Towards an information processing model of binding and coreference in Finnish

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Abstract. This article proposes an analysis for binding and coreference dependencies in Finnish (and English) that relies on a formally precise information processing model developed within the cognitive framework of Marr (1982). The model locates binding to the language-cognition interface and assumes that it 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 analysis, which was formalized in Python, was tested with the standard binding conditions together with several linguistically nontrivial specimen such as embedded infinitivals, DP-internal binding, picture nouns, null subject sentences, sentences with noncanonical word orders, filler-gap dependencies (both A- and Ā-chains) and whole conversations containing several sentences. The architecture was also designed to process pragmatic exempt anaphors.

Keywords: Binding; coreference; information processing; computational linguistics; Finnish; English

1 Introduction

Successful linguistic communication presupposes that both the speaker and hearer construct mutually consistent inventories of semantic objects corresponding to the subject matter under discussion. This allows the interlocutors to position themselves inside a common discourse space and share an implicit notion of what the conversation "is about." The 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. For example, the first use of a proper name or an indefinite article invites the hearer to assume a new object, whereas an unstressed pronoun or the use of a definite article signals that the reference is discourse old. These restrictions can also be structure-dependent. Sentences (1-3) illustrate structure-dependent coreference patterns for reflexives (1), pronouns (2) and proper names (3) in English.

(1) a. $John_1$ admires $himself_{1,*2}$.
b. *John's$_1$ sister admires $himself_1$.

(2) a. $John_1$ admires $him_{*1,2}$.
b. John's$_1$ sister admires $him_{1,2}$.

(3) a. He_1 admires $John_{*1,2}$.
b. $His_{1,2}$ sister hates $John_1$.

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 space available during language comprehension, are known as the binding conditions (Chomsky, 1981). Their ultimate 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) as well as in psycholinguistics (Aoshima, Yoshida, & Phillips, 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 and coreference from a new angle by developing a fully algorithmic information processing model in the sense of Marr (1982) that we then use to replicate binding patterns in a wide variety of constructions and in the two languages targeted for a detailed examination, Finnish and English. The model is based on several key hypotheses. First, it is assumed, contra most of the standard linguistic analyses available today, that binding and coreference patterns emerge from a process which regulates and restricts assignment generation during language comprehension at the hearer's end. Assignment generation refers to a process which provides the incoming sentences with a set of possible denotations, given a context. Binding reduces ambiguity of this process. The operation takes place at the language-cognition interface; syntax-internal binding theories are rejected.[1]

[1] Syntax-internal theories of binding are quite popular within the generative theory, see (Chomsky, 1981; Fiengo & May, 1994; Hicks, 2008; Reuland, 2001, 2006; Rooryck & Wyngaerd, 2011). Here we follow the style of analysis by (Chomsky, 1995; Culicover & Jackendoff, 1995; Schlenker, 2005) where binding regulates semantic interpretation at the

The second novel assumption is that we will provide the description by using the two levels of explanation in the sense of Marr (1982): computational and algorithmic. While Marr's computational level can be identified straightforwardly with what linguists call "competence theories," the algorithmic level introduces an extra concern: the data is ultimately captured by a complex interaction of several computational components of a complete information-processing pipeline. We will also take the context into account: previous sentences can modulate the set of possible assignments of any target sentence. Finally, the fact that the model is expressed by means of a computational algorithm means that the explanation is completely rigorous.

The argument is organized in the following way. Section 2 elucidates the hypothesis in three steps, first by describing the empirical and theoretical background, including Marr's cognitive framework, and then by defining the hypothesis at the computational and algorithmic levels. The implementation level is discussed but not realized in this work. Section 3 describes a computational experiment where the information processing model was tested with a dataset containing binding constructions from Finnish and English. Detailed empirical discussion of the binding dependencies in Finnish and English will be postponed until Section 4.2. where we examine the output of the model and compare it with native speaker intuitions and linguistic theories. Section 5 contains a brief discussion of the limitations of the present hypothesis as well as some of the main alternatives.

2 The hypothesis

2.1 Background

The general language comprehension framework and key terminology will be introduced next. These will be assumed throughout without further comment. Let us assume that the language faculty maps linguistic inputs through a lexico-morphological component into syntactic parses that are interpreted semantically (e.g., Nicol & Swinney, 2003). For example, the input string *the* + *horse* + *raced* + *past* + *the* + *barn* is mapped into a syntactic parse, such as $[_{S}[_{DP}$ *the horse*] $[_{VP}$ *raced* $[_{PP}$ *past* $[_{DP}$ *the barn*]]]], that feeds semantic interpretation and generates the reading 'the horse raced past the barn'. The sequence of operations between the sensory input

language-cognition interface and exists at what could be characterized as the "outer edge" of language. I will return to this controversy later in this article.

and the syntactic parsed output will be called the *syntactic processing pathway*, and the endpoint of the syntactic processing pathway will be called the *syntax-semantics interface* (LF interface in the generative theory). The syntax-semantics interface is followed by *semantic interpretation*. We do not assume that the syntactic processing pathway and the syntax-semantics interface exhaust the language comprehension systems of the human brain; rather, they suffice for the purposes of the present study. In addition, these assumptions, although they do describe processing components, do not commit us to the development of a linguistically irrelevant performance model. The model developed in this article judges the input sentences for grammaticality and provides them with syntactic analyses and semantic interpretations that should be evaluated against standard linguistic theorizing, hence it embodies and its main concern is competence.[2]

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 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 raced past the barn*, the inventory holds two spatiotemporal objects, the horse and the barn. The global discourse inventory is a language-external representational system that is accessed by general cognitive processes, such as thinking, decision making and problem solving. We limit the term “meaning” in this study to the temporal storage of discourse objects projected into existence and updated by the ongoing linguistic communication between the interlocutors.

Once there is a global discourse inventory, the model is no longer limited to the processing of single isolated sentences. 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, subsequent sentences will take those objects into account when evaluation assignments. Suppose *the horse ran past the barn* is followed by *it was very fast*. The most likely interpretation for this continuation is one where the inanimate pronoun *it* refers to the

[2] The underlying competence model has three components: *language-specific component*, created at runtime by instantiating separate idealized brain models for the speakers of different languages and thus modelling different acquisition trajectories; *universal language-specific components* (the UG), explicated in terms of grammatical principles and fixed constraints and bottlenecks of the information processing network; and *language-external* components that belong to general cognition.

horse, but it could also refer to the barn, a third 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. This is especially true of pronouns. Denotations, and therefore also assignments, are selected on the basis of what is contained in the discourse inventory at the moment the target sentence is processed. The semantic objects projected into the global discourse inventory are modelled in this work by using the standard Python dictionary data-structure, which makes them much like the familiar "file cards" proposed in the linguistic literature (Heim, 1982; Kamp, 1981). Referential linguistic expressions processed inside the syntactic processing pathway are then linked with the global discourse inventory objects by means of formal indexes matching the keys of the dictionary; when two referential expressions point to the same object, they stand in a *coreference* relation. If they point towards to different semantic objects, we say that they are *disjoint* in reference.[3]

These assumptions presuppose the existence of two cognitive systems, one which provides the hearer access to possible denotations and assignments for any referential expression in the input sentence (given a context and a discourse inventory) and another which evaluates the assignments for plausibility. I will call the former component *narrow semantics*. The term "narrow" refers to the fact that the component operates as an interface between the syntactic processing pathway and global cognition and does not exhaust what we usually mean by "semantics." Evaluation of plausibility, the second component, is part of global cognition. To illustrate, consider again the sequence of sentences *the horse raced past the barn*; *it was very fast*. Suppose that *the horse* and *the barn* project the horse$_1$ and the barn$_2$ to the global discourse inventory (indexes 1, 2 point to two distinct objects in the discourse inventory). The pronoun *it* projects an inanimate third person object it$_3$. When the whole expression is interpreted,

[3] This is a simplification and does not account for expressions such as *two dogs*, *every man* or *nobody* which do not stand for thing objects or "file cards." I return to this issue at the end of this article. Moreover, the system makes room for three types of coreference dependencies: *accidental coreference*, modelled by generating separate file structures pointing to the same external object or being linked by an identity relation (Frege's Morning/Evening Star cases); *semantic coreference*, modelled by linking two expressions with the same semantic object during assignment generation (binding, according to the present study); and *grammatical coreference*, where two expressions are indexed to the same semantic object inside the syntactic processing pathway by means of a grammatical law, applicable here to null subjects.

narrow semantics provides each referential expression with a set of possible denotations, for example, *it* will be linked with {the horse$_1$, the barn$_2$, it(thing)$_3$ and it(event)$_4$}, which generates assignments 'the horse$_1$ raced past the barn$_2$; it$_{1,2,3,4}$ was very fast'.[4] The list of assignments therefore provides the sentence with all possible readings when it comes to its referential expressions. Global cognitive processes then *rank* the assignments and select the most plausible one(s) for consideration by taking the context into account and drawing information from multiple sources.[5] In this case, the most plausible interpretation is one where *it* refers to the horse. An interpretation where *it* refers to the barn is possible but unlikely. Rankings are formalized by providing each assignment with a numerical *weight* corresponding to its plausibility (0=completely implausible, 1=very plausible). Finally, this system presupposes a mechanism for separating referential expressions like *the horse* from the nonreferential ones such as *raced* or *past*. Referential elements were correlated with feature [REF] for 'referential' in this study. Thus, only expression with [REF] are relevant for assignment generation and binding. This will feature will also play a role in capturing locality domains for binding.

2.2 The information processing framework

We will develop a fully formal linguistic analysis within the language comprehension context elucidated above by using the information processing framework proposed by Marr (1982). Since this framework cannot be assumed to be familiar to some linguist readers, the key assumptions and their motivation are explained in this section. Marr proposed to study human vision by means of a computational information processing model comprising of three levels of description: the *computational level*, *algorithmic level* and *implementation level*. A computational level description corresponds closely to what linguists call linguistic competence. In our case, it constitutes a mapping from the input sentences into grammaticality judgments and coreference dependencies, thus it implements an "abstract computational theory of the device [visual module, language faculty], in which the performance of the device is characterized as a mapping from one kind of information to another, the abstract properties of

[4] Notice that pronouns like *it* have features such as person, number and gender which limit the selection of denotations and assignments during language comprehension, see Kazanina et al., 2007; Nicol & Swinney, 2003; Parker, 2019; Parker & Phillips, 2017.

[5] There is substantial literature which supports the assumption that the human language comprehension systems use information from several sources in a nonmodular way when calculating denotations and assignments during language comprehension (e.g., Asher & Wada, 1988; Badecker & Straub, 2002; Garrod & Sanford, 1994; Kaiser, 2011).

this mapping are defined precisely, and its appropriateness and adequacy for the task at hand are demonstrated" (Marr, 1982, p. 24). We will provide a computational level description of binding in Section 2.3.1. Marr pointed out, correctly, that the generative theory (as well as most grammars) constitutes a computational level descriptions.

The *algorithmic level* describes the computational functions and data-structures which carry out the required calculations. It involves the "choice of representation for the input and output and the algorithm to be used to transform one into the other" (p. 24-5). These will be described in Section 2.3.2. In the present case, the Python formalization of the syntactic background theory and the semantic computations serve this function. The algorithmic level and the many issues it involve are less well-known in theoretical linguistics, and might be considered redundant or irrelevant to linguistic concerns. I do not concur. The three-tier structure emerged from Marr's attempts at integrating the many seemingly incompatible approaches to human vision that were relevant during his time (Marr, 1982: 8-15). At the time Marr entered the field, a lot of groundbreaking work had already been done and was in progress in the field of psychophysics and electrophysiology, including on the receptive field theory, feature detection and single cell responses, all which raised the question of what the relevance of these relatively isolated lower-level properties could be for human perception. The original research was too reductionist to provide answers, thus Marr points out that "[n]o neurophysiologists had recorded new and clear high-level correlates of perception" (p. 14). Marr's three-tiered explanatory framework provided a way forward. The essential point, according to Marr, is that

> if the notion of different types of understanding is taken very seriously, it allows the study of the information-processing basis of perception to be made rigorous. It becomes possible, by separating explanations into different levels, to make explicit statements about what is being computed and why and to construct theories stating that what is being computed is optimal in some sense or is guaranteed to function correctly. The ad hoc element is removed, and heuristic computer programs are replaced by solid foundations on which a real subject can be built. (p. 19).

