Reference to the dependency in a multiple-*wh* question

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Abstract It is known that a multiple-*wh* question can inquire about a dependency between *wh*-expressions, termed '*wh*-dependency', admitting a pair-list answer. In discourse, the dependency can even support a 'plural' interpretation of a singular pronoun. Consider *Which^u girl bought which^v book and how much did she$_u$ pay for it$_v$?*. The multiple-*wh* question is asking about a dependency between girls and books. In the subsequent question, the dependency is referred to and the resolution of the singular pronouns varies among the girls and the books they bought. While van Rooy (1998) and Dotlačil & Roelofsen (2019) have noticed this phenomenon, it is still understudied. Based on their insights, this paper argues that reference to *wh*-dependencies is facilitated in two types of subordination constructions—quantificational subordination, where reference to *wh*-dependencies is facilitated through quantificational structure, and question subordination, where reference to *wh*-dependencies is facilitated through conjoining questions. Building on Hamblin-Karttunen semantics of questions and Dynamic Plural Logic, this paper proposes a dynamic family-of-questions approach to multiple-*wh* questions. In particular, a multiple-*wh* question generates a set of sub-questions, i.e., a family of questions, and then the set is transformed into a set of possible pair-list answers. Both encode the relevant *wh*-dependency in a different manner. As a consequence, the dependency encoded in a family of questions is retrievable in question subordination, while the one encoded in a pair-list answer is retrievable in quantificational subordination.

Keywords multiple-*wh* questions · pair-list reading · dependency · anaphora · dynamic semantics · alternative semantics

1 Introduction

The truth conditions of quantificational sentences commonly encodes dependencies. Since Karttunen (1976), it has been argued that such a dependency is accessible beyond the sentence boundary. For example, in (1), the first universal sentence may express that, for each girl, there is a different book that she bought. This leads to a girl-book dependency (each girl is related to a different book). The second sentence refers to this dependency for elaboration, i.e., for each girl–book pair introduced by the previous sentence, the girl paid about $30 for the book.[1]

(1) Every^u girl bought a^v book. Each of them$_u$ paid about $30 for it$_v$.

The distributive quantifier *each of them* in the second sentence accesses the girl–book dependency established in the previous universal statement and divides it into a set of single girl–book

[1] In this paper, antecedents are superscripted with indices, while anaphoric expressions are subscripted with indices. Additionally, only items involved in an anaphoric relation are marked for simplicity. For example, in (1), the expression *$30* can also serve as an antecedent of an anaphoric expression, but does not bear a superscript because it is not referred to in this example.

pairs. Within the scope of the distributive quantifier, the singular pronoun *it* is evaluated relative to each pair, i.e., for each girl, *it* refers to the book she bought. This creates the impression that *it* is subordinated within the scope of *every girl*, giving rise to the phenomenon known as 'quantificational subordination' (Heim 1990; Krifka 1996; van den Berg 1996; Brasoveanu 2008, 2010; a.o.). Research on quantificational subordination evokes the idea that quantificational dependencies are incrementally built in the process of context update, which has grounded insightful semantic analyses of dependent indefinites (Henderson 2014; Kuhn 2017), cumulative interpretations (Brasoveanu 2013; Charlow to appeara), modal subordination (Brasoveanu 2010), quantifier-internal adjectives (Bumford & Barker 2013), and more.

In fact, the 'subordination' phenomenon is not limited to the sequences of sentences involving a quantified statement, but is also observed in ones involving a multiple-*wh* question. It is acknowledged that a multiple-*wh* question commonly asks about a dependency and requests a pair-list answer. In (2), for example, the question requests an answer specifying for every girl a particular book she bought. In other words, the addressee is asked to identify a specific dependency between the individuals in the domains of *which girl* and *which book*. Since this kind of dependency is formed between the domains of *wh*-expressions, it is named '*wh*-dependency' in this paper (see also Xiang 2023).

(2) Context: Annie, Becca, and Cindy bought different books.
A: Which girl bought which book?
B: Annie bought *Sense & Sensibility*, Becca *Pride & Prejudice*, and Cindy *War & Peace*.

van Rooy (1998) and Dotlačil & Roelofsen (2019) have noticed that a *wh*-dependency is also accessible in discourse and supports the subordination-like interpretation of pronouns. Consider (3), where the multiple-*wh* question in (2) is conjoined with another question.

