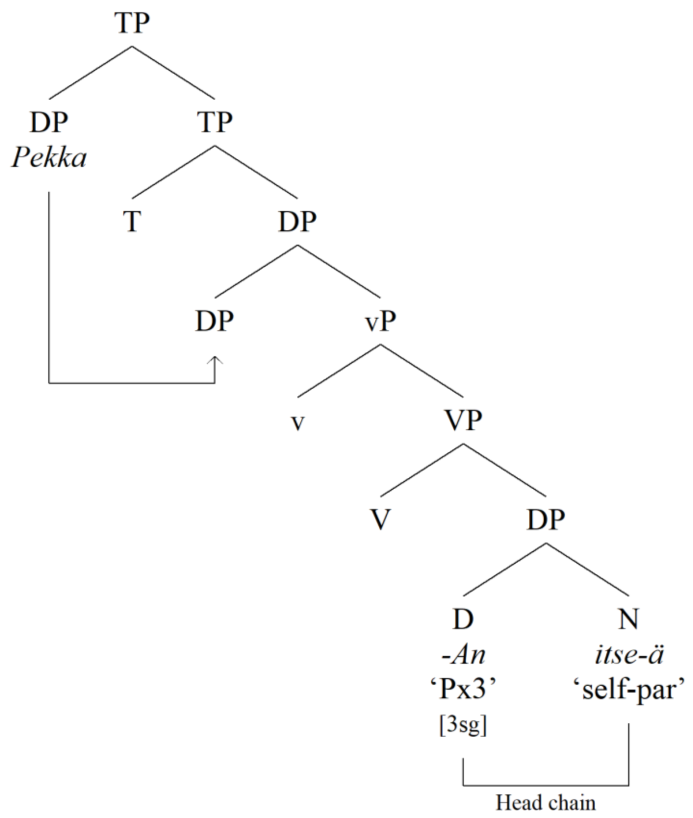
In this section we examine Conditions A-C in Finnish, beginning with the Condition A reflexive shown in (15).[22]

(15) Pekka$_{a}$ ihaile-e itse-ä-än$_{a,*b}$. (#44)
Pekka.NOM admire-PRS.3SG self-PAR-PX3
'Pekka admires himself.'

The Finnish reflexive contains a SELF-pronoun *itse* 'self' suffixed with an optional possessive suffix that must match with the antecedent in person and number. There is some controversy over the syntax of the Finnish possessive suffix (e.g., Holmberg 2021; Huhmarniemi & Brattico 2015; Kaiser 2003; Kanerva 1987; Pierrehumbert 1980; Toivonen 2000; Trosterud 1990, 1993; Vainikka 1989; van Steenbergen 1987, 1991). In the baseline computational model the possessive agreement suffixes map into valued phi-features of the head they are attached to. If *itse* 'self' is analyzed as a full phrasal pronoun, then *itse-ä-än* 'self-PAR-PX3' will be analyzed as [$_{DP}$ D$_{[3P, REF]}$ N] where D will have the third person feature [3P] generated from the possessive suffix (assuming, for simplicity, that all Finnish noun phrases project DPs; see below for a further detail concerning this assumption). This restricts the type of denotations the reflexive pronoun can have. If the phi-features of the reflexive and the antecedent do not match, the coreference reading is ruled out from all assignments (e.g., **Pekka ihailee itse-ä-*<u>*ni*</u> 'Pekka admires self-PAR-PX1SG). Given these assumptions about the possessive suffix, commented further at the end of this section, (15) will be analyzed as (16).

[22] Abbreviations: 1/2/3 = first, second and third person; A/INF = A-infinitival; ACC = accusative case, any form; GEN = genitive case; NOM = nominative case; PAR = partitive case; PL = plural; PST = past tense; PRS = present tense; PX = possessive suffix; Q = yes/no interrogative operator; REF = referential, a feature that all referential expressions have; SG = singular; VA/INF = VA-infinitival.

(16)



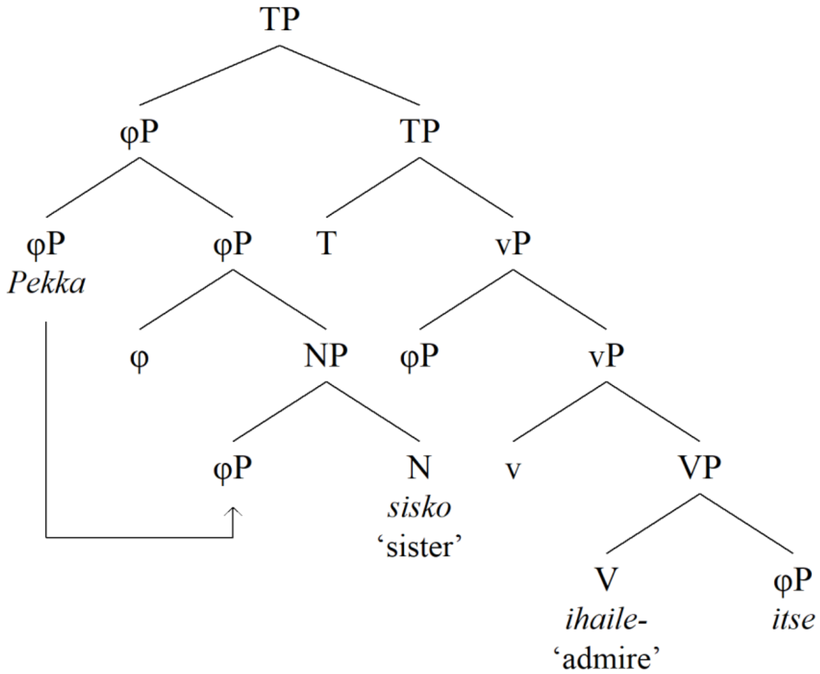
The possessive suffix -*An* 'PX3', which is analyzed as an inflectional agreement marker suffixed to D and not as a phonological exponent of the D-head itself, creates a feature set [3SG] inside D which restricts the denotations of the DP. D and N are linked by a head chain. Running the model with this input (lines 21570–21897) provides the correct reflexive profile (15):

```
21731      Assignments:
21732          Assignment [φ Pekka] ~ 1, [φ itse] ~ 1 +
21733          Assignment [φ Pekka] ~ 1, [φ itse] ~ 2 -
21734          Assignment [φ Pekka] ~ 2, [φ itse] ~ 1 -
21735          Assignment [φ Pekka] ~ 2, [φ itse] ~ 2 +
21736          Summary:  Pekka[a] ihaile- itse[a]
```

Next we want to replicate the two other tests performed with the English reflexive. The analysis provided for the test sentence (17) is (18).

(17) [Peka-n$_{a}$ sisko]$_{b}$ ihaile-e itse-ä-än$_{*a,b}$. (#45)
Pekka-GEN sister.NOM admire-PRS.3SG self-PAR-PX3
'Pekka's sister admires himself/*herself.'

(18)



A new property shown here is the analysis of Finnish noun phrases as φPs ("phi-phrases"), not full DPs. φPs are minimal referential noun phrases, φ being a "weak" D-element. This has to do with the fact that Finnish does not have obligatory articles, a matter I discuss in some more detail in Section 3.9. However, φPs and DPs have the same status with respect to binding (φ likewise has [Ref]). Given these preliminaries, there are no assignments in which the reflexive is coreferential with the *Pekka*, while it must be coreferential with Pekka's sister (*Pekka* is outside of the semantic working memory of the reflexive, while *Pekka's sister* is inside)(lines 22768–22820). The locality of Condition A was tested by (19). Binding dependencies were calculated correctly.

(19)	Pekka$_a$	sano-i	että	Merja$_b$	ihaile-e	itse-ä-än$_{*a,b}$. (#46)
	Pekka.NOM	say-PST.3SG	that	Merja.NOM	admire-PRS.3SG	self-PAR-PX3

'Pekka$_1$ said that Merja$_2$ admires herself$_2$/*himself$_1$.'

Condition B and Condition C tests were performed by using the constructions shown in (20) and (21) where the correct calculated coreference relations are marked by subscripts.