Thus, the point of this framework is not so much to create new explanatory levels but to do this in a way which allows researchers to use the rigorous methods of the more advanced sciences, such as physics, where the theory replicates the data by deductive calculation. The computational level tells us *what* we need to calculate; the algorithmic level tells us *how*; and the implementation level tells how the real physical system, the human brain, performs the calculations. All levels are part of the same theory and can potentially unify the different concerns, such as psychophysiology and computer vision, under a rigorous umbrella. Thus, the algorithmic level does not necessarily drain attention into irrelevant performance issues; it can be considered as a calculation aid showing that the proposed theory is "guaranteed to function correctly." Once we have such guarantees – again, as required in all advanced sciences – other researchers may work on the details of the algorithm so that it takes performance and brain-related knowledge into account.[6]

In addition to the algorithmic level, the system could also be described at the *implementation level* where the abstract information processing algorithm is replaced by, or reduced to, a (ultimately physical) neuronal description arguably more realistic from the point of view of biological implementation. This is especially interesting in the case of language, where most of the algorithmic processing makes use of symbol manipulation, but which are sometimes viewed as unrealistic, rightly or wrongly, from the point of view of the brain. This will be the case here too. But once we have reached an algorithmic analysis of some phenomenon of interest that covers a sufficiently large crosslinguistic dataset, it becomes possible to attempt a reduction that retains linguistic relevance while pursuing plausibility in the light of evidence from the neurosciences, and other related disciplines. This would amount to an implementation level description of binding and would make it possible to integrate abstract linguistic theories with what is understood about brain electrophysiology and anatomy. While the present author does not pose sufficient expertise to imagine what the implementation level description could be, it does appear to me to be inevitable that such models will eventually be explored.

2.3 The hypothesis

2.3.1 Computational level

We hypothesize that binding restricts the way global discourse inventory is harvested for assignment generation, forcing coreference dependencies into the apperceived sentence. The legitimate assignments for reflexive pronouns such as *himself*, for example, only include the

[6] Marr's ideas were also criticized, and they were never realized fully. Indeed, we should not adopt them uncritically. The argument presented here will be limited to showing that when it comes to binding and coreference in Finnish and English, a linguistically sound model can be constructed within this framework.

denotations of its clause-mate subjects (under the same assignment). The legitimate assignments for ordinary pronouns exclude clause-mate subjects but include everything else (again, under some assignment). We can think of the binding principles are serving the role of a 'filter' that guides semantic disambiguation at the hearer's end.

Let us assume that global cognition contains a function EVAL evaluating whether a cognitive object X is *new* or *old* in relation to a *reference set* of other cognitive objects. EVAL could be depicted as an attention mechanism that allows the cognitive system to focus selectively on some mental objects by excluding others. Since EVAL is part of global cognition, it operates with semantic objects such as the horse and the barn accessed by general cognition. Let us assume, furthermore, that the assignment computations in narrow semantics can determine the reference set for EVAL on the basis of phrase structure objects it accesses from the endpoint of the syntactic processing pathway, the syntax-semantics interface. This assumption is based on considerable amount of psycholinguistic experimentation which suggests that structure-dependent mechanisms limit the antecedent search during language comprehension (e.g., Aoshima et al., 2009; Asher & Wada, 1988; Clifton, Kennison, & Albrecht, 1997; Cunnings & Felser, 2013; Cunnings & Sturt, 2014; Dillon, Mishler, Sloggett, & Phillips, 2013; Fedele & Kaiser, 2014; Hankamer & Sag, 1976; Kazanina et al., 2007; Koornneef & Reuland, 2016; Nicol & Swinney, 1989; Sturt, 2003). More formally, suppose EXP_i is a referential expression with feature [REF] in a phrase structure object α denoting object *i* in the global discourse inventory; then

(4) *Reference set*
the *reference set* for EXP_i is a set of cognitive objects accessed by narrow semantics from EXP_i in α by using an upward path (5), where

(5) *Upward path*
the *upward path* from EXP_i contains the nodes dominating EXP_i plus the heads of their immediate daughters such that they can be reached from EXP_i without encountering a head with an *intervention feature*.

The intervention feature will create locality domains for binding by restricting the amount of phrase structure "scanned" by the operation (4-5). For Finnish and English, we assume that the intervention feature is [REF], the same referential feature which activates assignment calculations. Finally, to activate the whole apparatus we assume that referential lexical items can contain the following instructions for EVAL:

(6) Binding features
a. [OLD:REF], b. [NEW:REF], c. [NEW:_], d. [OLD:_].

The label NEW/OLD tells the attentional mechanism EVAL whether the object X must be new or old in relation to a reference set, as defined above, and [REF] is the intervention feature.[7] We assume that assignment computations must satisfy these features if any is present in a referential lexical item. Intuitively, these features trigger a mechanism that will restrict coreference dependencies during assignment evaluation, and can thus be considered as "grammaticalizations" of that system. We will examine the operation of these principles in detail in Section 4.2.

2.3.2 Algorithmic level

To create an algorithm for implementing the abstract analysis provided in the previous section, a Python-based sentence processor toolkit (Brattico, 2019a) was used as an initial platform. From a computational point of view, the algorithm maps linear sequences of phonological words into sets of asymmetric binary branching bare phrase structure representations and filters the results by using grammatical principles of the UG. The model has two components, a *lexico-morphological component*, which maps phonological words into grammatical particles (c, Figure 1) by using the *lexicon* (b), and a *syntactic component* (d), which generates phrase structure solutions in a ranked order and then filters the resulting sets on the basis of grammatical principles and lexical features. The solutions are forwarded to the system responsible for semantic interpretation (g), which computes thematic roles, operator scopes, information structure interpretations, and a few other semantic attributes, including denotations and assignments proposed here and described below. The architecture is illustrated in Figure 1.

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[7] The assumption that the mechanism makes use of a separate intervention feature is based on crosslinguistic research which suggests that binding could involve several possible intervention factors (e.g., Raposo, 1986; Déchaine & Wiltschko, 2012, 2017; Manzini and Wexler, 1987). Instead of adopting a fixed intervention strategy, then, it seems more correct that we leave room for several features and possible parametrization.

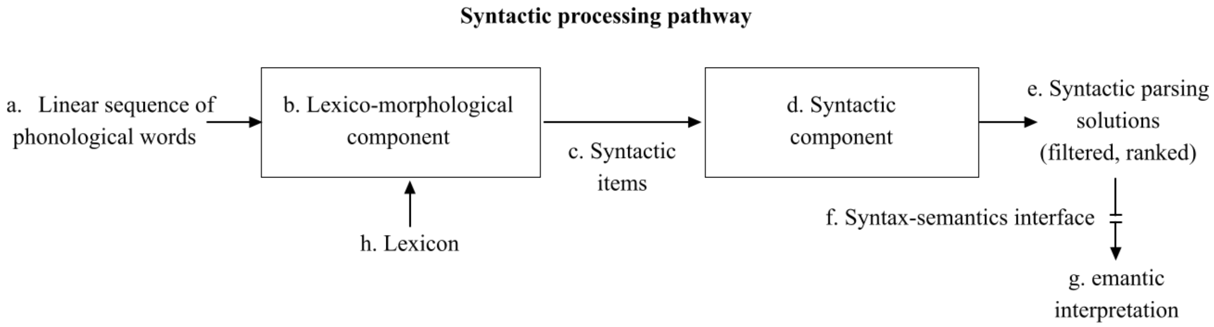


Fig. 1. The syntactic processing pathway. See the main text for explanation.

The architecture therefore uses several “representational stages,” to use the term by Marr (1982: 37), to process linguistic information. The “syntactic items” forwarded from the lexicon-morphological component into the syntactic component are *lexical items* and *inflectional features*. Inflectional features are inserted inside adjacent lexical items, so that the finite tensed verb, for example, will include the person and number features extracted from its suffix. If no parsing solution was found, the input sentence is judged *ungrammatical*; if there is one solution, the solution is returned as grammatical and the sentence is judged unambiguous; otherwise the input sentence is judged grammatical and ambiguous, with all solutions listed in the output. A model of this kind is *observationally adequate* if it judges the input sentence grammatical if and only if it is judged grammatical by a native speaker. It is *descriptively adequate* if it also predicts the syntactic and semantic intuitions elicited from native speakers.

The computational analysis proposed earlier was added to this system by creating the global discourse inventory and the narrow semantic component mediating information processing between the global discourse inventory and the endpoint of the syntactic processing pathway (f). The result is illustrated in Figure 2.

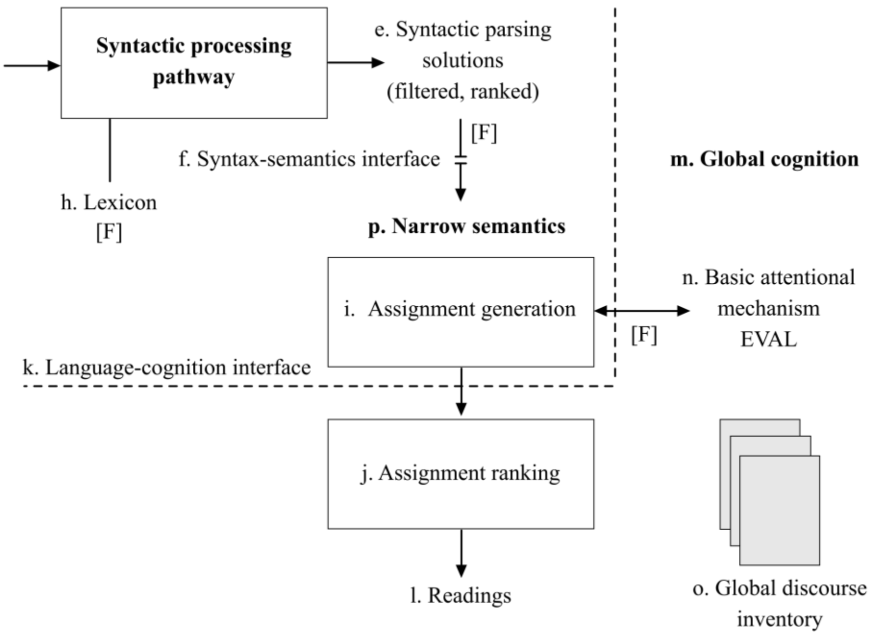


Fig. 2. The semantic architecture. The lexicon was populated with binding features [F] which are picked up from the output of the syntactic processing pathway and constraint assignment calculations (i, n).

Assignments were generated inside narrow semantics (p). The lexicon (h) was populated with the binding features [F] (6), which trigger the reference set calculations defined by (4)(5) and are executed on the basis of the phrase structure outputs of the syntactic pathway (e). The features [F] together with the reference sets were forwarded as instructions to EVAL (n), which restricted assignments (i). The assignments are ranked by global cognition, by relying on pragmatic principles and context (j-k). The output is a ranked list of possible readings (l). Denotations pick up objects from the global discourse inventory (o), which restricts the domain of semantics in this study. Intuitively we think of [F] as "grammaticalizing" the (i)-(n) interface. Functionally the mechanism makes language comprehension more efficient by restricting discourse inventory search.

3 Methods

3.1 Design and procedure

A test corpus containing Finnish and English binding constructions was selected and constructed on the basis of the existing linguistic literature on binding and fed to an algorithm implementing the hypothesis to test if it replicates human behavior. Contents of the test corpus are elucidated in Section 3.2. The model provided each input sentence with a *grammaticality judgment* and, if it was judged grammatical, also a *syntactic derivation*, *syntactic analysis* and *semantic/conceptual interpretation*. Syntactic analyses and semantic interpretations are analyzed in detail in this research report; whole syntactic derivations are available as raw output files but are not discussed due to the high volume of the data produced.[8] Semantic interpretation contained the weighted/ranked assignments, including coreference dependencies and the contents of the global discourse inventory as predicated by the analysis. The design is illustrated in Figure 3.