(3) Context: Annie, Becca, and Cindy bought different books.
A: Which^{u} girl bought which^{v} book and how much did **each** of them$_{u}$ pay for it$_{v}$?
B: Annie bought *Sense & Sensibility*, Becca *Pride & Prejudice*, and Cindy *War & Peace*. They each paid about $30.

Similar to (1), the distributive quantifier in the subsequent question quantifies over the girls in the domain of *which girl* (via the reference of the plural pronoun) and the singular pronoun in its scope is interpreted relative to each girl. So, the subsequent question asks for each girl how much she paid for the book she bought. In this sense, the pronominal interpretation is subordinated in the *wh*-dependency established in the previous multiple-*wh* question.

However, subordination involving a question does not always exhibit a pattern like quantificational subordination, which is conditioned on the appearance of pronouns inside the scope of a quantifier. As shown in (4), if no quantifier is involved in a follow-up sentence, a singular pronoun cannot interpretively be subordinated in the scope of the previous quantifier.[2]

[2] There is also another strategy of retrieving the dependency in a quantified statement—*telescoping*, as shown in (i) (Sells 1985; Roberts 1989). No quantifier appears in the subsequent sentence, but the singular pronoun looks as if it is evaluated in the scope of the universal quantifier in a previous sentence.

(4) Every^u girl bought a^v book. # It$_v$ cost about $30.

By contrast, a *wh*-dependency can be accessed by pronouns that are not in the scope of a quantifier. Consider (5). The first multiple-*wh* question asks about a girl–book dependency. Although no quantifier is used in the subsequent question, both singular pronouns in the subsequent question are interpreted relative to every girl–book pair involved in the dependency: for each girl–book pair, *she* refers to the girl and *it* the book she bought.

(5) Context: Annie, Becca, and Cindy bought different books.
A: Which^u girl bought which^v book and how much did she$_u$ pay for it$_v$?
B: Annie bought *Sense & Sensibility*, Becca *Pride & Prejudice*, and Cindy *War & Peace*. They each paid about $30.

van Rooy (1998) called this pattern 'question subordination'. In section 2.4, I will demonstrate that question subordination is constrained by the discourse closeness of the involved questions. Briefly, this kind of subordination is available only when two questions form a single interrogative act. This explains the fact that question subordination is more readily perceived in conjunction of questions. Based on Szabolcsi (1997) and Hoeks (2018), conjunction of questions may occur at the intra-sentential level, where questions are conjoined below the interrogative force. In this case, the speaker requests the addressee to respond to conjoined questions collectively.[3]

Both (3) and (5) are an instance of reference to *wh*-dependencies. Although this phenomenon is relatively understudied, methodologically speaking, it would be ideal if both instances could receive a uniform account. However, I argue that they should be set apart. Section 2 shows that question subordination is more restricted than quantificational subordination. Essentially, the interpretations of pronouns in both types of subordination are subordinated to *distinct semantic objects*—a family of questions and a pair-list answer. In particular, the pair-list answer to a multiple-*wh* question can be treated as a composite of answers to individual sub-questions derived from the original question, as illustrated below.

(6) Answer(which^u girl bought which^v book)
$=$ $\underbrace{\text{Answer}(\text{which}^v \text{ book did Annie}^u \text{ buy})}_{\text{Annie bought } \textit{Sense \& Sensibility}}$; $\underbrace{\text{Answer}(\text{which}^v \text{ book did Becca}^u \text{ buy})}_{\text{Becca bought } \textit{Pride \& Prejudice}}$;
$\underbrace{\text{Answer}(\text{which}^v \text{ book did Cindy}^u \text{ buy})}_{\text{Cindy bought } \textit{War \& Peace}}$

This idea motivates a family-of-questions approach to multiple-*wh* questions (Hagstrom 1998;

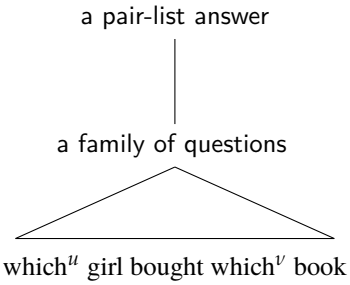
(i) Every^u chess set comes with a^v spare pawn. It$_v$ is taped to the top of the box.