(20)	a.	Pekka$_a$	ihaile-e	hän-tä$_{*a,b}$.	(#47)	
		Pekka.NOM	admire-PRS.3SG	he-PAR		

'Pekka admires him.'

b.	Peka-n$_a$	sisko$_b$	ihaile-e	hän-tä$_{a,*b,c}$.	(#48)

Pekka-GEN sister.NOM admire-PRS.3SG he-PAR
'Pekka's sister admires him.'

c. Pekka$_{a}$ sano-i että Merja$_{b}$ ihaile-e hän-tä$_{a,*b,c}$.(#49)
Pekka.NOM say-PST.3SG that Merja.NOM admire-PRS.3SG he-PAR
'Pekka said that Merja admires him.'

(21) a. Pekka$_{a}$ ihaile-e Merja-a$_{b}$. (#50)
Pekka.NOM admire-PRS.3SG Merja-PAR
'Pekka admires Merja.'

b. Peka-n$_{a}$ sisko$_{b}$ ihaile-e Pekka-a$_{a,*b,c}$. (#51)
Pekka-GEN sister.NOM admire-PRS.3SG Pekka-PAR
'Pekka's sister admires Pekka.'

c. Pekka$_{a}$ sano-i että Merja$_{b}$ ihaile-e Pekka-a$_{c}$.(#52)
Pekka.NOM say-PST.3SG that Merja.NOM admire-PRS.3SG Pekka-PAR
'Pekka said that Merja admires Pekka.'

As pointed out above, this analysis depends on certain specific assumptions concerning the possessive suffix. The assumption that the possessive suffix expresses valued phi-features much like finite agreement (e.g., Anderson 2005: 235–239; Huhmarniemi & Brattico 2015; Karlsson 1977; Vainikka 1989; van Steenbergen 1991) is one possible analysis among others.[23] That being said, that assumption plays only a minor role because the binding-theoretical profile of the Finnish reflexive pronoun comes almost in its entirety from its lexical feature specification elucidated in Section 1.2; the possessive suffix only limits the denotations further by matching the possessive phi-features with the semantic features of the objects in the global

[23] A further noteworthy fact is that the possessive occurs in many other grammatical environments besides reflexives (e.g., prepositions *minun lähellä-ni* 'my near-PX', nouns *minun koira-ni* 'my dog-PX', infinitives *uskon lähtevä-ni* 'believe.1SG leave.VA/INF-PX', adjectives *ostama-ni koira* 'bought-PX dog'; see Kanerva (1987). The binding possibilities for the SELF + PX construction and for the possessive suffix PX alone are not the same (Trosterud 1990: 2.1.2; Vainikka 1989: 196–197, 213–216). The possessive can be analyzed as its own anaphoric possessive head or pronoun (Holmberg 2021; Trosterud 1993; Vainikka 1989), an infinitival agreement marker that licenses pro-drop (Brattico, 2017; Brattico & Huhmarniemi 2016; Huhmarniemi & Brattico 2015; Kaiser 2003; van Steenbergen 1989, 1991) or both (Toivonen, 2000).

discourse inventory. Thus, *itse-ä-ni* 'self-PAR-PX1SG' can only refer to first person singular objects. See Section 3.2.4. If the possessive suffix is removed, that restriction is lifted (#89–96):

(22) a. Pekka$_a$ ihail-i itse-ä$_a$. (#94)
Pekka.NOM admire-PST.3SG self-PAR
'Pekka admired himself.'

b. Minä$_a$ ihail-i-n itse-ä$_a$. (#93)
I.NOM admire-PST-1SG self-PAR
'I admired myself.'

The proofs are on lines 52249–54940. The crucial assumption concerning the possessive suffix is that the phi-features expressed by the suffix – in whichever way the possessive is represented inside the noun phrase – must end up in the head which regulates denotations. For example, if the possessive suffix projects a separate possessive head Px^0, as assumed in some models such as Holmberg (2021) and Trosterud (1993), the assignment algorithm must see that head and its features so that the denotations are restricted correctly.[24]

3.2.4 Restrictions on denotations and antecedents

So far all referential expressions used in the computational testing had similar feature compositions in that they referred to singular third person objects normally presupposed to be men (John, Tim, Bill). When processing *John admires Bill*, two objects were projected into the global discourse inventory while both names could denote both objects as long as the denotations were disjoint under all assignments. The situation changes with *John admires it*. While two separate objects John and it must still exist in the inventory, most speakers/contexts rule out an interpretation in which *it* refers to John. This restriction is first represented as a lexical feature [HUM:NONHUM] in the lexical entry of the nonhuman pronoun and is then translated into a semantic class attribute 'nonhuman' that characterizes objects in the global discourse inventory. The model takes these limitations into account when creating denotations.

[24] The antecedents of reflexives as far as their phi-features are concerned are restricted not by syntactic binding or agreement relations (e.g., Agree) but by limitations on denotations. The language-cognition interface therefore creates its own 'agreement system'. What sets this agreement system apart from syntactic agreement dependencies is that it extends beyond clause boundaries. It remains to be examined if and to what extent it could supplement or even replace the syntactic agreement mechanism (operation Agree in the minimalist theory).

These mechanisms were tested by expressions in the dataset verifying gender, number, person and class (human, nonhuman) mismatches in English and Finnish (#62−100). Restrictions based on semantic attributes were tested by using input data such as

```
John admires him
¦-> Number of assignments: 2

John admires her
¦-> Number of assignments: 1
```

which verify that the model is not creating too few or too many assignments.[25] Specifically, *John admires her* can only generate one assignment, since *John* cannot denote her while *her* cannot denote John due to gender mismatch. Finnish third person pronouns are gender-neutral and generate two assignments independent of whether they are used in connection with male or female arguments. Since the issue is linguistically quite trivial (with one possible exception examined below) I do not examine the experiments here in detail; see the output data for items #62−100. Since the error files were empty, we know that the sentences produce correct outputs.[26]

One special case merits discussion. We have assumed that possible denotations are restricted by phi-features and the corresponding object attributes. Not all referential expressions, however, need to define all attributes. Finnish third person pronouns *hän*/*he* 'he/they', for example, are gender-neutral. When they are mentioned during a conversation, the gender attribute of the underlying semantic object remains undefined. However, the assignment management component may later create an assignment *Merja*$_1$ which disambiguates gender by declaring that *hän* 's/he' is coreferential with a female person (Finnish proper name *Merja*

[25] The actual assignments were verified from the derivational log file. It is possible to verify the data mechanically, though the data items would be quite complex.
[26] Sentences such as *John admires herself* or *Mary admires himself* are judged grammatical but return zero assignments, according to current assumptions. In both cases the global discourse inventory contains two objects, but there are no suitable objects in the semantic working memory when the assignments for the reflexives are calculated, hence no assignments. The fact that these sentences are judged grammatical is arbitrary, however. We assume so in order to distinguish syntactic problems (represented by grammaticality) from semantic problems (represented by the number of assignments). An alternative is to judge sentences without assignments ungrammatical. The Finnish reflexive has no gender feature, hence the corresponding sentences generate two assignments (#66–69).

is specified as [GEN:F] in the lexicon). If we ignore this mechanism, some illicit assignments, such as those illustrated in (23), will be generated.

(23) Hän$_a$ oli rikas. [Peka-n$_a$ sisko]$_b$ ihaile-e Merja-a$_a$.
S/he was rich. Pekka-GEN sister.NOM admire-PRS.3SG Merja.PAR
'S/he was rich. Pekka's sister admires Merja.'

Under this assignment *Pekka* and *Merja* denote the person introduced by *hän* 's/he'. This remains true even if Pekka is classified as a male, Merja female: their coreference relation is "mediated" by the gender-neutral third object denoted by *hän*$_a$. We can avoid this problem by verifying not only that the phi-features of referential expressions do not mismatch with the semantic attributes of their denotations, but that they do not mismatch with the attributes of any other expression denoting the same thing under that particular assignment. This additional internal consistency check, as I will call it, is part of the assignment algorithm. Sentences #38–43 test this condition explicitly.