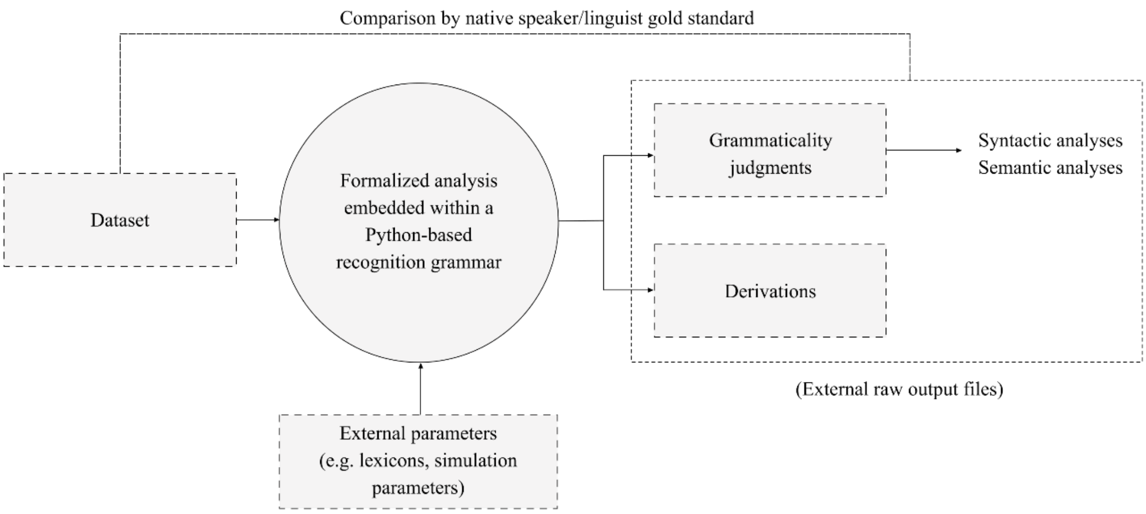


Fig. 3. Design of the study. Each sentence in the dataset was processed by the (same) model and was mapped into the raw output files, which contains syntactic derivations, grammaticality judgments, syntactic and semantic analyses. Binding data (assignments, global discourse inventories) were contained in the semantic analysis.

3.2 Stimuli (test corpus)

The hypothesis was tested against a *test corpus* that contained binding constructions, both grammatical and ungrammatical, and both in Finnish and English. Some test sentences formed

[8] The derivational log file records all cognitively and linguistically meaningful processing steps that occurred during the processing of each input sentence together with all the output (semantic interpretation, syntactic analysis) generated by the algorithm. This data serves as a "bridge" between abstract linguistic evaluations, such as grammaticality, and the underlying processing model. It shows how the algorithm implemented the computational analysis.

conversations, 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 many 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 organized hierarchically. No morphosyntactic tagging was used apart from few cases where the input item was disambiguated 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 semicolon; otherwise, no special punctuation was used. The contents of the test corpus are summarized in Table 1.

Table 1. Structure and contents of the test corpus.

#	Category (sentence numbers)	examples and/or explanation
0	Core sentences from the article	
0.1	Binding conditions (1-19)	Sentences from this article
0.2	Null pro subjects (20-25)	Sentences from this article
0.3	DP-internal syntax (27-31)	Sentences from this article
0.4	Embedded infinitivals (32-37)	Sentences from this article
1	Proper names (R-expressions)	
1.1	Grammatical, assignment possible (38-45)	John sleeps. John admires Mary. Pekka nukku-u. ‘Pekka.NOM sleep-PRS.3SG’ Pekka ihaile-e Merja-a. ‘Pekka.NOM admire-PRS.3SG Merja-PAR’
1.2	Proper names inside that-clauses (46-47)	John said that Mary admires Bill. Pekka sanoi että Merja ihaile-e Jukka-a. ‘Pekka.NOM said that Merja.NOM admire-3SG.PRS Jukka-PAR’
1.3	Proper names inside embedded infinitival (48-49)	John wants Mary to admire Bill. Pekka sanoo Merja-n ihaile-van Jukka-a. ‘Pekka.NOM says.PRS.3SG Merja-GEN admire-VA/INF Jukka-PAR’
1.4	Condition C (50-58)	He admires John. She admires John. He admires Mary. She admires Mary. He said that John admires Mary. He wants John to admire Mary. Hän ihaile-e Merja-a. ‘He.NOM admire-3SG.PRS Merja-PAR’ Hän sanoo että Pekka ihaile-e Merja-a. ‘He.NOM says that Pekka.NOM admire-3SG.PRS Merja-PAR’

		Hänen siskonsa sanoo että Pekka ihaile-e Merja-a. ‘His/her sister says that Pekka.NOM admire-3SG.PRS Merja-PAR’
1.5	Conversations (59-62)	John sleeps; John admires Mary. John sleeps; Mary sleeps.
1.6	Pro-drop sentences (63)	Ihaile-n Merja-a. ‘admire-PRS.1SG Merja-PAR’
2	Regular pronouns	
2.1	Pronouns and proper names (64-83)	John admires him. John admires her. He admires Mary. She admires John. It admires John. It admires Mary. It admires him. It admires her. John admires it. Mary admires it. He admires it. She admires it. It admires it. John admires his sister. John admires her sister. Pekka ihaile-e hän-tä. ‘Pekka.NOM admire-3SG.PRS he-PAR’ Pekka ihaile-e sitä. ‘Pekka.NOM admire-.3SG.PRS it.PAR’ Se ihaile-e Pekka-a. ‘it.NOM admire-3SG.PRS Pekka-PAR’ Se ihaile-e sitä. ‘It.NOM admire-3SG.PRS it.PAR’ Pekka ihaile-e hän-en sisko-a-an. ‘Pekka.NOM admire-3SG.PRS he-GEN sister-PAR(Px/3sg)’
2.2	Only pronouns (84-89)	He admires him. She admires her. He admires her. She admires him. Hän ihailee häntä. ‘He.NOM admire.3SG.PRS he.PAR’ Se ihaile-e sitä. ‘it.NOM admire-3SG.PRS it.PAR’
2.3	*Pronouns with wrong case forms (90-97)	*Him admires he. *Him admires she. *Him admires him. *Him admires her. *Her admires he. *Her admires she. *Her admires him. *Her admires her. Not applicable to Finnish due to free word order profile
2.4	Pronouns inside that-clauses (98-107)	John said that Mary admires Bill. John said that Mary admires him. John said that he admires Mary. John said that he admires him. He said that he admires him. He said that John admires Mary. Pekka sanoo että Merja ihaile-e Jukka-a. ‘Pekka.NOM says that Merja.NOM admire-3SG.PRS Jukka-PAR’

		Pekka sanoo että Merja ihaile-e hän-tä. ‘Pekka.NOM says that Merja.NOM admire-3SG.PRS he-PAR’ Pekka sanoo että hän ihaile-e Jukka-a. ‘Pekka.NOM says that he.NOM admire-3SG.PRS Jukka-PAR’ Pekka sanoo että hän ihaile-e hän-tä. ‘Pekka.NOM says that he.NOM admire-3SG.PRS he-PAR’
2.5	Pronouns inside infinitivals (108-121)	John wants Mary to admire him. Mary wants John to admire her. John wants John to admire him. Mary wants Mary to admire her. John wants Mary to admire it. Mary wants John to admire it. John wants him to admire Mary. John wants her to admire Mary. Mary wants him to admire Mary. Mary wants her to admire Mary.
2.6	Possessive pronouns (122-124)	His sister sleeps. Her sister sleeps. Hänen siskonsa nukku-u. His/her sister sleep-PRS.3SG
2.7	Pronouns inside conversations (125-136)	John sleeps; he admires Mary. John admires Mary; he admires her. John admires Mary; his sister sleeps. It sleeps; he admires Mary. It sleeps; he admires her. It sleeps; it admires her.
2.8	Human vs. nonhuman pronouns (137-144)	John admires Mary; it sleeps. John admires Mary; he sleeps. Pekka ihaile-e Merja-a; se nukkuu. ‘Pekka.NOM admire-PRS.3SG Merja-PAR; it sleeps’ Pekka ihaile-e Merja-a; hän nukkuu. ‘Pekka.NOM admire-PRS.3SG Merja-PAR; he sleeps’
2.9	C-command tests (145-146)	John’s sister admires him. Peka-n sisko ihaile-e hän-tä. ‘Pekka-GEN sister admire-PRS.3SG he.PAR’
2.10	Pronouns and null subject sentences (147-150)	Pekka sanoo että ihaile-e hän-tä. 'Pekka says that admire.3SG.PRS he-PAR' Pekka sanoo että ihaile-n hän-tä. 'Pekka says that admire.1SG.PRS he-PAR' Hän sanoo että ihaile-e hän-tä. 'He says that admire.3SG.PRS he-PAR' Hän sanoo että ihaile-n hän-tä 'He says that admire.1SG.PRS h.e-PAR'
3	Reflexive pronouns, anaphors	
3.1	Grammatical, assignment possible (151-155)	John admires himself. Mary admires herself. he admires himself. she admires herself. Pekka ihaile-e itse-ä-än. ‘Pekka.NOM admire-3SG.PRS self-PAR-Px/3sg’ Hän ihaile-e itse-ä-än. ‘He.NOM admire-3SG.PRS self-PAR-Px/3sg’

3.2	*Gender mismatch (157-160)	John admires herself. Mary admires himself. He admires herself. She admires himself.
3.3	*Human mismatches (161-162)	It admires herself. It admires himself.
3.4	*Subject reflexives (163-176)	Himself admires John. Himself admires Mary. Himself admires he. Himself admires him. Himself admires she. Himself admires her. Himself admires it. Herself admires John. Herself admires Mary. Herself admires he. Herself admires him. Herself admires she. Herself admires her. Herself admires it.
3.5	Reflexives in conversations (177-182)	John admires Bill; he admires himself. John admires himself; he sleeps. John admires Mary; Bill admires himself.
3.6	C-command condition (183-184)	John's sister admires himself. Peka-n sisko ihaile-e itse-ä-än. 'Pekka-GEN sister.NOM admire-3SG.PRS self-PAR-Px/3sg'
3.7	Reflexives and control (185-201)	John wants Mary to admire herself. *John wants Mary to admire himself. John wants to admire himself. He wants to admire himself. Mary wants to admire herself. She wants to admire herself. *John wants to admire herself. *He wants to admire herself. John wants himself to admire Mary. *John wants herself to admire John. *Mary wants himself to admire John. Pekka halua-a Merja-n ihailevan itse-ä-än. 'Pekka.NOM want-3SG.PRS Merja-GEN admire.VA/inf self-PAR-Px/3SG' Pekka halu-si Merja-n ihaile-van itse-ä-än. 'Pekka.NOM want-3SG.PRS Merja-GEN admire-VA/inf self-PAR-Px/3SG' Pekka halua-a ihail-la itse-ä-än. 'Pekka.NOM want-3SG.PRS admire-A/inf self-PAR-Px/3SG' Hän halua-a ihail-la itse-ä-än. 'He.NOM want-3SG.PRD admire-A/inf self-PAR-Px/3sg' Pekka halua-a itse-nsä ihaile-van Merja-a. 'Pekka.NOM want-3SG.PRS self-GEN.Px/3SG admire-VA/inf Merja-PAR'
3.8	Ungrammatical reflexive inside that-clause (202-203)	John said that Mary admires himself. Mary said that John admires herself.
3.8	Reflexives and null subjects (204-207)	Pekka sanoo että ihaile-e itse-ä-än. 'Pekka says that admire-3SG.PRS self-PAR-.PX/3SG' Pekka sanoo että ihaile-n itse-ä-ni. 'Pekka says that admire-1SG.PRS self-PAR-PX/1SG'

We wanted to cover the basic empirical signature of the binding theory in order to show that the information processing model can reach the descriptive and explanatory depth of the standard autonomous linguistic analyses. Finnish was selected as the second target language for this study for three reasons. The first was because binding in Finnish has not been provided a systematic and comprehensive analysis in the previous literature that would also cover nontrivial binding configurations. It is hoped that this research could fill in that gap in the literature. The second reason was due to a few special properties of Finnish that were targeted for analysis in this study, such as its free word order profile and null subject behavior. Third, the author had access to native speaker informants of this language.

4 Results

4.1 Summary

Native speaker grammaticality judgments were first compared with the grammaticality judgments generated by the model. The comparison was performed with a mechanical file-comparison tool. The model reached 100% accuracy. It accepted all grammatical sentences and rejected the ungrammatical ones.