Compared with quantificational subordination, telescoping is highly restrictive and conditioned by some specific rhetorical relations (Roberts 1989; Wang et al. 2006). So far, it's still unclear what role rhetorical relations play in telescoping. In addition, a survey conducted by Wang et al. (2006) shows that even in telescoping examples plural pronouns are preferred over singular pronouns. Therefore, this paper sets aside telescoping.

[3] It is not uncommon that two *wh*-questions in a sequence can form a single interrogative act. Dayal (2000) notices that a sequence of questions like *What do you think? Who will Mary see?* is also likely to be understood as one question asking 'who do you think Mary will see?'.

Willis 2008; Fox 2012; Nicolae 2013; Kotek 2014; a.o.). Basically, the meaning of a multiple-*wh* question is derived through two steps, as depicted in (7). The clause containing multiple *wh*-expressions compositionally gives rise to a set of question meanings, which is transformed into a pair-list answers at the top of the question.[4]

(7)



Based on the family-of-question approach, this paper dynamicizes the meaning of a multiple-*wh* question, which is a set of *dynamic* pair-list answers transformed from a family of *dynamic* question meanings. Both meaning components encode an instance of the relevant *wh*-dependency that is retrievable for pronouns. Specifically, a pair-list answer produces an output context with a dependency between the discourse referents (dref, henceforth) introduced by *wh*-expressions, which has the same structure as the one established in a universal statement; whereas, a family of questions consists of sub-questions about singular individuals in the domain of a *wh*-expression, implying a dependency between the individuals and the answers to the sub-questions.

Reference to *wh*-dependencies is accomplished by dynamically conjoining a multiple-*wh* question with a subsequent sentence at two levels.

- On one hand, a multiple-*wh* question can be conjoined with a subsequent sentence at the root level. In this case, the subsequent sentence accesses the dependency encoded in pair-list answers, which mirrors the one in a quantified statement. Reference to this dependency is unsurprisingly facilitated in the same way as we observed in quantificational subordination.
- On the other hand, a multiple-*wh* question can be conjoined with a subsequent sentence at the level where a family of questions is generated. Consequently, every question in the family becomes accessible to the subsequent question. As exemplified in (7), these questions may involve singular individuals (e.g., *Annie*, *which book*), which can directly support singular anaphora without need of any quantifier. This leads to question subordination.

Based on the dynamic analysis, I will also address several long-standing issues in question and dynamic semantics. Specifically, it will be demonstrated that discourse dependencies in both multiple-*wh* questions and quantified sentences are generated uniformly, and a family-of-questions approach has an advantage in capturing the uniqueness requirements of *wh*-questions in discourse. Additionally, it is noticed that *wh*-dependencies cannot be referred to by singular

[4] In addition to the family-of-questions approach, Dayal (1996) and Xiang (2023) follows Chierchia (1993) and proposes a functional approach to pair-list readings of multiple-*wh* questions. This approach is also dynamicizable. Appendix B.3 illustrates a potential way of dynamicizing the functional approach. Nevertheless, as discussed in the appendix, a dynamic functional approach is confronted with some difficulties when accounting for reference to dependencies established in multiple-*wh* questions.

definite expressions, calling into question the static, E-type approach to discourse anaphora and emphasizing the necessity of dynamic semantics.

The rest of the paper is organized as follows. Section 2 describes both ways of referring to *wh*-dependencies by emphasizing their empirical differences. Section 3 presents a dynamic family-of-questions approach to multiple-*wh* questions. Section 4 demonstrates how the dynamic family-of-questions approach accounts for reference to *wh*-dependencies. Section 5 extends the present analysis to embedded questions. Section 6 discusses implications and consequences of the present analysis. Section 7 concludes. All formal derivations are deferred to Appendix A. Comparisons with previous studies are offered in Appendix B.

2 Data

2.1 Singular and plural anaphora to *wh*-expressions

Like an indefinite, a *wh*-expression does not have a determinate reference, i.e., both do not refer to a specific object. However, they can support discourse anaphora, as illustrated in (8).

(8) a. Which^{u} girl called and what did she$_{u}$ say?
b. Which^{u} one of your daughters lives in Beijing? Is she$_{u}$ happy there?
c. Who^{u} is Max dating? I heard she$_{u}$ is a doctor.