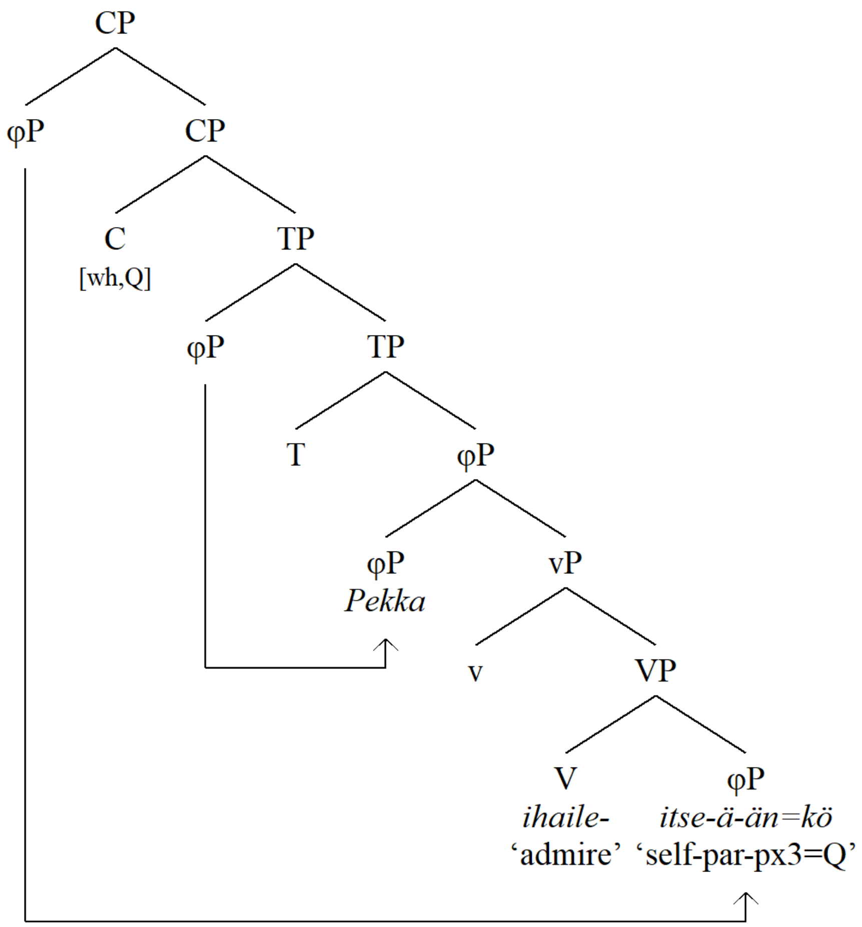
3.2.5 Reconstruction

Binding is said to reconstruct for movement if it is determined on the basis of the input and not output conditions (using movement as a descriptive framework). Finnish binding reconstructs for both Ā-movement (24a) and scrambling (24b).

(24) a. Itse-ä-än=kö$_{a,*b}$ Pekka$_a$ ihaile-e __$_1$? (#101)
self-PAR-PX3=Q Pekka.NOM admire-PRS.3SG
'Does Pekka admire himself?'
b. Itse-ä-än$_{a,*b}$ ihaile-e Pekka$_a$. (#104)
self-PAR-PX3 admire-PRS.3SG Pekka.NOM
'(Who admires himself?) It is Pekka who admires himself.'

Reconstruction for Ā-movement and scrambling follows from the fact that the assignment calculations target the syntax-semantic interface. At that linguistic level all head and phrasal constituents are at their thematic base-generated positions. Consider the syntactic analysis of (24a) as calculated by the syntactic processing pathway[27]:

(25)



The reflexive is suffixed with the yes/no question clitic =*kO*, which forces it to occupy the SpecCP position and triggers Ā-chain reconstruction inside the syntactic processing pipeline (Brattico 2021a; Holmberg 2013, 2016; Huhmarniemi 2012). Assignment calculations then find the reflexive at CompVP, which creates the binding dependencies shown in (24a).[28]

---

[27] The calculations of Ā-chains assumed here were first described by Brattico & Chesi (2020), which was based on data and observations by Huhmarniemi (2012).

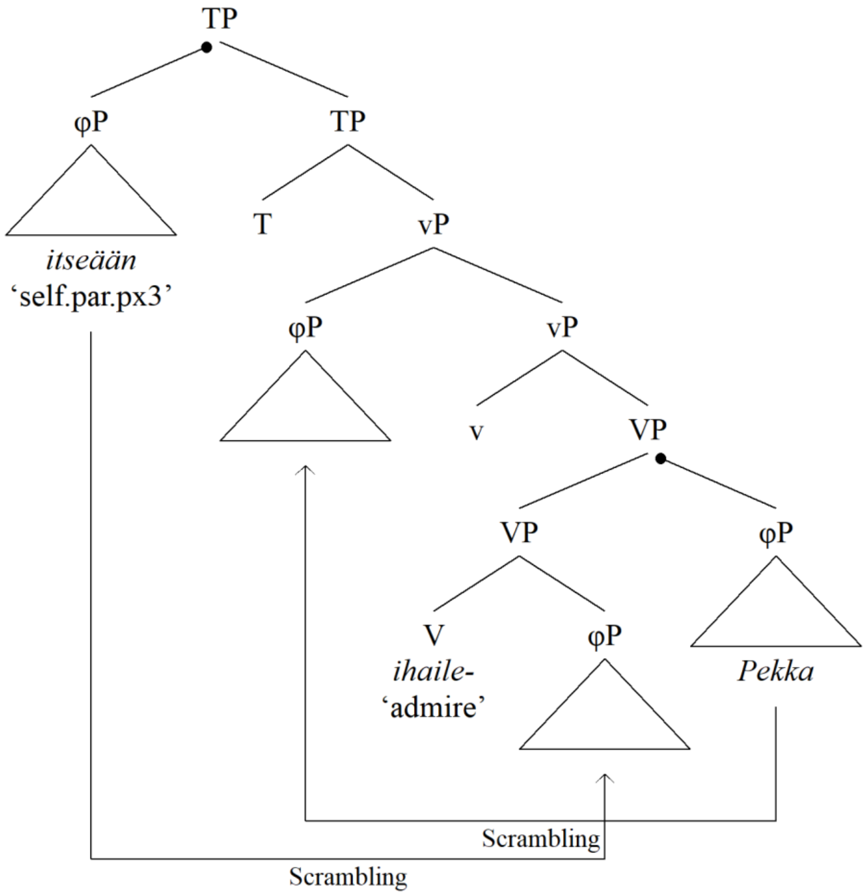
[28] It is presupposed that other copies, although they are present at the LF-interface, are disregarded. They do not receive independent denotations and are invisible for assignment calculations.

```
        Assignment [φ Pekka] ~ 1, [φ-kO itse] ~ 1 +
        Assignment [φ Pekka] ~ 1, [φ-kO itse] ~ 2 -
        Assignment [φ Pekka] ~ 2, [φ-kO itse] ~ 1 -
        Assignment [φ Pekka] ~ 2, [φ-kO itse] ~ 2 +
        Summary:  Pekka[a] ihaile- itse[a]
```

The scrambling reconstruction (24b) is captured in the same way by supplying the assignment calculations with LF-interface representations. The nontrivial part is scrambling itself. The basic descriptive facts are that the word order in Finnish finite clause is quite flexible when compared to languages such as English, while the variations correlate with shifts in discourse interpretations such as topic and information focus. The noncanonical order (24b) is associated with an interpretation in which *Pekka* is interpreted as the information focus, the reflexive as the topic. We call grammatical processes that create noncanonical word orders observed here and in other noncanonical sentences *scrambling*; other terms are “free word-order,” “topicalization,” “stylistic movement” and “discourse-based movement.” What exact operation or operations is/are responsible for these word order changes is less important as long as all constituents find their way to the thematic base-positions at the LF-interface where assignment calculations take place.

There is currently very little controversy over the hypothesis (e.g., Vilkuna 1995) that the Finnish preverbal subject position is a topic position and not reserved for grammatical subjects. In the sentence (24b) the direct object reflexive occupies the topic position. The underlying computational model analyses these sentences in the same way. It is assumed, furthermore, that the Finnish free word order and scrambling are licensed by the rich case system which alone is often able to determine the thematic roles and base positions of referential arguments irrespective of surface positions (Brattico 2020, 2023b). For example, the fact that the preverbal reflexive pronoun represents the direct object in (24b) is signaled by the partitive case, which causes it to be reconstructed into the verb phrase where the case feature can be checked (26).