The coreference dependencies calculated by the model were evaluated next. The success rate was 100%. Whenever a coreference dependency was possible between two referential expressions in the input sentence, the model generated it (as in *John*$_1$ *claims that Mary*$_2$ *likes him*$_{1,*2}$); whenever a coreference dependency was not possible (e.g., *John*$_1$ *likes him*$_{*1}$), it was rejected. The details are examined in Section 4.2., but in principle this means that the analysis proposed here deduced the effects of the binding theory over the standard binding conditions as well as several nontrivial constructions.

While observational adequacy was checked by using a mechanical file-comparison tool, evaluation of coreference dependencies and other predicted syntactic properties cannot be mechanized and had to be checked by hand and by using linguistic expertise. This introduces a potential source of error or bias into the process. All the raw output is therefore available in the public domain. The detailed output of the algorithm is discussed in the next section.

4.2 Detailed results

4.2.1 Condition A

Binding condition A, illustrated by the example (7) from Finnish, requires reflexives to be bound locally. Symbol # refers to the same or equivalent sentence in the raw data generated by the algorithm (also Table 1).[9]

(7) a.	Pekka$_1$	ihaile-e	itse-ä(-än)$_{1,*2}$/	*itse-ä(-ni). (#1, 2)	
	Pekka.NOM	admire-3SG.PRS	self-PAR(-PX/3SG)	self-PAR(-PX/1SG)	
	‘Pekka admires himself/*myself.’				
b.	Minä$_1$	ihaile-n	*itse-ä(-än)/	itse-ä(-ni)$_{1,*2}$ (#3, 4)	
	I.NOM	admire-1SG.PRS	self-PAR(-PX/3SG)	self-PAR(-PX/1SG)	
	‘I admire *himself/myself.’				

The relevant assignments, calculated by the algorithm and available in the output files, are marked by the subscripts. When the numerical identifiers are identical, the corresponding assignment was *accepted* by the model (weight = 1); when the identifier is prefixed with the asterisk, it was *rejected* (weight = 0). Recall that the numbers are represented as indexes linking the expressions with objects in the global discourse inventory. The presence of a numeral identifier by itself means that a corresponding semantic object was generated into the global discourse inventory during sentence processing.

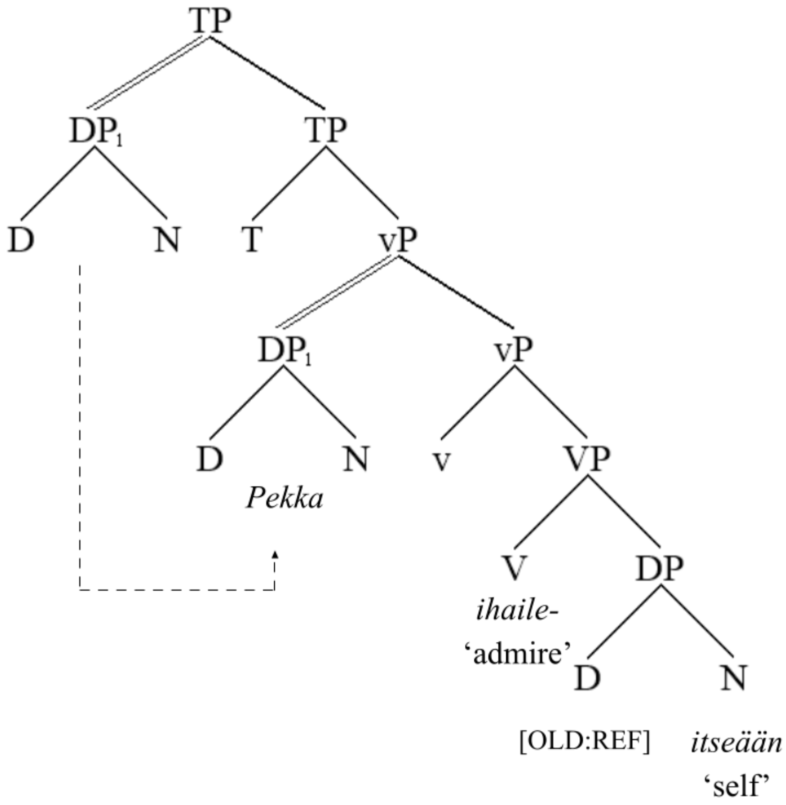
In (7a), the mechanism filters out all assignments where *Pekka* and *itseään* ‘self.PX/3SG’ do not refer to same entity in the discourse inventory.[10] If the reflexive is marked for the first person singular, this solution is filtered out on the basis of the mismatching phi-features, and therefore

[9] 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.

[10] Notice that neither *he* nor *himself* is ‘defective’ in its capacity to refer. Both are assigned independent denotations. This could be seen as controversial in the case of reflexive pronoun *himself*, but the assumption is made due to the data reported by Pollard & Sag (1992), discussed later in Section 4.2.4, which shows that reflexives can sustain independent denotations under pragmatic conditions. Since the operation takes place inside narrow semantics, the rankings can be adjusted downstream.

no solutions are found. Example (7b) is calculated in the same way. The syntactic analysis calculated by the algorithm for (7) is (8)(all phrase structure images presented here were generated by the algorithm, the author added few illustrations; the original images are available online).

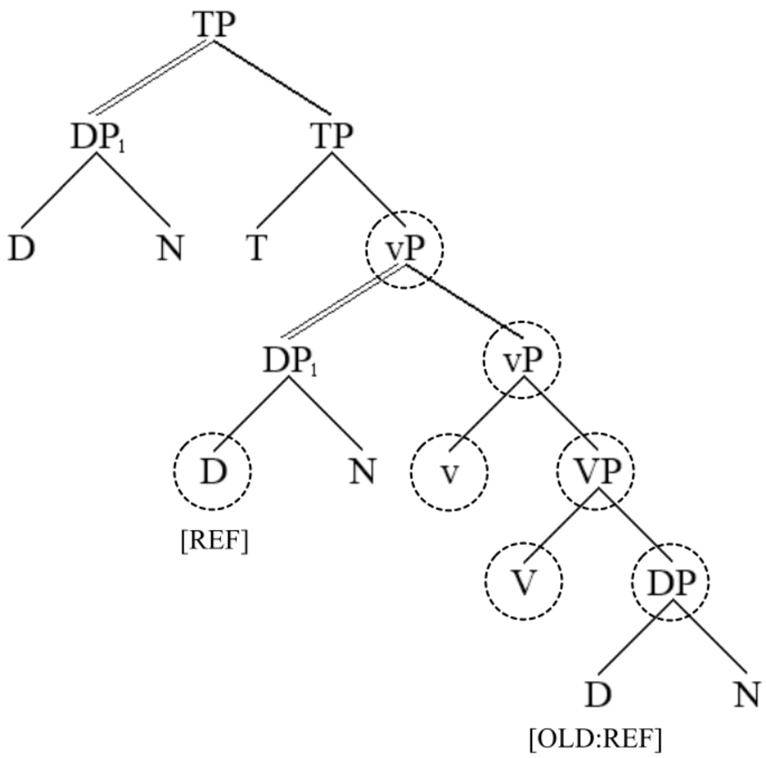
(8)



The model generates binary-branching phrase structures by chunking two constituents, either lexical items or complex constituents, into complex hierarchical representations α = [A B]. Each chunk is asymmetric, containing a left and right constituent. Polymorphemic words are first decomposed into primitive lexical items by the lexico-morphological component, followed by chunking (e.g., *admires* $\rightarrow$ $T_{[3sg]}$ + v + V $\rightarrow$ [T…[v…V…]]). Labels are generated by a general labelling algorithm and are not part of the chunks themselves.

On the basis of the output of the syntactic processing pathway, narrow semantics first generates two semantic objects into the global discourse space, 'Pekka'$_1$ and 'self'$_2$. Four possible assignments were considered: 'Pekka$_{\{1,2\}}$ admires self$_{\{1,2\}}$', and of these four, two are accepted: 'Pekka$_1$ admires self$_1$' and 'Pekka$_2$ admires self$_2$'. For any assignment, feature [OLD:REF] at the reflexive requires that whatever denotation is provided for this element under the particular assignment considered must be found from the reference set that can be accessed by upward path until the intervention feature [REF] is encountered. The following elements are in the upward path and are included into the reference set and thus considered by the algorithm:

(9)



The intervention feature [REF] at the thematic agent DP halts the search at vP. It follows that under any assignment the denotation for the reflexive must be the same as the denotation of the agent DP at SpecvP. Reflexive binding also ignores all referential elements that are not inside the upward path from the reflexive pronoun, which derives (10) in our dataset.

(10) a. *[John's$_1$ sister] admires himself$_1$. (#183)

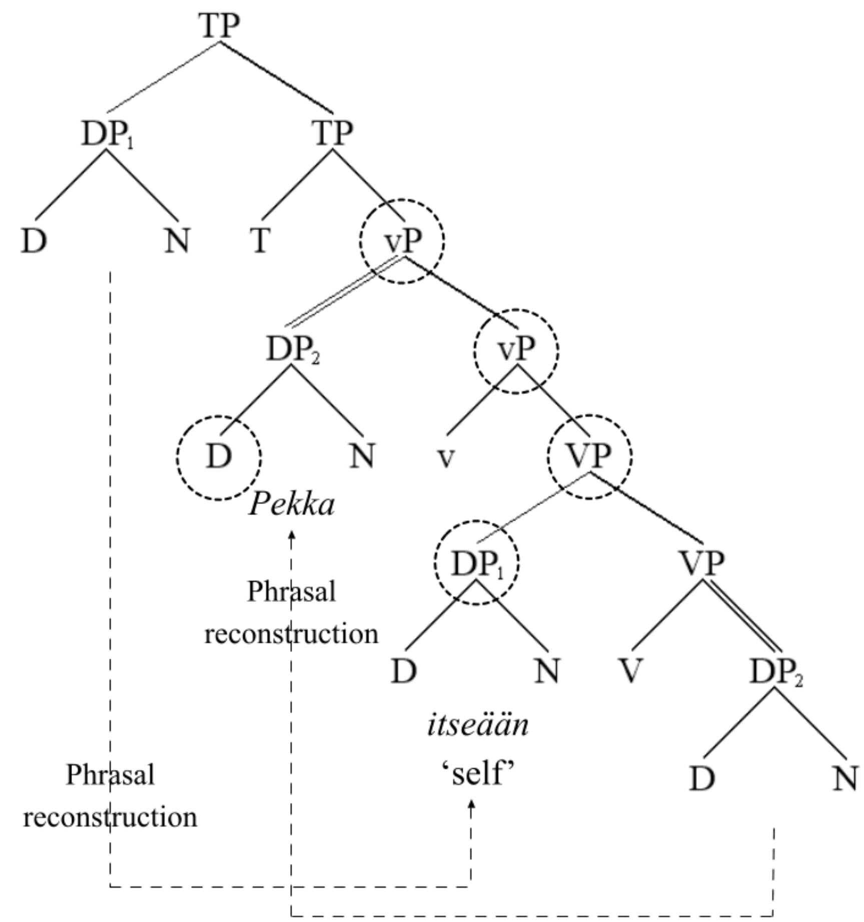
b. *[Peka-n$_1$ sisko] ihaile-e itse-ä-än$_1$. (#184)
Pekka-GEN sister.NOM admire-PRS.3SG self-PAR-PX/3SG
'Pekka's sister admires himself/*herself.'

John cannot be accessed from the reflexive; the only option is coreference between *John's sister* and *himself* that is rejected on the basis of the gender feature mismatch.[11]

Narrow semantics works with the endpoint of syntax in our analysis. If we reverse the order of the arguments in the input, the syntactic processing path first normalizes the expression and calculates the assignments on the basis of the normalized representation. The result is (11). Binding condition A ignores discourse-based word order permutations, as shown by (12), so this assumption seems valid.

[11] The morphological form of the Finnish reflexive pronoun merits a comment. The Finnish reflexive contains a SELF-pronoun *itse* 'self' suffixed with an infinitival agreement marker (also called "possessive suffix" in the literature), glossed as PX, that must match with the antecedent in person and number. There is some controversy over the syntactic nature of the Finnish possessive suffix *ni*/*An/nsA* in the literature (Huhmarniemi & Brattico, 2015; Kaiser, 2003; Kanerva, 1987; Toivonen, 2000; Trosterud, 1990, 1993; Vainikka, 1989; van Steenbergen, 1987, 1991). Because it is optional in these contexts and has a wide variety of other uses, I did not attempt to include it into the calculations as a separate morpheme. The reflexive *itse-nsä* 'self-PX/3SG' was represented as a reflexive pronoun with no further syntactic structure. Note that 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, pp. 196–197, 213–216). This assumption might require revision in the future, but it was sufficient to calculate the present dataset.