Take (8-a) as an example. The hearer must name the girl who called and specify the thing she said. Importantly, the pronoun *she* co-varies with the girl identified by the answer to the first question, creating an impression that the *wh*-expression binds the pronoun.

Cross-sentential anaphora to *wh*-expressions motivates the assumption that *wh*-expressions introduce drefs, which serve as antecedents for anaphoric expressions (Comorovski 1996; van Rooy 1998; Aloni & van Rooy 2002; Haida 2007; Murray 2010; Dotlačil & Roelofsen 2018; Roelofsen & Dotlačil 2023).

Generally, the number of an anaphoric expression must agree with its antecedent. This is also the case for cross-sentential anaphora to *wh*-expressions. For example, in (9), the first question involves a singular *wh*-expression *which boy*, which supports a singular pronoun only. Conversely, in (10), the plural *wh*-expression *which boys* only supports a plural pronoun.

(9) Which^{u} girl called? What did { she$_{u}$ / #they$_{u}$ } say?

(10) Which^{u} girls called? What did { #she$_{u}$ / they$_{u}$ } say?

In the sense of Hamblin semantics (Hamblin 1973), the meaning of a *wh*-question is taken to be a set of possible answers. From the dynamic perspective, each possible answer may lead to a possible update of discourse information (Farkas & Bruce 2010). (11) depicts how the first *wh*-question in (9) updates the discourse. In (11), each possible answer to the question adds a dref for the girl. In this paper, $[\![\cdot]\!]_d$ stands for the function mapping linguistic expressions to context change potentials, whose formal definition is given in Section 3.1. As a result, we get different possible outputs. In a conversation, the addressee is directed to decide which output

matches the fact.[5]

(11) $[\![\text{which}^u \text{ girl called}]\!]_d = \left\{ \begin{array}{l} [\![\text{Annie}^u \text{ called}]\!]_d, \\ [\![\text{Becca}^u \text{ called}]\!]_d, \\ [\![\text{Cindy}^u \text{ called}]\!]_d \end{array} \right\} \Rightarrow [\![\text{what did she}_u \text{ say}]\!]_d$

In (9), the second question is asked before the first one is resolved. Intuitively, it is interpreted relative to every possible answer to the first question. Therefore, the pronoun *she*$_u$ retrieves the value of the dref u. In (11), since u only stores a single girl for each possible answer, the singular pronoun, instead of plural ones, is allowed.

Following Dayal (1996), the possible answers to the first question in (10) may involve atomic or non-atomic girls. For example, they could be Annie^u called', 'Annie and^u Becca called', 'Annie, Becca, and^u Cindy called', etc. Based on the discourse update shown in (11), the dref u in each possible answer may store an atomic individual or a non-atomic individual. In the second question in (10), only a plural pronoun can retrieve the value of u, because the plural pronoun is not subject to the atomicity requirement and its antecedent can be non-atomic.[6]

2.2 Multiple-*wh* questions and cross-sentential anaphora

The empirical picture becomes more complex when multiple-*wh* questions are concerned. As for a multiple-*wh* question admitting a pair-list answer, the interrogation concerns the dependency between two sets of entities. In this situation, the relevant singular *wh*-expressions can support cross-sentential *plural* anaphora, as in (12).

(12) Context: Annie, Becca, and Cindy bought different books.

A: Which^u girl bought which^v book and where did they$_u$ leave them$_v$?

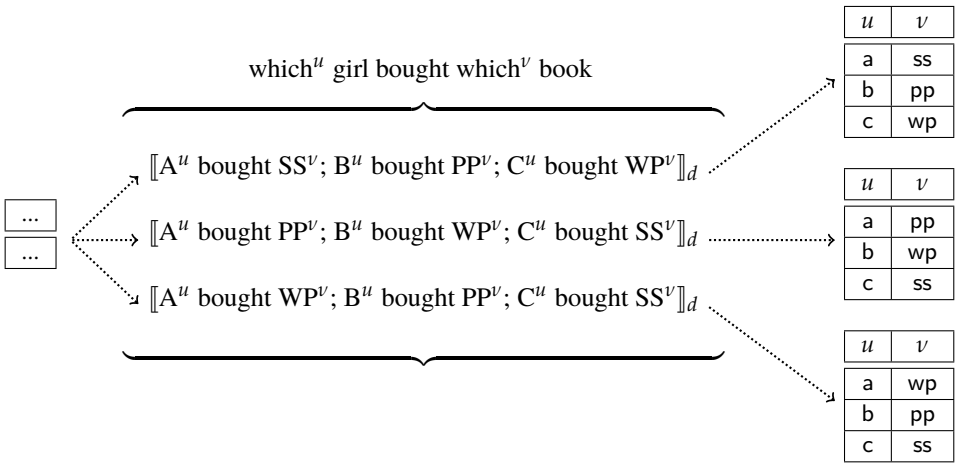
B: Annie bought *Sense & Sensibility*, Becca *Pride & Prejudice*, and Cindy *War & Peace*. They left them in a jumbled up pile.