(26)



Reflexive binding takes place between *Pekka* at the higher SpecvP position and the reflexive at the lower CompVP position. The scrambling operations are visible in the derivational log file, lines 56559 and 56565:

```
57101       Scrambling([φ Pekka])
57102        = [[φ itse] [-VT [__:5 [v [ihaile- <φ Pekka>:5]]]]]
57103       Feature inheritance(φ)
57104        = [φ itse]
57105       Agree(φ) did not find suitable goal.
57106        = [φ itse]
57107       Scrambling([φ itse])
57108        = [<φ itse>:6 [-VT [  :5 [v [[ihaile-   :6] <φ Pekka>:5]]]]]
```

Correct assignments follow:

```
57144       Assignments:
57145           Assignment [φ Pekka] ~ 1, [φ itse] ~ 1 +
57146           Assignment [φ Pekka] ~ 1, [φ itse] ~ 2 -
57147           Assignment [φ Pekka] ~ 2, [φ itse] ~ 1 -
57148           Assignment [φ Pekka] ~ 2, [φ itse] ~ 2 +
57149           Summary:  Pekka[a] ihaile- itse[a]
```

Scrambling reconstruction was tested also in connection with proper names and pronouns (#103−107). The case with A-reconstruction is more complex (e.g., Barss 1986; Hicks 2008; Lebeaux 2009). To illustrate the issue in Finnish, I used Finnish equivalents of the A-reconstruction constructions discussed by Lebeaux (2009)(27).

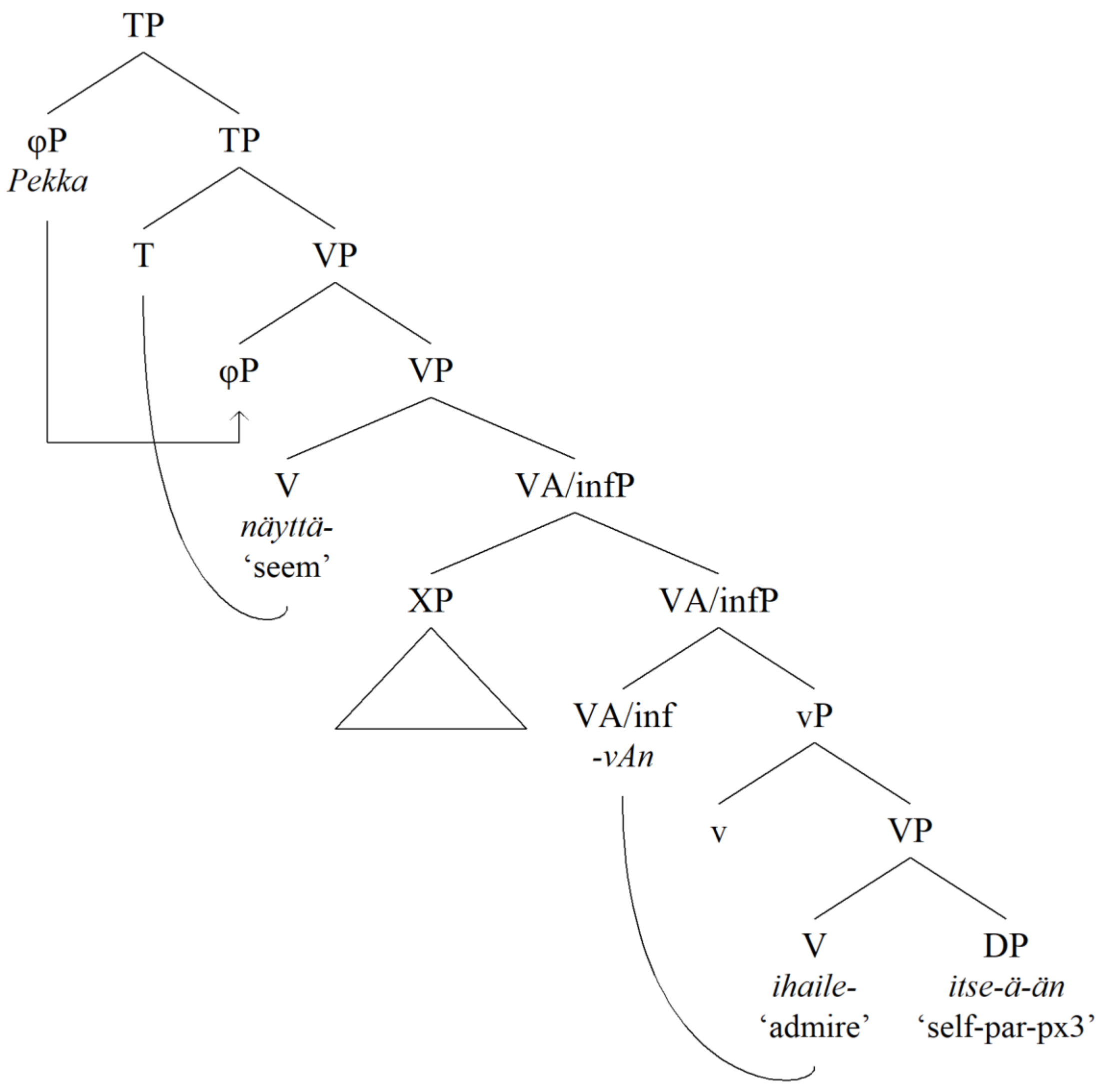
(27) a. Pekka$_{a,1}$ näyttä-ä omasta mielestä-än$_{a}$ __$_{1}$ ole-va-n(sa) valmis.
Pekka.NOM seem-3SG.PRS own mind-PX3 be-VA/INF-(PX3) ready
'Pekka seems to his own mind to be ready.'

b. Pekka$_{a,1}$ näyttä-ä opettaja-nsa$_{1}$ mielestä __$_{1}$ ole-van älykäs.
Pekka.NOM seem-3SG.PRS teacher-PX3 opinion be-VA/INF intelligent
'Pekka seems to his teacher to be intelligent.'

c. Pekka$_{a,1}$ näyttä-ä itse-nsä$_{a}$ mielestä __$_{1}$ komealta.
Pekka.NOM seem-3SG.PRS self-PX3 opinion handsome
'Pekka seems to himself (to be) handsome.'

The subject constitutes a binder for anaphoric and/or reflexive elements inside the main clause. Many linguistic theories assume, however, that it is reconstructed into the trace position where the required interpretations can no longer be accessed. Here this problem does not arise because the baseline algorithm does *not* reconstruct the grammatical subject into the embedded infinitival; rather, these sentences are analyzed as obligatory control constructions. Specifically, *Pekka näyttä-ä ihaile-van itse-ä-än* 'Pekka.NOM seem-PRS.3SG admire-VA/INF self-PAR-PX3'(#90) is analyzed as (28) where the subject can function as an antecedent for reflexive elements inside XP:

(28)



The control dependency, calculated as proposed in Brattico (2021b), is visible on line 59707.[29] Despite the fact that the model creates correct coreference dependencies for reflexives both in the upper (XP) and lower (CompVP) position, the analysis cannot be judged uncontroversial. If these infinitives are analyzed as raising constructions, contrary to what is done here, then the grammatical subject reconstructs to SpecvP and the model fails to generate correct reflexive readings from XP. But because the current analysis does not lead into this problem, it is not possible to explore the issue further: corrections or alternative analyses cannot be tested if the

[29] See Brattico (2023a) for a computational analysis of Finnish nonfinite clauses that was assumed here as a baseline model. The underlying model rejects the reconstruction analysis in Finnish because different case features are checked at the surface and reconstructed positions: nominative at the surface subject position, genitive at the embedded position.

data is calculated correctly. I propose, instead, that the Finnish raising constructions are obligatory control constructions. This leaves the case of English and other languages exhibiting the same binding pattern open. The underlying model *can* reconstruct the subject into the embedded position via an A-chain in languages like English (the operation is blocked in Finnish for case reasons, see note 28); moreover, ad hoc tests reveal that the subject *will* reconstruct successive-cyclically if we categorize the raising verb as a non-thematic predicate. This will create wrong binding relations. If reconstruction is blocked or rejected, on the other hand, then the same Finnish-style obligatory control dependency emerges and the binding facts are calculated correctly. Technically, then, the English facts can be handled by blocking reconstruction optionally or obligatorily (perhaps 'seem to himself' can be regarded as a thematic predicate, with the subject interpreted as an agent or experiencer of 'seem'), but the hypothesis must be evaluated against a dataset containing expressions probing English A-reconstruction specifically, such as personal passives, raising, hyperraising, successive-cyclic movement and others. In addition, there are alternatives, such as providing the assignment generation access to copies at LF or even to syntax-internal representations. Being restricted to the current dataset focusing on Finnish, I prefer to leave the case of English raising open.