(11)



(12) Itse-ä-än$_1$ ihaile-e Pekka$_1$. (#5)
self-PAR-PX/3SG admire-3SG.PRS Pekka.NOM
'Pekka (information focus) admires himself (topic).'

The same reasoning applies to the standard filler-gap dependencies (Ā-dependencies in linguistic parlance) such as interrogatives: operators are canonicalized inside the syntactic processing pathway (Brattico & Chesi, 2020) and only then considered for assignment according to our analysis (13).

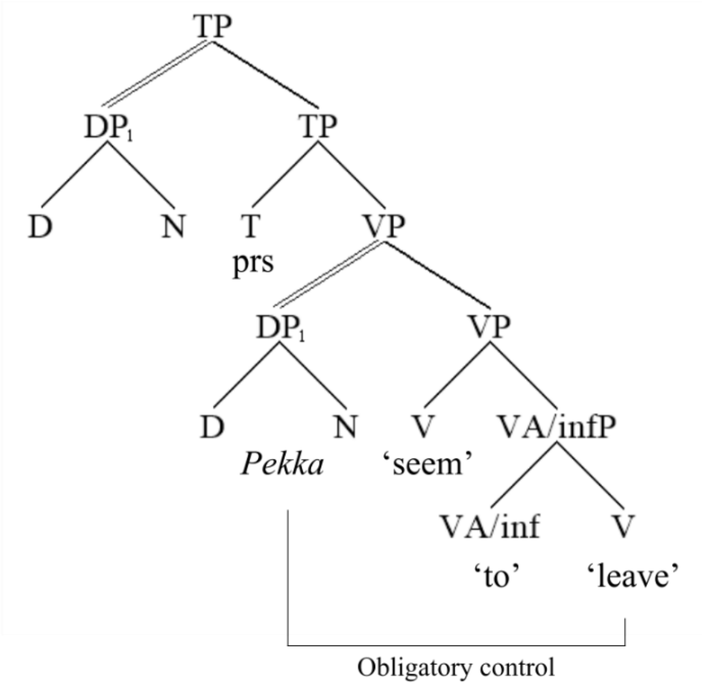
(13) Itse-ä-än$_{1,*2}$-kö Pekka$_1$ ihailee __? (#6)
self-PAR-PX/3SG-Q Pekka.NOM admire-3SG.PRS
'Was it himself that Pekka admires?'

Q is a yes/no particle corresponding to yes/no interrogativization and an interrogative operator reading of the fronted reflexive direct object argument (see the translation). Data from Finnish Ā-reconstruction and adjunct reconstruction therefore support the hypothesis that narrow semantics accesses only the endpoint of syntax, as assumed in the model (see Figures 1, 2). The case with successive-cyclic Ā-reconstruction and 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). They are provided in (14).

(14)	a.	Pekka$_{1, i}$	näyttä-ä	omasta	mielestä-än$_1$	__$_i$	ole-va-n(sa)	valmis.
		Pekka.NOM	seem-3SG.PRS	own	mind-PX/3SG		be-VA/INF-(PX/3SG)	ready
		‘Pekka seems to his own mind to be ready.’						
	b.	Pekka$_{1, i}$	näyttä-ä	opettaja-nsa$_1$	mielestä	__$_i$	ole-van	älykäs.
		Pekka.NOM	seem-3SG.PRS	teacher-PX/3SG	opinion		be-VA/INF	intelligent
		‘Pekka seem to his teacher to be intelligent.’						
	c.	Pekka$_{1, i}$	näyttä-ä	itse-nsä$_1$	mielestä	__$_i$	komealta.	
		Pekka.NOM	seem-3SG.PRS	self-PX/3SG	opinion		handsome	
		‘Pekka seem to himself (to be) handsome.’						

The subject constitutes a binder for an anaphoric and/or reflexive element inside the main clause. Many linguistic theories assume, however, that it is A-reconstructed into the trace position, marked by the gap __, where the required interpretations can no longer be accessed. This is a potential problem. It does not arise here, however, because the syntactic background algorithm does *not* reconstruct the grammatical subject into the embedded infinitival; rather, these sentences are analysed as obligatory control constructions (15)(#7).

(15)



This is not self-evidently correct. If the control analysis of the Finnish raising construction is deemed problematic, then I do not see any other option than to question the assumption that assignments are determined solely on the basis of the endpoint of the syntactic processing pathway. This would require rethinking of the architecture depicted in Figures 1 and 2 and was left for future research, also because the coreference dependencies *were* calculated correctly, making the possible adjustments untestable in the context of the present dataset.[12]

English reflexives are processed in the same way, but involve an additional gender factor. Sentence **John admires herself* (#8, 157) receives no assignment because the gender feature of the reflexive does not match with the gender feature of any object that appears in its reference set (e.g., 'John').[13] English reflexives and gender mismatches are tested by sentences #151-154

[12] I encountered a few additional examples of potential surface effects on binding in the course of this research, suggesting that the more complex alternative could eventually be warranted, but the examples were too complex and nontrivial to be used in an argument without a detailed, article-length analysis.

[13] It is assumed, however, that the impossible coreference dependencies may get revised downstream by global cognition. This related to cases in which John decides to use female gender pronouns, for example, and this knowledge overrides phi-feature calculations inside narrow syntax that is not sensitive to nonmodular knowledge of the world.

and #157-162. Several additional English gender mismatches were tested by sentences in groups §3.2, 3.3. Finnish pronouns and reflexives do not exhibit gender distinctions; human and nonhuman distinction (*se* 'it' ~ *hän* 's/he') was used for testing purposes (#9-11). Examples like (16)(#11) show that the system works correctly. Thus, in a context where some nonhuman object, such as a pet dog, is discussed, the following assignments are possible:

(16) Pekka$_1$ sanoi että Merja$_2$ ihaile-e sitä$_{*1,*2,3}$ (#11)
Pekka.NOM said that Merja.NOM admire-PRS.3SG it.PAR (e.g., a pet dog)
'Pekka said that Merja admires it (a pet dog, for example).'

The test corpus has sentences testing inverse subject-reflexive constructions such as *himself admires John* (§3.4), which were correctly ruled out, and reflexives inside conversations (§3.5). Reflexive binding was also tested in connection with control constructions (§3.6). Examples (17) show the tested patterns in English, but the same constructions or equivalents were also tested in Finnish.

(17) a. John wants Mary$_1$ to admire herself$_1$/*himself. (#185, 187)
b. John$_1$ wants to admire himself$_{1,*2}$/*herself (#189-192, 195-6)
c. John$_1$ wants himself$_{1,*2}$/*herself to admire Mary (#197-201)

Presence of the infinitival subject (specifically, its [REF] feature) cuts the upward paths (17a); its absence allows the binding dependency to link an embedded object with the main clause subject (17b). On the other hand, infinitivals involve an extra complication because their grammatical analyses are controversial, and particularly so in Finnish. The syntactic analyses calculated by the syntactic background model, both Finnish and English, are visible in the output and must be assessed in a separate study; to me they do not appear completely implausible. I will ignore the issue here, because the infinitival data was calculated correctly and no change in the underlying assumptions was needed. Binding from an embedded *that*-clause into the main clause subject was correctly ruled out (group §3.7 in the dataset, Table 1).

4.2.2 Condition B

Condition B of the binding theory, tested systematically by sentences in group §2, restricts pronouns into positions where they are not locally bound in Finnish, as first discussed by van Steenbergen (1991). Pronouns are endowed with [NEW:REF] requiring an assignment that does *not* denote the same object as another expression inside the reference set. This assumption derives (18) in our dataset. Only the relevant assignments are shown.

(18) a. Pekka$_1$ ihaile-e hän-tä$_{*1,2}$. (#12, #79-80)
Pekka.NOM admire-3SG.PRS he-PAR
'Pekka$_1$ admires him$_{*1,2}$.'

b. Pekka$_1$ sanoo että Merja$_2$ ihaile-e hän-tä$_{1,*2,3}$. (#13)
Pekka.NOM says that Merja.NOM admire-3SG.PRS he-PAR
'Pekka$_1$ said that Merja admires him$_{1,2}$.'

c. [Peka-n$_1$ sisko]$_2$ ihaile-e hän-tä$_{1,*2,3}$. (#14, §2.9)
Pekka-GEN sister admire-3SG.PRS he-PAR
'Pekka's sister admires him.'

d. Pekka$_1$ ihaile-e [hän-en$_{1,2}$ sisko-a-an.] (#83)
Pekka.NOM admire-PRS.3SG he-GEN sister-PAR-PX/3SG
'Pekka admires his sister.'

Under no assignment can the pronoun refer to the same person as the subject. This condition does not prevent coreference in (18), because the embedded clause triggers intervention by [REF] at the head of the embedded subject. In example (18), the possessive DP *Peka-n* 'Pekka-GEN' does not occur inside the reference set calculated for the pronoun *hän-tä* 'he-PAR', because it is not visible in the upward path from the pronoun. Example (18b) will be discussed in detail in Section 4.4.4; the internal structure of the possessive constructions more generally is discussed in Section 4.4.5. Combinations of pronouns, proper names and various phi-features (gender, human) in English, formed from (19), are in the group §2.1 (sentences #64-78) and in group §2.2 (sentences #84-87). The case assignment patters were tested in group §2.3, sentences #90-97. They were computed correctly.

(19) John/Mary/he/she/it admires John/Mary/him/her/it (all combinations).

The testing of English possessive constructions such as *John admires his sister* (#77, 78) requires a comment. The possessive sentence is represented by *John admires he='s sister* in the test corpus, where symbol = denotes a clitic boundary and *'s* is the possessive clitic. The syntactic model calculates (20). Pronoun *his* can share reference with the main clause subject due to the intervening referential constituent D('*s*) and is [REF] feature. I will return to the internal analysis of DPs in Section 4.4.5.

(20) [*John*$_1$ [*admires* [$_{DP}$ D(’*s*) [$_{NP}$ *he*$_{1,2}$ *sister*]]]
[REF]

Pronouns can co-refer with the main clause subject if they occur inside embedded that-clauses (21), #98-103 for equivalent sentences in English. These tests are in group §2.4.

(21)	a.	Pekka$_1$	sanoi	että	hän$_{1,2}$	ihaile-e	Jukka-a$_{*1,*2,3}$. (#106)
		Pekka.NOM	said	that	he.NOM	admire-PRS.3SG	Jukka-PAR
		‘Pekka said that he (Pekka, third party) admires Jukka.’					
	b.	Pekka$_1$	sanoi	että	Merja$_2$	ihaile-e	hän-tä$_{1,*2,3}$. (#105)
		Pekka.NOM	said	that	Merja.NOM	admire-PRS.3SG	he-PAR
		‘Pekka said that Merja admires him (Pekka, third party).’					
	c.	Pekka$_1$	sanoi	että	hän$_{1,2}$	ihaile-e	hän-tä$_{1,*2,3}$ (#107)
		Pekka.NOM	said	that	he.NOM	admire-PRS.3SG	he-PAR
		‘Pekka said that he (Pekka, third party) admires him (Pekka, fourth party).’					

The calculated assignment possibilities for the second pronoun in (21c) depend on the assignments provided for the first pronoun. If the first pronoun *hän* ‘he’ denotes the same object as Pekka under some assignment, then under that same assignment the second pronoun cannot denote Pekka because the denotation is reserved by the first pronoun (*Pekka*$_1$ – *he*$_1$ – *him*$_{*1,2}$). If the first pronoun denotes somebody else, then coreference is again possible (*Pekka*$_1$ – *he*$_2$ – *him*$_{1,*2,3}$). These were calculated correctly by the algorithm.

These data suggest that the complementizer creates an intervention, which follows if it has [REF]. This is supported by the observation that infinitivals, such as (22), do not have the coreference reading (group §2.5). The complementizer is missing, hence no intervention.