The multiple-*wh* question allows for possible answers that specify a proper pairing between the girls and the books. Every possible pair-list answer has the effect of adding two drefs u and v for multiple girls and books respectively, as illustrated in (13).

[5] It should be noted that the dynamic effect of a question can also be implemented in other theories of question meaning, such as partition semantics (Groenendijk 1999; Haida 2007) and a structured meaning approach (Aloni & van Rooy 2002). The formal analysis proposed in this paper is built on Hamblin semantics, so the dynamic effect of questions is described along the same lines here for convenience. However, this paper is neutral to how best to dynamicize question meaning and leaves the comparison of dynamic questions accounts for another occasion.

[6] Plural number morphology on pronouns just indicates the absence of the atomicity requirement. Semantically, a plural pronoun can be anaphoric to a singular entity. The unacceptability of the plural pronoun in (9) is derived pragmatically. Following Sauerland (2003), a Maximize Presupposition principle of the kind proposed in Heim (1991) requires us to use singular pronouns whenever we can.

(13)



For each output, every girl stored in u is related to a book stored in v. These possible outputs each create a local context for the subsequent question. For each output, the values stored in u and v can be retrieved by the plural pronouns: *they*$_u$ refers to the set of girls, while *them*$_v$ the set of books (van den Berg 1996, Brasoveanu 2008). As a result, the second question is interpreted cumulatively. That is, given that each girl bought a book and each book was bought by a girl, the question asks about the places where the girls left the books.[7]

In addition to a pair-list answer, a multiple-*wh* question may admit a single-pair answer, as shown in (14). The context clearly indicates that a unique girl–book pair is under discussion and the question is resolved by identifying that specific pair. It has been noted that a single-pair answer sounds less natural out of the blue than a pair-list answer for a multiple-*wh* question (see Dayal (1996) for a detailed discussion of contexts favoring single-pair answers).

(14) A: Among these girls, only one bought a book.
B: Which girl bought which book?
A: Annie bought *Sense & Sensibility*.

Following the common view of the single-pair reading (Dayal 1996; Nicolae 2013; Kotek 2014; a.o.), the possible single-pair answers are propositions naming a single pair. These single-pair answers add the drefs u and v for two atomic individuals. As a consequence, the *wh*-expressions involved in such a multiple-*wh* question support cross-sentential singular anaphora, as exemplified in (15).

(15) A: Among these girls, only one bought a book.
B: Which^u girl bought which^v book and how much did she$_u$ paid for it$_v$?
A: Annie bought *Sense & Sensibility* and she paid $30 for it.

[7] The second question in (12) may be understood as *where did each girl leave the book she bought*, which is not just asking where the girls left the books, but also refers to the dependency between the girls and the books. As commented in Brasoveanu (2008), the reference to the girl–book dependency might be pragmatically supplied, because the dependency is brought to salience by the first multiple-*wh* question.

2.3 Quantificational subordination

Now that the background of cross-sentential anaphora to *wh*-expressions has been clarified, we are ready to discuss subordination patterns with *wh*-questions. The discussion starts from quantificational subordination. Consider (16). Given the context, the multiple-*wh* question is seeking to identify a dependency between the domains of *which girl* and *which book*. In the subsequent question, the plural pronoun *them* restricts the domain of the distributive quantifier and is understood to be the set of girls.

(16) Context: Annie, Becca, and Cindy bought different books.
A: Which^u girl bought which^v book and how much did each of them$_u$ pay for it$_v$?
B: Annie bought *Sense & Sensibility*, Becca *Price & Prejudice*, and Cindy *War & Peace*. Each of them paid about $30.