3.2.6 Null subjects and binding

Finnish null subject sentences (29)(Vainikka 1989; Vainikka & Levy 1999) present at least two nontrivial issues.

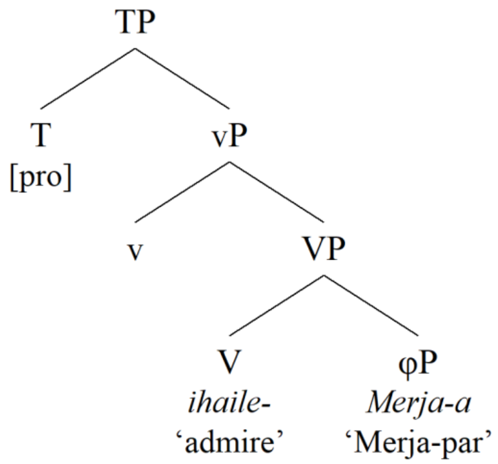
(29) Ihail-e-n Merja-a. (#53)
admire-PRS-1SG Merja-PAR
'I admire Merja.'

The literature contains two basic analyses of Finnish finite null subject sentences, one which assumes that the null subject sentences contain a phonologically silent but syntactically present phrasal pro subject (30a)(Vainikka & Levy 1999; Holmberg 2005) and another which assumes that the null subject interpretation arises from the rich agreement features correlating with a sublexical pro-element present in the verbal head (V or T)(30b)(Brattico 2021b). The latter analysis was inspired by Alexiadou & Anagnostopoulou (1998).

(30) a. [$_{TP}$ pro [$_{TP}$ T VP]]
b. [$_{TP}$ T_{pro} VP]

In either case we get the correct binding properties if pro has [Ref]. This assumption is plausible on independent grounds, since (29) denotes an event with two participants, the first person singular subject and Merja. The baseline algorithm generates an analysis (30b) for (29) shown in (31) where [pro] refers to a sublexical pronominal generated from the first person singular agreement features.

(31)

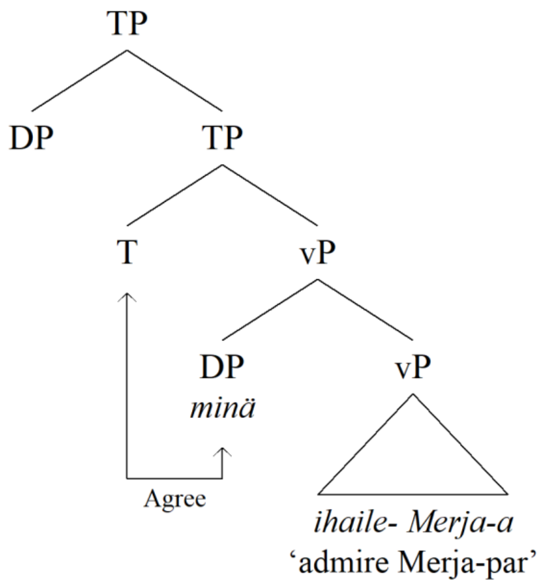


Because pro has [Ref], it will show up in the assignment calculations, thus both the phrasal subject and an Agr head (here T_{pro}) define local domains for anaphors (Chomsky 1981: 209–211). On the other hand, this analysis runs into a problem when the sentence contains a separate grammatical subject (32).

(32)	Minä	ihail-e-n	Merja-a. (#54)
	I.NOM	admire-PRS-3SG	Merja-PAR
	'I admire Merja.'		

If all referential expressions with [Ref] project semantic objects and generate independent assignments, then (32) projects *three* objects corresponding to *minä* 'I', the first person singular pro and *Merja*. This shows that we must take subject-verb agreement into account when creating assignments. Agreement between T and the grammatical subject is handled in the baseline model by a syntax-internal operation Agree shown in the analysis (33) of (32) below.

(33)



To get the correct assignment properties for (32), then, we assume that pro-elements do not project independent objects if Agree finds a corresponding full phrasal argument. A further complication, however, comes from the fact that a third person embedded pro-drop clause is grammatical in Finnish if (and only if) the null pronoun can be paired with a c-commanding antecedent (34).

(34) a. Pekka sano-o että [ihail-e-e Merja-a.] (#56)
Pekka.NOM say-PRS.3SG that admire-PRS-3SG Merja-PAR
'Pekka$_1$ says that he (=Pekka$_1$) admires Merja.'

b. *Ihaile-e Merja-a. (#55)
admire-PRS.3SG Merja-PAR
Intended: 'He admires Merja.'

Null subjects are possible in all but the third person, the latter only if there is an antecedent (Brattico 2017; Frascarelli 2018; Heinonen 1995; Holmberg 2005; Holmberg & Sheehan 2010; Vainikka 1989; Vainikka & Levy 1999). One explanation is that the third person agreement suffixes and/or the corresponding pro-element is 'weak' in some sense and requires support from an antecedent (Holmberg & Sheehan 2010). The syntactic background theory follows this analysis and assumes that the third person pro element lacks a fully specified definiteness feature, which triggers the antecedent support visible in (34a)(Brattico 2021b). Specifically, it does not project a full-fledged pro-element able to function as an argument. Sentence (34b) is judged ungrammatical because T with the weak third person suffixes cannot be mapped with a suitable argument (see #55 in the dataset, and line 36413 in particular which registers the missing argument). Sentence (34a) is grammatical because T can locate its argument from the superordinate clause by control (item #56). Because the third person phi-features at T are weak and do not generate independent denotations, the issue of generating too many assignments does not arise: there will only be two, one for the main clause subject and another for the direct object. Also pronouns (35a) and reflexives (35b) were tested in this environment.

(35)	a.	$Pekka_a$	sano-o	että	ihaile-e	hän-$tä_{*a,b}$. (#57)
		Pekka.NOM	say-PRS.3SG	that	admire-PRS.3SG	he-PAR
		’$Pekka_a$ says that he admires him_b.’				
	b.	$Pekka_a$	sano-o	että	ihaile-e	itse-ä-$än_{a,*b}$. (#58)
		Pekka.NOM	say-PRS.3SG	that	admire-PRS.3SG	self-PAR-PX3
		’$Pekka_a$ says that he admires $himself_a$.’				

If the embedded clause contains a separate grammatical subject, whether overt or covert, intervention blocks all upward paths from the embedded clause (#59−61).[30]

3.2.7 Binding and infinitives

The binding properties of English nonfinite clause constructions such as (36) are calculated correctly (the binding dependencies shown here come from the output of the model, ‖ shows the location of intervention).

(36) a. $John_a$ wants to admire $himself_a$. (#111)

b. $John_a$ wants ‖ $Mary_b$ to admire $herself_b$. (#112)

c. $John_a$ wants to admire him_b. (#113)

d. $John_a$ wants ‖ $Mary_b$ to admire $him_{a,c}$. (#114)

[30] Both Agree and the control mechanism are separate modules of the UG and not part of binding. Their function in the baseline algorithm is to pair predicates with arguments. The assignment mechanism presupposes these pairings in the sense that it must know what the real referential arguments of the sentence are before any assignments can be generated. The same logic applies to many other situations, thus expletive arguments must be ignored; doubles (e.g., clitic doubling) must be recognized and ignored; arguments removed by ellipsis must be reconstructed, and so on.

e. John$_a$ wants to admire Mary$_b$. (#115)

f. John$_a$ wants ‖ Mary$_b$ to admire Bill$_c$. (#116).