(22)	a.	Pekka$_1$	halua-a	[hän-en$_{*1,2}$	ihaile-van	Merja-a.]
		Pekka	want-PRS.3SG	he-GEN	admire-VA/INF	Merja-PAR
		‘Pekka wants him (≠Pekka) to admire Merja.’				
	b.	John$_1$ wants him$_{*1,2}$ to admire Mary.				

Perhaps complementizers function like sentential D-elements. They will project propositional ‘thing objects’ into the discourse inventory that can function as antecedents of nonhuman pronouns (e.g., *Mary claimed that* [*the dog was dead*]$_1$ *and John believed it*$_1$). Projection of propositional thing objects and propositional binding of this type was originally excluded from this study and was not added later on. If the phi-features match, coreference reading is available from the direct object position, as the embedded subject causes intervention (23)(#108-111, #118-120, #121).

(23) John$_1$ wants Mary$_2$ to admire him$_{1,*2,3}$/her$_{*1,*2,3}$.

Pronouns can refer to any object inside the global discourse inventory as long as the phi-features match. This feature was tested by embedding pronouns inside conversations (group §2.7). The model calculates these dependencies correctly, as shown by example (24).

(24) a. John$_1$ admires Mary$_2$; he$_{1,3}$ admires her$_{2,4}$. (#127-128)
b. It$_1$ sleeps; he$_{*1,2}$ admires Mary$_{*1,*2,3}$. (#131-132)

In (24a), the first sentence generates two objects 'John' and 'Mary' into the discourse inventory. This inventory is available when denotations are calculated for the pronouns in the second sentence. Taking the phi-features into account, both pronouns can refer either to an existing object in the discourse inventory (*he* = 'John', *her* = 'Mary') or to new objects generated while reading the second sentence. Phi-feature mismatches prevent all coreference readings in (24b). Systematic phi-feature tests are in group §2.8.

4.2.3 Condition C

Condition C of the binding theory, which was tested systematically by sentences in group §1.4, states that an r-expression (represented by proper names in the present study) cannot be bound. This condition was captured by feature [NEW:_] which requires that the denotation must be new in relation to its reference set calculated by assuming no intervention. This derives the dataset (25). All coreference readings are ruled out in these examples unless specifically marked as possible (e.g., example c).

(25) a. Hän$_1$ ihaile-e Merja-a$_{*1,2}$. (#15, #56)
he.NOM admire-3SG.PRS Merja-PAR
'He admires Merja.'
b. Pekka$_1$ sanoi että Merja$_2$ ihaile-e Jukka-a$_3$. (#16)
Pekka.NOM said that Merja.NOM admire-3SG.PRS Jukka-PAR
'Pekka said that Merja admires Jukka.'
c. [Hänen$_1$ siskonsa]$_2$ sanoi että Pekka$_{1,3}$ ihaile-e Merja-a$_{1,*2,*3}$. (#17, #58)

S/he.GEN sister said that Pekka.NOM admire-3SG.PRS Merja-PAR
'His/her$_1$ sister said that Pekka admires Merja$_{1,2}$.'

d. Hän$_1$ sanoi että Pekka$_2$ ihaile-e Merja-a$_3$. (#57)
S/he said that Pekka.NOM admire-PRS.3SG Merja-PAR
'He said that Pekka admires Merja.'

The corresponding English sentences are #50-55, group §1.4. Without intervention feature the dependency extends through the whole structure (25b) (group §1.2 in test corpus). These dependencies are regulated by the upward path mechanism (25c); hence it is possible to use a proper name to denote a discourse old object, as shown by (26) below.

(26) John$_1$ sleeps; John$_{1,2}$ admires Mary. (#18-19, also group §1.5, #59-62)

The same logic extends to infinitivals (27)(group §1.3), where all proper names must be disjoint in reference.

(27) a. John$_1$ wants Mary$_{*1,2}$ to admire Bill$_{*1,*2,3}$. (#48)
b. Pekka$_1$ sanoo Merja-n$_{*1,2}$ ihaile-van Jukka-a$_{*1,*2,3}$. (#49)
Pekka says Merja-GEN admire-VA/INF Jukka-PAR
'Pekka says that Merja admires Jukka.'

Sentences (28) were also calculated correctly.

(28) a. John$_1$ admires Mary$_{*1,2}$. (#40)
b. John$_1$ admires John$_{*1,2}$. (#42)

The coreference reading in (28a) is ruled out both by the binding conditions and by gender mismatch; in (28b) it is ruled out only by binding. Thus, repetition of upward path connected proper names generates disjoint reference readings that can be resurrected downstream if prompted by pragmatic conditions. All sentences of this type, for English and Finnish, are in group §1.1 in the test corpus.

4.2.4 Apparent violations of the Binding Conditions

Previous literature has reported several examples where binding conditions are seemingly violated. The following examples were discussed by Reinhart (1983, pp. 168–169), who cites

Evans (1980). These sentences played a major role in shaping the cognitive architecture assumed here.

(29) a. I know what John and Bill have in common. John thinks that Bill is terrific and Bill thinks that Bill is terrific. (Example (55a), p. 168, in the original)

b. I know what Bill and Mary have in common. Mary adores Bill and Bill adores Bill / and Bill adores him too. (Example (57a), p. 169, in the original)

Example (29a) violates Condition C; example (29b) Condition B. A long list of similar exempt anaphors including reflexives were listed in Pollard & Sag (1992), reviewing and relying on much previous work, and then discussed by many others (see Charnavel 2021 for a recent work). According to the model proposed here, violations of binding conditions reduce the weights of the corresponding assignments to zero instead of eliminating them, so that downstream cognitive processes can resurrect them. Recall that the output of narrow semantics must still pass through global cognition before it appears in the output of the algorithm (Figure 2). Thus, the output does not contain just the accepted assignments and coreference dependencies; assignments that were rejected by narrow semantics component appear in the output but with the weight set to 0. They may then get resurrected under the appropriate plausibility conditions, some of which are illustrated by (29). Formulation of the relevant pragmatic conditions presupposes, however, that we have access to an extremely fine-grained and advanced semantic system, so the issue was not tackled here.

4.2.5 Null subject sentences

Finnish is a partial pro-drop language, which allows grammatical subject pronouns to be dropped in all person and number configurations with the exception of the third person (31a-b) (Vainikka, 1989; Vainikka & Levy, 1999).

(30) a. Ihaile-n Merja-a. (#20, 63)
admire-1SG.PRS Merja-PAR
’(I) admire Merja.’

b. *Ihaile-e Merja-a.
admire-3SG.PRS Merja-PAR
Intended: ’He admires Merja.’

The calculated output for (30a) is [$_{TP}$ T_{pro} [$_{vP}$ v [$_{DP}$ *Merjaa*]]] where the first person agreement suffix -*n* in the input projects a phi-set φ = [1SG] inside the tense node T = $T_{[3SG]}$. The pronominal agreement cluster functions as a pro-element in syntax, generating T_{pro}. Because the assignment mechanism is triggered by nominal phi-features, T_{pro} projects the singular first person object (speaker) to the discourse inventory and derives (31), where the reflexive is bound by the pro-element inside the predicate.

(31) Ihaile-n_1 itse-ä-$ni_{1,*2}$. (#21)
admire-1SG.PRS self-PAR-PX/3SG
'I admire myself.'
[T_{pro1} [v [DP $self_1$]]]

Notice that the model correctly calculates a disjoint reference reading for (30b) due to the Condition C of the binding theory: T_{pro} and the proper name cannot refer to the same thing even though their phi-features match (#63). A 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 (32). As shown by the translation, the thematic subject of the embedded but subjectless clause must be the same as the subject of the main clause.

(32) Pekka sanoo että [ihaile-e Merja-a.] (#22)
Pekka says that admire-3SG.PRS Merja-PAR
'$Pekka_1$ says that he (=$Pekka_1$) admires Merja.'

This phenomenon has received much interest in the literature (Brattico, 2017; Holmberg, 2005; Holmberg & Sheehan, 2010; Vainikka, 1989; Vainikka & Levy, 1999), one view being that the third person pro-element is too 'weak' and requires semantic 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 D-feature, which triggers antecedent support (Brattico, 2021b). The problem is that antecedent support does not constraint assignments. What we need to do is to introduce an additional condition which makes it so that if a predicate is assigned an argument by antecedent support, as in (33), its own pro-element must be assigned the same interpretation. Once I added this restriction to the algorithm, the data comes our correctly (33)(also group §2.10). Also reflexive binding was tested inside these environments (§3.8, #204-207).

(33) a. Pekka$_{1}$ sanoo että pro$_{1,*2}$ ihaile-e Merja-a$_{*1,*2,3}$. (#22, #147)
Pekka says that admire-3SG.PRS Merja-PAR
'Pekka says that he =(Pekka) admires Merja.'

b. Pekka$_{1}$ sanoo että pro$_{1,*2}$ ihaile-e itse-ä-än$_{1,*2,*3}$. (#23)
Pekka says that admire-3SG.PRS self-PAR-PX/3SG
'Pekka says that he (=Pekka) admires himself.'

c. Pekka$_{1}$ sanoo että pro$_{1,*2}$ ihaile-e hän-tä$_{*1,*2,3}$. (#24)
Pekka says that admire-3SG.PRS he-PAR
'Pekka says that he (=Pekka) admires him (≠ Pekka).'

d. Pekka$_{1}$ sanoo että pro$_{*1,2}$ ihaile-n hän-tä$_{1,*2,3}$. (#25, #148)
Pekka says that admire-1SG.PRS he-PAR
'Pekka says that I admire him (Pekka or someone else).'

Pro-subject functions as an intervention element for the pronoun, allowing the pronoun to pair with the main clause subject. This is because it contains the intervention feature [REF]. This means that both the subject and an Agr head (here T_{pro}) can define a local domain for anaphors (Chomsky, 1981: 209–211). The results are the same if *Pekka* is replaced with *hän* 'he' (#149, 150).

When the input sentence contains both a grammatical subject and a T_{pro}-element, the model still creates rogue interpretations illustrated in (34).

(34) Hän$_{1}$ ihaile-e$_{1,2,3}$ Merja-a$_{3}$.
he.NOM admire-3SG.PRS Merja-PAR
'He admires Merja.'

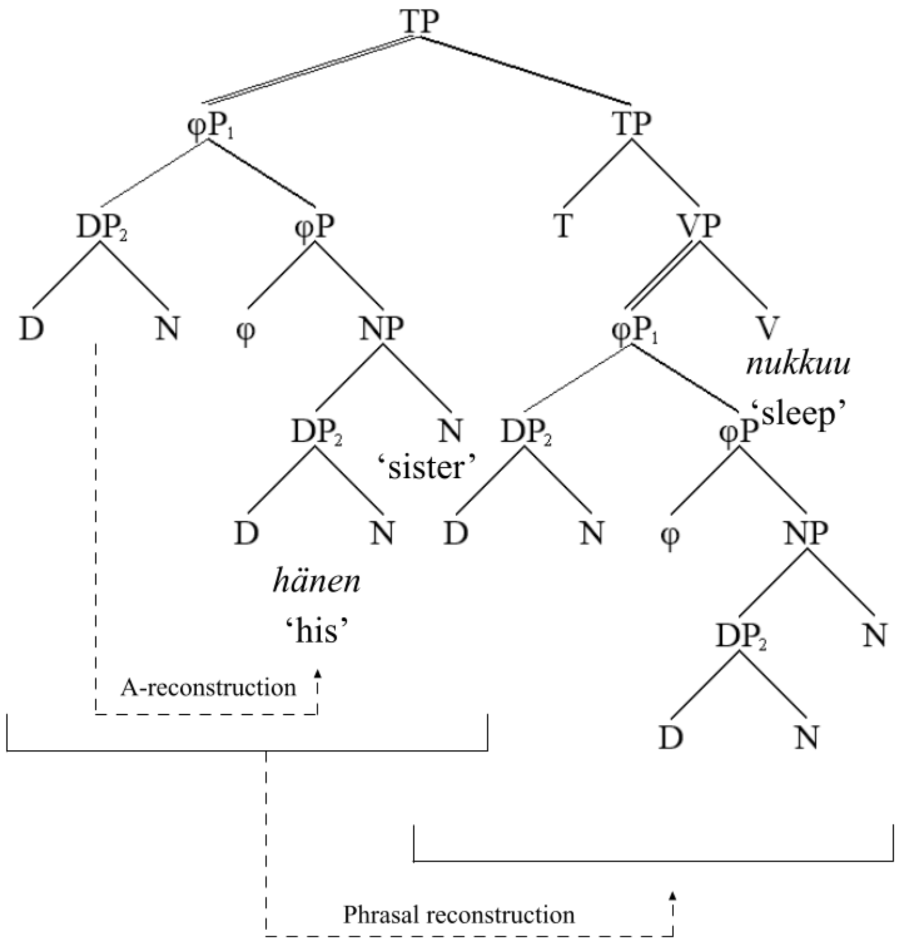
The pro-element inside T_{pro} establishes its own denotation. The subject and the pro-element at T_{pro} cannot, however, refer to separate semantic objects. This problem was solved by assuming that the operation Agree, which checks the phi-features of the predicate against the properties of the grammatical subject, pre-empts both antecedent support and the projection of a separate pro-element into the discourse inventory. The fact that these connections had to be forced into the algorithm suggests that the three mechanisms – control, agreement and binding – share an underlying (to me, unknown) mechanism.

4.2.6 DP-internal binding

The syntax and semantics of full argument DPs and binding inside such constructions present special issues. In some earlier models that used the same syntactic background, full arguments were assumed to consist of [$_{DP}$ D NP] structures, following the DP-hypothesis (Longobardi, 1994). The problem is that Finnish lacks grammaticalized articles and D elements cannot be assumed to be present in the input. This issue was solved in this study by assuming, following the line of analysis by Déchaine & Wiltschko (2017), Déchaine & Wiltschko (2002) and van Steenbergen (1987, 1991), that full bare nominal arguments can be analyzed as [$_{\varphi P}$ φ N] structures, where φ is a nominal agreement cluster carrying phi-features. All bare noun arguments in Finnish were analyzed in this way (e.g., *sisko* ‘sister’ → [$_{\varphi P}$ φ sister]). The possessive argument is then generated to SpecφP and gets reconstructed to SpecNP (36-37).

(35)	Hän-en	sisko-nsa	nukku-u. (#26)
	S/he-GEN	sister.NOM-PX/3SG	sleep-3SG.PRS
	’His/her sister sleeps.’		

(36)

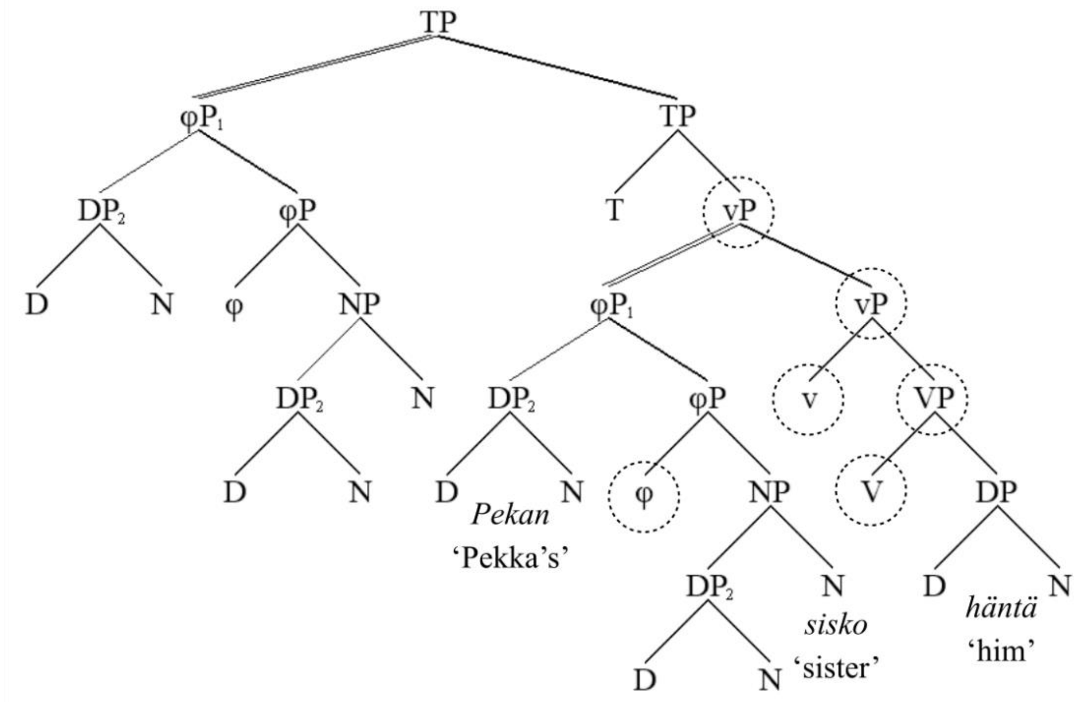


In English, ’*s* is interpreted by the syntactic background theory as a clitic, projecting *his sister* = [$_{DP}$ D(’s) [[D he] N]], assuming that ’*s* represents D. While this is controversial, what matters is that the possessive DP is invisible for upward paths emerging from any element inside the hosting clause. Such upward paths will see φ but not the possessive pronoun:

(37) [$_{φP}$ Peka-n$_1$ sisko]$_2$ ihaile-e hän-tä$_{1,*2,3}$. (#27)
Pekka-GEN sister admire-3SG.PRS s/he-PAR
‘Pekka’s sister admires him.’

The analysis, showing the upward path calculations from the direct object pronoun, is (38).

(38)



Another consequence of this analysis is that both (39a-b) are calculated correctly. D^0 and φ^0 intervene, allowing the pronoun to refer to the main clause subject.

(39) a. John$_1$ admires [$_{DP}$ D his$_{1,2}$ sister]$_3$. (#28)

b. Pekka$_1$ ihaile-e [$_{\varphi P}$ φ (hän-en$_1$) sisko-a(-an).] (#29)
Pekka.NOM admire-3SG.PRS (he-GEN) sister-PAR(-PX/3SG)
'Pekka admires his sister.'

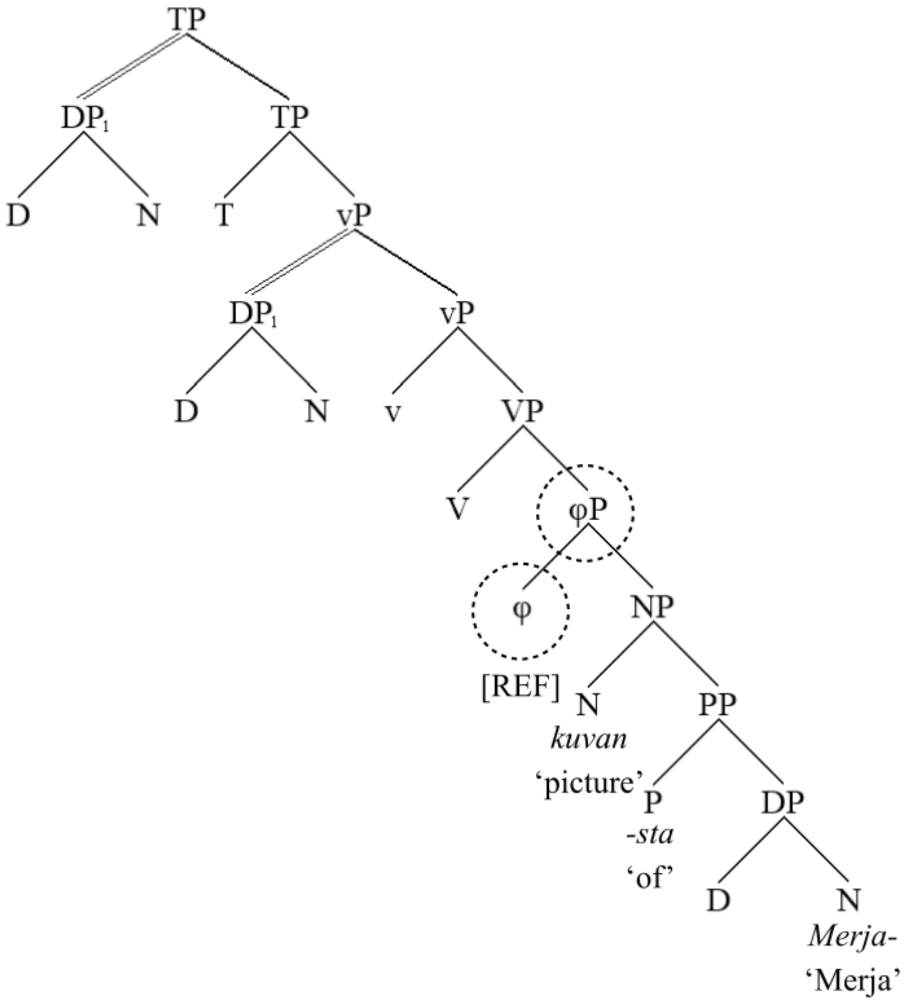
The Finnish version (39b) with the coreference reading feels marginal but not ungrammatical. Chomsky (1981, p. 65) proposes that these constructions exhibit an "avoid pronoun" principle that prefers null pronouns when an overt pronoun would be redundant; see also Kaiser (2003), footnote 2, p. 9, who notices that her native speakers "permit" reading (39b) against "standard judgments." It is unclear to me what Kaiser means by "standard judgments" here, most likely it is meant to exclude sentences judged as marginally acceptable; to me, (39b) is indeed possible but marginal. A potential issue is that both pronouns and reflexives are possible in the complement positions of nouns (40).

(40) a. Pekka$_1$ ott-i kuva-n itse-stä-än$_{1,*2}$
Pekka.NOM take-3SG.PST picture-ACC self-ELA-PX/3SG
'Pekka took a picture of himself.'

b.	Pekka$_1$	ott-i	kuva-n	hän-estä$_{??1,2}$.
	Pekka.NOM	take-3SG.PST	picture-ACC	he-ELA
	'Pekka took a picture of him.'			
c.	Pekka$_1$	ott-i	kuva-n	Merja-sta$_2$. (#31)
	Pekka.NOM	take-3SG.PST	picture-ACC	Merja-ELA
	'Pekka took a picture of Merja.'			

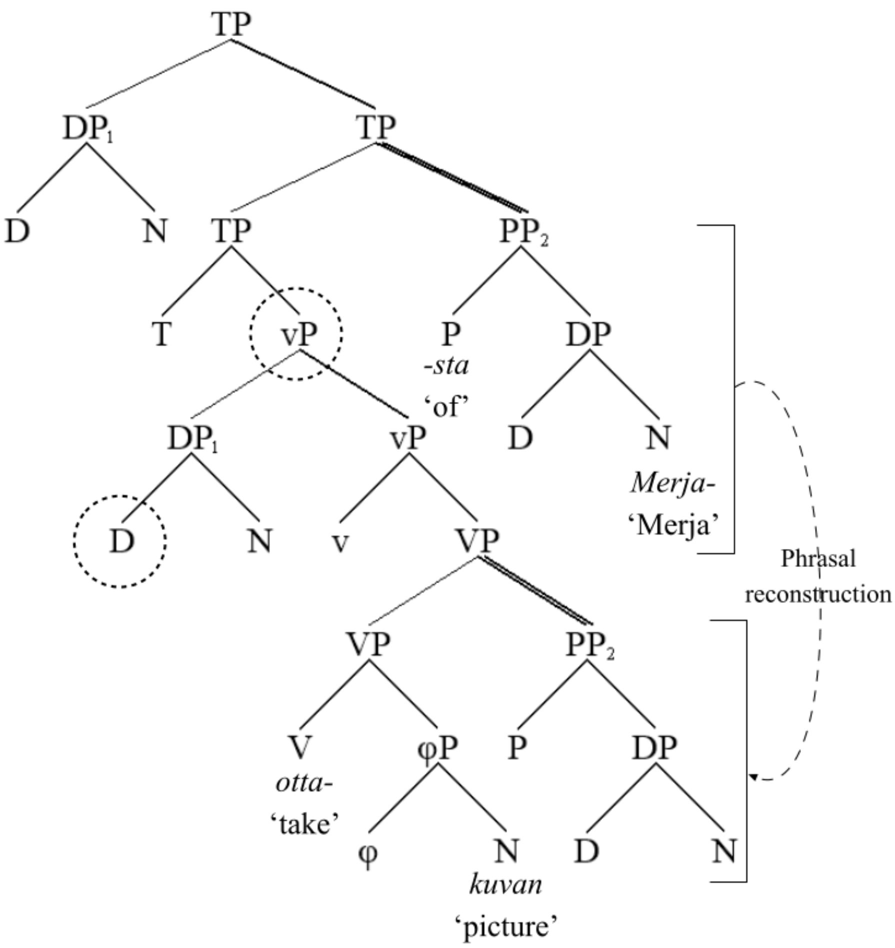
At first this data seems to contradict the present hypothesis, which predicts pronouns and reflexives to be complementary. Feeding these expressions to the syntactic background model reveals a different picture. Due to the discourse-configurationality of Finnish, the syntactic background model treats both the accusative-marked direct object and the preposition as adjuncts. This means that input sentences such as (40a-c) will have multiple ambiguities depending on the assumed position of both the direct object and the PP. The first solution found by the model is (41)(see #31).