If the embedded nonfinite clause contains a separate subject, then the limited semantic working memory contains only the nonfinite clause portion. These results correspond to the effects of the Specified Subject Condition of the standard binding theory (Chomsky 1977, 1981; Chomsky & Lasnik 1977).[31] Reflexives see main clause subjects if and only if there is no separate subject in the embedded nonfinite clause. This regulates the binding properties of reflexives and pronouns; r-expressions such as proper names operate with complete semantic working memory and ignore embedded subjects.[32] If there is no embedded subject, then the limited semantic working memory accessed from the reflexive pronoun contains elements in the superordinate clause. The same tests for Finnish are items #119–130, which were correctly calculated. The A-infinitive, which has similar properties as the English *to*-infinitive, was used in the testing.[33]

van Steenbergen (1991) suggests that the binding domain for the Finnish reflexive is determined by tense, not by an intervening subject, and supports the generalization by citing the VA-infinitival construction (example (6a) in the original, p. 235, my glossing):

(37)	Pekka$_a$	näki	[$_{VA/infP}$	Mati-n$_b$	katso-van	itse-ä-än$_{a,\ b}$.]
	Pekka.NOM	see.3SG.PST		Matti-GEN	look-VA/INF	self-PAR-PX3

‘Pekka saw Matti watch himself.’

[31] The Specified Subject Condition (SSC) blocks certain rules such as binding from crossing S and NP boundaries if they project a non-controlled independent subject (Chomsky 1977: 74–75). The case with NP-boundaries will be discussed in Section 3.2.8.

[32] If the subjectless nonfinite clauses are analyzed as containing a separate PRO-subject, then the correct facts still follow if PRO does not have [Ref]. This assumption does not seem implausible, given that PRO-elements are by definition arguments that cannot establish (why was this deleted?)

[33] Finnish has a large catalog of nonfinite constructions (traditionally divided into infinitives and participles) all formed by suffixing the verbal stem with one of the infinitival suffixes. The structure proposed here for the Finnish nonfinite clauses comes from Brattico (2023a). Their binding properties follow the template of Finnish A-infinitivals and English to-infinitivals: overt embedded phrasal subjects cause intervention. If the infinitival predicate exhibits overt agreement but no overt subject, then the agreement suffixes cause intervention. This follows from the present model for reasons elucidated in Section 3.2.6.

To me the long-distance binding configuration is marginal, and indeed van Steenbergen cites other infinitival constructions where she agrees with my judgment (e.g., example (8) in her paper). However, also Trosterud (1990: 69) judges (38) grammatical (=ex. 35b in the original).

(38)	Maija$_a$	käsk-i	meidän	pes-tä	itse-nsä$_a$.
	Maija.NOM	order-3SG.PST	we.GEN	wash-A/INF	self-ACC.PX3

‘Maija ordered us to wash herself.’

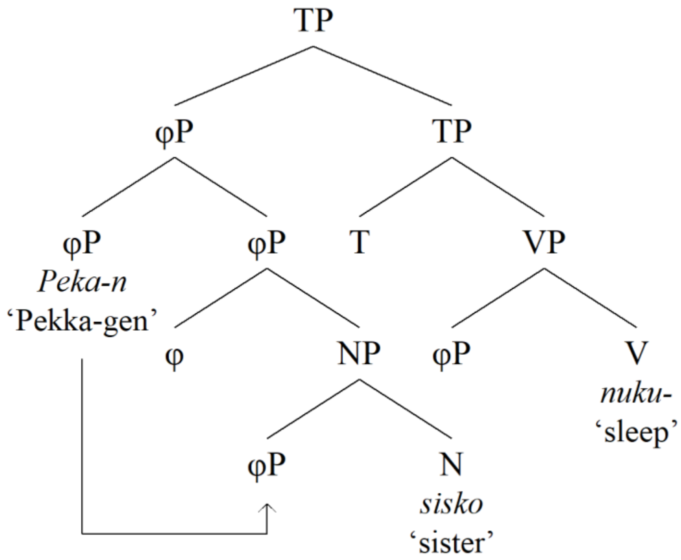
I find (38) marginal, and ungrammatical if the embedded subject and the reflexive agree in phi-features (*meidän – itse-mme* ‘us.GEN – self-PX1PL’ or *hän-en – itse-nsä* ‘he.GEN – self-PX3’). Trosterud reports the same result from Pyssyjoki Finnish (pp. 95−96), thus his informants did not accept long-distance binding when the intervening subject and the anaphor agreed. Long-distance binding was absent from the Finnmark dialect (pp. 93−94). Finally, Trosterud reported between-speaker variation in the judgments. This instability corresponds with my own intuition. I therefore think that a clear-cut conclusion cannot be reached without further data. The feature intervention analysis proposed in this article nevertheless allows one to define locality also on the basis of minimal tense phrase by replacing [Ref] with [T]. The hypothesis must be tested over several constructions in the dialects/languages where it looks reasonable and with native speakers who, unlike the present author, accept such sentences. An alternative is that these speakers have long-distance reflexives in their lexicon.

3.2.8 DP-internal binding and the picture nouns

In most generative literature on nominal syntax full arguments are assumed to consist of [$_{DP}$ D NP] structures, following the DP-hypothesis (Longobardi 1994; see Gröndahl 2015, Holmberg 2021 and Vangsnes 2001 for Finnish). Finnish lacks obligatory articles (Chesterman 1991; Gröndahl 2015; Laury 1997; Vilkuna 1992), which means that D elements cannot be assumed to be present in the input sentences. This was handled by assuming, following the line of analysis by Déchaine & Wiltschko (2017), Déchaine & Wiltschko (2002) and van Steenbergen (1987, 1991), that bare nominal arguments in the input are [$_{\varphi P}$ φ N] structures where φ is a minimal nominal agreement cluster carrying phi-features and [Ref]. All bare noun arguments appearing in Finnish input sentences were analyzed accordingly (e.g.*, sisko* ‘sister’ → [$_{\varphi P}$ φ sister]). The genitive-marked nominal argument is then generated to SpecφP and reconstructs to SpecNP, as shown by (39) and (40).

(39) Peka-n sisko nukku-u. (#133)
S/he-GEN sister.NOM sleep-PRS.3SG
'Pekka's sister sleeps.'

(40)

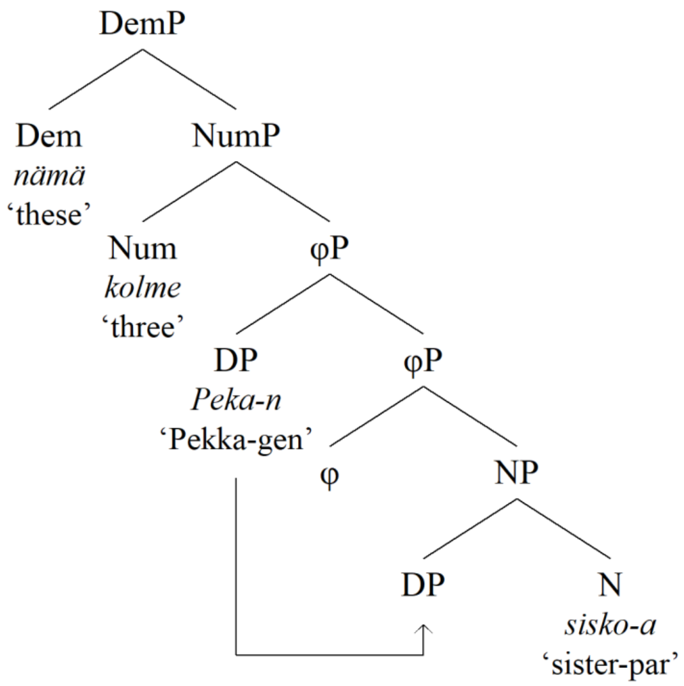


Notice that the input sentence that generates this analysis does not contain overt D-elements: φ comes into the structure as part of the lexical entry for *sisko* 'sister'.[34] All prenominal modifiers such as demonstratives, quantifiers and numerals are generated above φP, including the optional quasi-determiners *se* (definite) and *yks* (indefinite) which project D-elements. Thus, *nämä kolme Pekan siskoa* 'these three Pekka-GEN sisters' is analyzed as (41).

---

[34] There must of course be a lexical entry for bare N = *sisko* as well since the $[_{\varphi P}\ \varphi\ N]$ analysis presupposes an N. Lexical ambiguity does not create special problems for the baseline model: all lexical entries retrieved on the basis of some surface string are inserted into the derivational search where they generate separate derivations. To avoid excessive generation of irrelevant derivations it is possible to disambiguate expressions at the level of surface expressions.