(41)



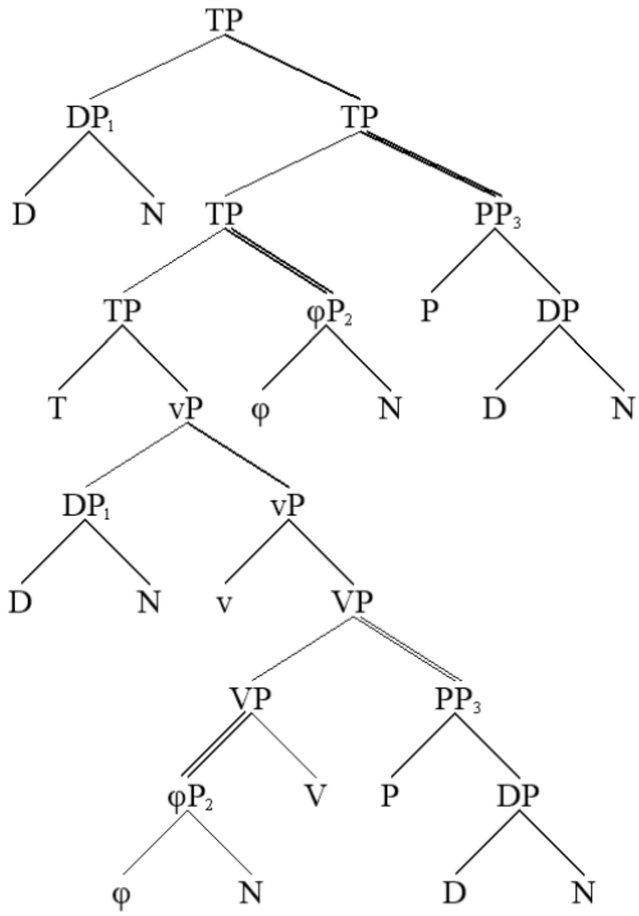
The PP 'of Merja' was analysed as the complement of the noun head 'picture' to create a complex DP with the meaning 'a picture of Merja'. Because φ causes intervention, shown by the circles in (41), upward path reaches φ, licensing 'Pekka$_1$ took a picture of him$_1$' but not 'Pekka$_1$ took a picture of himself$_1$'. The second parse is (42), line 1398.

(42)



The parser assumed that the PP is right-adjoined to the TP, and reconstructed it as right-adjoined to VP. Under this interpretation, the sentence means roughly 'Pekka took a picture, and it was of Merja', so that 'of Merja' is interpreted as an argument of the verb or event and not as the complement of N. The reference set for the DP inside PP contains everything up to the subject and the direct object is invisible, thus we get 'Pekka$_1$ took a picture of himself$_1$' and not 'Pekka$_1$ took a picture of him$_1$'. This ambiguity derives the data in (40). The third analysis is (43).

(43)



Here both the direct object and the PP were initially analysed as being adjoined to the right of TP, and both were reconstructed. The binding possibilities are those of (42). If we assume that in English picture PPs can be adjoined while DPs can't, then we get (41) and (42) but not (43), which is sufficient to capture data from English.

4.2.7 Embedded infinitivals

Embedded infinitivals are transparent to upward paths. Embedded pronouns cannot co-refer with main clause subjects, while reflexives can. The model calculates these dependencies correctly, both for English (44) and Finnish (45). Note that Finnish has several infinitival forms glossed as A/INF (A-infinitival) and VA/INF (VA-infinitival)(Koskinen, 1998; Vainikka, 1989).

(44) a. John$_1$ wants to admire him$_{*1,2}$. (#32)

b. John$_1$ wants to admire himself$_{1,*2}$ (#33)

(45)	a.	Pekka$_1$	halua-a	[ihail-la	hän-tä$_{*1,2}$.] (#34)
		Pekka.NOM	want-3SG.PRS	admire-A/INF	he-PAR
		‘Pekka wants to admire him.’			
	b.	Pekka$_1$	halua-a	[ihail-la	itse-ä-än$_{1,*2}$.] (#35)
		Pekka.NOM	want-3SG.PRS	admire-A/INF	self-PAR-PX/3SG
		‘Pekka wants to admire himself.’			

An embedded subject, however, does cause intervention and reverses the pattern (46).[14]

(46)	a.	Pekka$_1$	halua-a	[Merja-n$_2$	ihaile-van	hän-tä$_{1,*2,3}$.] (#36)
		Pekka.NOM	want-3SG.PRS	Merja-GEN	admire-VA/INF	he-PAR
		‘Pekka wants Merja to admire him.’				
	b.	Pekka$_1$	halua-a	[Merja-n$_2$	ihaile-van	itse-ä-än$_{*1, 2,*3}$.] (#37)
		Pekka.NOM	want-3SG.PRS	Merja-GEN	admire-VA/INF	self-par-PX/3SG
		‘Pekka wants Merja to admire herself/*himself.’				

Positioning the pronouns to the embedded subject position calculates the expected results: pronouns cannot co-refer with the main clause subject while reflexives can. van Steenbergen (1991) suggests however that the binding domain for the Finnish reflexive is determined by tense and supports the generalization by citing the VA-infinitival construction (example (6a) in the original, p. 235, my glossing):

(47)	Pekka$_1$	näki	[$_{\text{VA/infP}}$	Mat-in$_2$	katso-van	itse-ä-än$_{1,2}$.]
	Pekka.NOM	see.3SG.PST		Matti-GEN	look-VA/INF	self-PAR-PX/3SG
	‘Pekka saw Matti watch himself.’					

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). This claim is not isolated, however; also Trosterud (1990, p. 69) judges (48) grammatical (=ex. 35b in the original).

[14] These results correspond to the effects of the “Specified Subject Condition” of the standard binding theory (Chomsky, 1977, 1981; Chomsky & Lasnik, 1977).

(48) Maija$_1$ käsk-i meidän pes-tä itse-nsä$_1$.
Maija.NOM order-3SG.PST we.GEN wash-A/INF self-PX/3SG
'Maija ordered us to wash herself.'

I find this marginal, and ungrammatical if the embedded subject and the reflexive agree in phi-features (*meidän – itsemme* 'us – self.PX/1PL' or *hänen – itsensä* 'self.PX/3SG'). 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 that there was between-speaker variation in the elicited judgments. This instability corresponds with my own intuition, equally unclear and marginal at best. Therefore, I think that a clear-cut conclusion cannot be reached without further data. The analysis proposed in this article allows, however, one to define locality on the basis of the minimal tense phrase (by feature [OLD:T]), but the hypothesis must be tested over several constructions in the dialect/language where it looks reasonable. In my Finnish, it does not.

5 Discussion and conclusions

Binding and coreference dependencies were calculated from a formal information processing model which assumes that binding operates at the language-cognition interface and regulates assignment calculations. In addition to standard binding configurations, also picture nouns, noncanonical word orders, operator constructions, null subject clauses, whole conversations and embedded infinitivals follow from the hypothesis. The hypothesis was formulated as a Python algorithm and tested against a dataset.

One potential limitation of the present model concerns long-distance anaphors. Long-distance anaphors and logophors do not follow the standard binding conditions (e.g., Clements, 1975; Hellan, 1988; Huang, 2000a: Ch. 2.3; Sells, 1987; Thráinsson, 1990, 1991), hence they cannot be modeled by using the four binding features and the intervention feature assumed here. Some long-distance anaphors are, moreover, sensitive to pragmatic discourse features such as 'point of view', 'topic' or 'salience' that were excluded here, requiring a different dataset. On the other hand, the model assumes that pronouns can denote any object in the global discourse inventory, which gives it access to discourse-based and/or long-distance anaphors. To implement them, the objects in the global discourse inventory could be labelled by discourse tags, such as those just mentioned. A mechanism of this type might be required on independent grounds, since there is both linguistic (e.g., Ariel, 1990; Givón, 1983; Grosz, Joshi, & Weinstein, 1995; Huang, 2000b; Pollard & Sag, 1992; Schlenker, 2005; Sperber & Wilson, 1995; Thráinsson, 1991) and psycholinguistic (e.g., Almor, 1999; Cunnings & Sturt, 2014; Kazanina, Lau, Lieberman, Yoshida, & Phillips, 2007; Malt, 1985; Murphy, 1985a, b; Nicol & Swinney, 2003; Parker, 2019) evidence that such features perform important functions in languages and language comprehension.

One set of data that was excluded concerns plurals and quantifiers of various kinds. Expressions such as *nobody* or *two men* cannot be indexed directly with the file card objects in the inventory. This limitation, crucially, excluded plural reciprocals such as *each other* from this study. Calculating the denotations and assignments for quantifiers is further complicated by the fact that their denotations exceed the resources available in any finite semantics (e.g., *all natural numbers*, *every set*).[15] Similar problems emerge when we consider the issue of quantifier scope. The general idea would be to model these items (plurals, quantifiers, numerals) by complicating the mapping functions inside narrow semantics, which provides the required extra layer between syntax and the discourse inventory. Whereas *John* denotes a person named John, *two men* could be modelled as denoting all possible sets of two men, given a context and the discourse inventory. This, when formalized properly, would make it possible to model simple conversations such as *John*$_1$ *met Bill*$_2$; *the two men*$_{\{1, 2\}}$ *were friends and liked each other*$_{\{1, 2\}}$.

The main alternative to the model presented here is a syntax-internal analysis of binding that would restrict assignments inside the syntactic processing pathway (Figures 1, 2). It is important to note in this connection that the syntax-internal theory cannot be justified solely on the grounds that binding involves syntactic constraints such as c-command, since syntax-external mechanisms have access to such properties at the interfaces (at the endpoint of the syntactic processing pathway, possibly at other interfaces). Furthermore, an imaginable semantically oriented theory of binding (not advocated here) could rely on the syntax-like properties of a conceptual-representational system. Third, any descriptively adequate linguistic theory must posit a system calculating assignments that link syntactic objects with language-external semantic objects. The full denotation for a pronoun such as *he* cannot be determined

[15] It appears inevitable that the semantic system must be provided with an ability generate objects, such as natural numbers, of its own. The human ability to imagine nonexistent objects without limitation must be based on the same creative ability.

inside syntax; it depends on the context. The difference between a syntax-internal analysis and an analysis such as the one proposed in this article therefore boils down to whether there *must* exist an additional syntax-internal mechanism that biases or forces the assignment mechanism towards some solutions. Consider (49).

(49)	Pekka	sanoi	että	hän(1.)	ihaile-e	hän-tä(2.). (#107)
	Pekka.NOM	said	that	he.NOM	admire-PRS.3SG	he-PAR

‘Pekka said that he (Pekka, third party) admires him (Pekka, fourth party).’

The possible denotations for the second pronoun (2.) depend on how the first pronoun (1.) is interpreted. If the first pronoun denotes Pekka, then the second pronoun must denote somebody else; if the first pronoun does not denote Pekka, then the second pronoun can. It seems unlikely that the syntactic processing pathway could know what the first pronoun denotes, since the matter depends on a number of contextual factors. It cannot, therefore, do anything with the second pronoun either. What is possible, though, is to force the pronouns to be disjoint *under any assignment*, which suggests that the issue must be decided when assignments are calculated. Adding a new layer of syntactic complexity into the model seems redundant. Concerns such as this and others, in particular those briefly mentioned in Section 4.2.4, suggest that much more information is available for binding than what can be found inside the syntactic system.

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