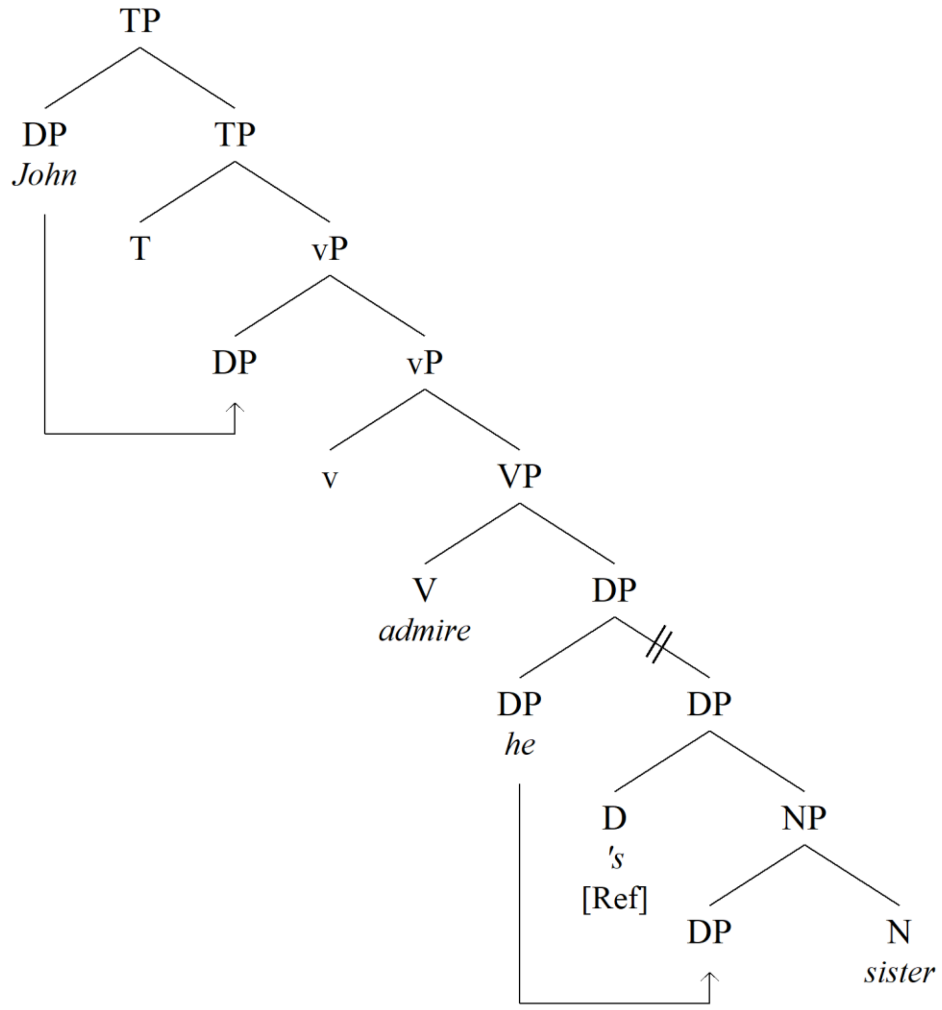
(41)



English ’*s* is interpreted as a D-element, thus *his sister* = [$_{\mathrm{DP}}$ [$_{\mathrm{DP}}$ *he*$_1$ D(’*s*) __$_1$ *sister*]]. Let us, then, consider (42) and its analysis (43).

(42) John$_a$ admires his$_{a,b}$ sister. (#129)

(43)



The possessive pronoun *his* reconstructs to SpecNP at the LF-interface, where its assignment options are determined. Because D contains [Ref], the grammatical subject *John* is not inside the limited semantic working memory and the model returns the binding options stated in (44)

(44) John$_{a}$ admires his$_{a,c}$ sister$_{b}$. (#133)

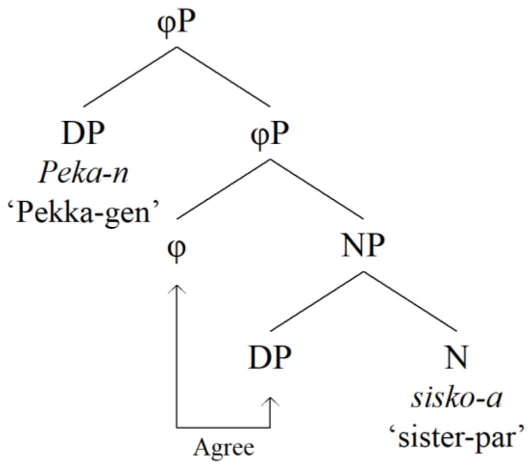
where *his* can denote both John and a third party. The same result is calculated for the equivalent Finnish clause (45).

(45) Pekka$_{a}$	ihaile-e	hän-en$_{a,c}$	sisko-a$_{b}$(-an). (#134)
Pekka.NOM	admire-PRS.3SG	he-GEN	sister-PAR(-PX3)

‘Pekka admires his sister.’

The Finnish version (45) with the coreference reading feels marginal but not ungrammatical to me.[35] Subscript [b] denotes the sister projected into the global discourse inventory by φP. The reason the model predicts correct binding dependencies for these constructions is because it triggers possessive reconstruction and brings the possessor below φ. If the grammatical theory does *not* reconstruct possessors, correct binding facts do not follow without further assumptions or modifications. In Finnish the φ-head can furthermore agree with the reconstructed argument, assigning genitive and triggering agreement (if present, as in *minun sisko-ni* 'I.GEN sister-PX1SG)(46).

(46)



This supports further the assumption that there is reconstruction. This accounts also for the fact that the possessive argument and the possessive suffix must agree in phi-features and, when this happens, the possessive suffix does not project its own semantic object (cf. finite clause, Section 3.2.6). Let us then consider (47), where the marked coreference relations reflect native speaker judgments.

(47) a. Pekka$_a$ ott-i kuva-n itse-stä(-än)$_{a,*b}$ (#137)
Pekka.NOM take-3SG.PST picture-ACC self-ELA-PX3
'Pekka took a picture of himself.'

---

[35] Chomsky (1981: 65) proposes that these constructions exhibit an "avoid pronoun" principle that prefers null pronouns when an overt pronoun would be redundant; see also Kaiser (2003), footnote 2, p. 9, who notices that her native speakers "permit" reading (45) against "standard judgments." It is unclear to me what Kaiser meant by "standard judgments" here, most likely it was meant to exclude sentences judged as marginally acceptable. To me (45) is possible but marginal.

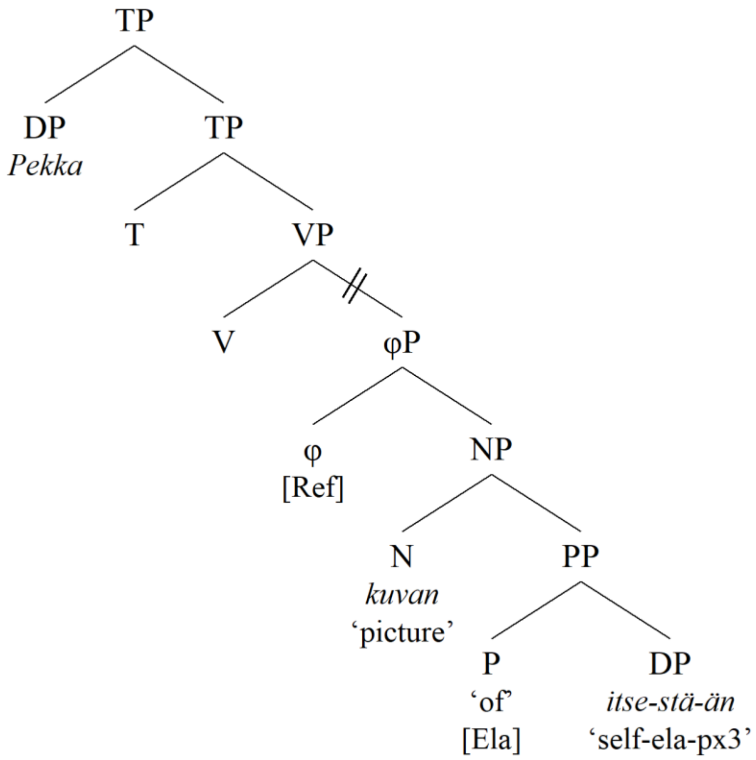
b. Pekka$_{a}$ ott-i kuva-n häne-stä$_{?a,b}$. (#135, 136)

Pekka.NOM take-3SG.PST picture-ACC he-ELA

'Pekka took a picture of him.'

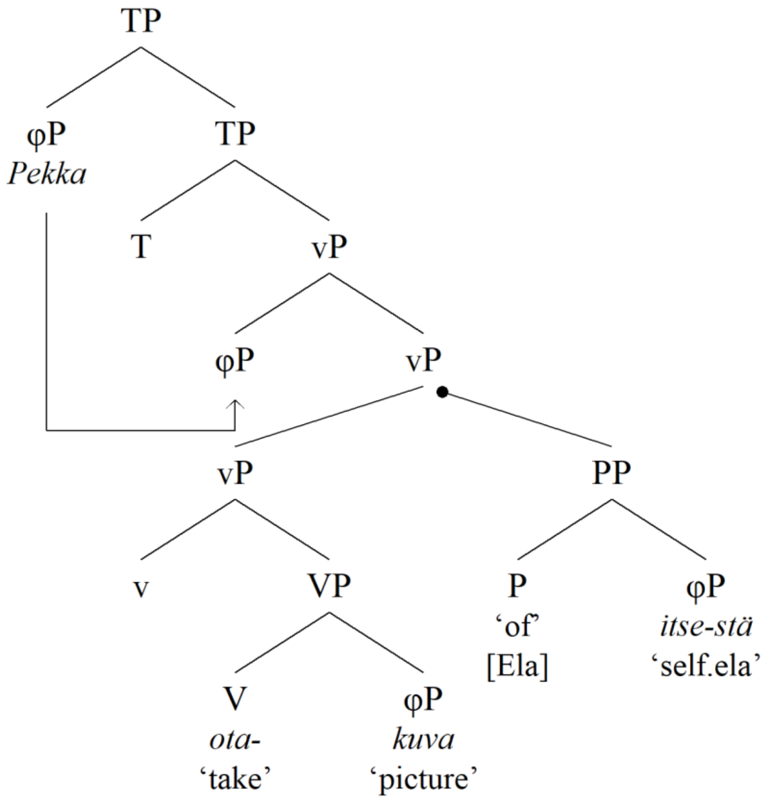
Sentence (47a) shows that the reflexive pronoun is grammatical inside the noun phrase, taking the main clause subject as an antecedent. The problem is that this dependency should be intervened by the φ-head inside the noun phrase:

(48)



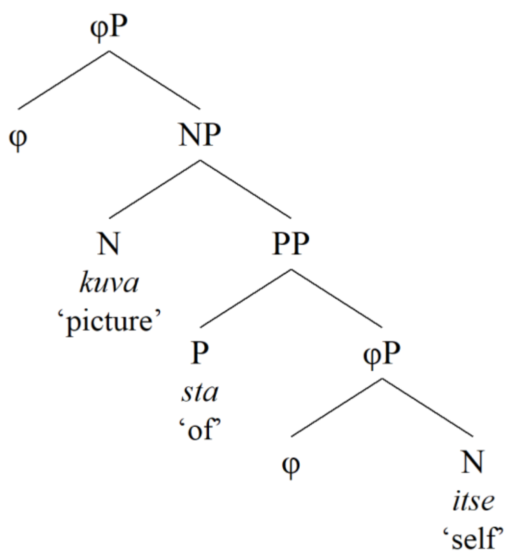
The elative-marked complement has been analyzed as PP, but this assumption is inessential since whatever its analysis the φ-head will intervene, predicting, against the facts, that the reflexive should *not* be possible. Instead, the hypothesis proposed here predicts (47b). Testing the input sentences with the underlying computational model reveals, however, a more complex picture. First, PP arguments can be merged with their host structure in one of two ways: either as an ordinary specifier/complement constituents or as adjuncts. The first attachment option produces (48) and corresponds to the reading (marginal in Finnish) in which a regular pronoun is optionally coreferential with the main clause subject. The adjunction option produces an "extraposition" analysis (49)(–• marks adjunct attachment).

(49)



Now the upward path from the reflexive sees the grammatical subject and generates the reflexive reading 'Pekka$_a$ took a picture of himself$_a$'. The hypothesis therefore captures the data. The underlying explanation is structural ambiguity. These experiments also revealed a problem. Consider the internal structure of the complex noun phrase *kuva itse-stä* 'picture self-ELA' when the elative-marked constituent is analyzed as the complement of 'picture' (50):

(50)



Although the higher φ-head correctly blocks the upward path from the reflexive, it will also generate a reflexive reading ‘a picture$_a$ of itself$_a$’ (i.e., ‘a picture of the picture itself’, as in two mirrors facing each other) where the reflexive is coreferential with *a picture*. The reflexive is ‘inside its own antecedent’. Coreference dependencies of this type are semantically possible (e.g., *a man$_a$ who admires himself$_a$*), so what rules out this interpretation, if it indeed should be ruled out, remains to be explained.

4 Discussion

The main alternative to the interface analysis presented in this article is the syntactic hypothesis, in which all or some binding dependencies are determined inside syntax by relying on a formal device such as indexing. The analysis could be supported by citing evidence showing that binding is sensitive to some syntax-internal mechanism (say, Agee and/or Move) whose effects are not visible at the LF-interface. Such evidence (see, e.g., Paparounas & Akkuş 2024) will eventually find its way into a dataset such as the one proposed here and pose a potential problem for the interface hypothesis. Whether it does pose a problem remains to be seen. There is no other way to resolve this controversy than to test unambiguous formal theories against unambiguous datasets.[36]

One limitation of the present model is that it only applies to referential expressions denoting single spatiotemporal objects. Consider an expression such as *two men*. When an expression like this is introduced for the first time in a conversation, it must introduce at least two men into the discourse inventory, while its possible denotations must constitute two-membered sets of men. Similarly, *some men* can denote any arbitrary set of men while introducing at least two.

[36] Since the present analysis is sufficient to calculate the dataset defined in Section 2.2, it can be improved in one of two ways. One is by (i) showing that there is an alternative model which calculates the same data and some additional data not captured by the present hypothesis; another is (ii) by constructing a model that is simpler that the one proposed here while calculating the same or larger dataset. (i) would show that the present hypothesis is not sufficient, (ii) that it is not necessary. That being said we can only compare two complete models in the context of the whole datasets; citing isolated examples deemed problematic will not convince anybody in the long run. In addition, there is nothing else than (i–ii) that can contribute to this debate since all we can hope for is a model that is both sufficient and necessary to calculate the largest amount of data possible.

Minimally the notion of denotation must be generalized so that it targets *extensions*, not only singular objects; and the binding principles must be generalized accordingly.[37]

Because the model generates assignments and binding configurations from input sentences by consuming them in a left-to-right order, as if they were comprehended in real time, its properties could potentially be evaluated against psycholinguistic experiments. The algorithm monitors its own internal operation and provides feedback concerning the cognitive resources consumed during the processing of each sentence. Moreover, some assumptions of the present model were informed by psycholinguistic evidence. Although most linguists regard performance factors irrelevant to linguistic theorizing – perhaps rightly so – psycholinguistic experimentation could be employed to enrich the dataset when arguing for or against of some model.

5 Conclusions

A hypothesis was considered according to which binding restricts assignments during comprehension by grammaticalizing assignment management at the language-cognition interface. A computational experiment verified that the data, which came from English and Finnish, follow from the hypothesis.

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[37] One possibility is to define coreference not as 'identity of denotation' but as 'overlap in extension'. Necessary coreference would then be 'identity of extension under all assignments'. Quantifiers regulate assignments. Plurals denote plural extensions. Several limitations emerge, however, once we consider unbounded domains such as *every natural number* which cannot be defined by relying on any finite inventory; minimally the semantic entries at the narrow semantic level must be able to contain 'extension generators' such as the successor function.

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