The singular pronoun *it* co-indexed with *which book* refers neither to a single specific book nor to the set of all books, but rather varies depending on different books: for each girl in the set retrieved by *them*, *it* is interpreted as the book she bought. In this sense, the evaluation of the singular pronoun is subordinated to the *wh*-dependency in the multiple-*wh* question.

In addition to a distributive quantifier, such as the one appearing in (16), other quantifiers also enable the interpretive subordination, as exemplified in (17) and (18).

(17) Context: The students of Classroom 21 went to different shops to buy Halloween costumes. Most of them bought the same kind of costumes.
A: Which^u student went to which^v shop and what did most of them$_u$ buy from it$_v$?

(18) Context: The third year graduate students in the linguistics department are working on different topics.
A: Which^u one is working on which^v topic and would some of them$_u$ like to continue working on it$_v$ for their PhD theses?

Furthermore, conjunction is unnecessary for this kind of subordination, which can be observed when a multiple-*wh* question and a subsequent sentence are simply posted one by one, as evidenced by the following examples.

(19) Context: Annie, Becca, and Cindy bought different books.
A: Which^u girl bought which^v book? Each of them$_u$ might have paid a lot for it$_v$.

(20) Context: The students of Classroom 21 went to different shops to buy Halloween costumes. Most of them bought the same kind of costumes.
A: Which^u student went to which^v shop? What did most of them$_u$ buy from it$_v$?

Note that in this paper a sequence comprising a question and a declarative sentence is called 'Q−D sequence', whereas a sequence consisting of two questions 'Q−Q sequence'.

The pattern exhibited by these examples is the same as the so-called 'quantificational subordination' in the literature (Heim 1990; Krifka 1996; van den Berg 1996; Brasoveanu 2008,

2010; a.o.). As shown in (21), the singular pronoun in the scope of *each of them* is interpreted relative to the girl–book dependency established in the antecedent quantified sentence.

(21) Every^u boy bought a^v book and each of them$_u$ spent about $30 on it$_v$.

Thus, a quantifier is able to subordinate pronominal resolution within the dependency established by either a quantified statement or a multiple-*wh* question. In addition to explaining the empirical facts, an adequate analysis should also illuminate the connection of multiple-*wh* questions and quantified statements.

2.4 Question subordination

This section turns to question subordination. As noticed in van Rooy (1998), quantifiers are not necessary to facilitate reference to *wh*-dependency. Consider (22), where no quantifier is involved in the subsequent question, but the singular pronouns still can access the *wh*-dependency established in the first multiple-*wh* question.

(22) Context: Annie, Becca, and Cindy bought different books.
A: Which^u girl bought which^v book and how much did she$_u$ pay for it$_v$?
B: Annie bought *Sense & Sensibility*, Becca *Price & Prejudice*, and Cindy *War & Peace*. They each paid about $100.

(23) Context: Annie, Becca, and Cindy took different courses this term.
A: Which^u girl took which^v course and how many credits did she$_u$ get from it$_v$?
B: Annie took Algebra, Becca Statistics, and Cindy Geometry. Each of them got three credits.

However, if a subsequent sentence lacks a quantifier, it must be another question to access a previously established *wh*-dependency. Consider (24) and (25), where the *wh*-dependency is not accessible to the singular pronouns in the subsequent declarative sentences.

(24) Context: Annie, Becca, and Cindy bought different books.
A: #Which^u girl bought which^v book? She$_u$ might have spent a lot on it$_v$.

(25) Context: Annie, Becca, and Cindy took different courses this term.
A: #Which^u girl took which^v course? I heard that she$_u$ got four credits from it$_v$.

The use of the singular pronouns in the subsequent declarative sentences strongly implies that the multiple-*wh* questions are seeking to identify a single pair. In other words, the appearance of the singular pronouns prevents the pair-list readings of the multiple-*wh* questions. Given that the interrogative nature of the subsequent sentences in (22) and (23) is crucial for subordination, this phenomenon is termed 'question subordination'.

In terms of discourse relation, the multiple-*wh* questions and their subsequent sentences in (22) and (23) are closer than those in (24) and (25). The former examples involve *wh*-conjunctions, the construal of which can be clausal conjunction in the scope of interrogative

force (Szabolcsi 1997; see also Hoeks 2018; Dayal 2023), as shown below. In this sense, the conjoined *wh*-questions form a single interrogative act: the speaker requests the addressee to provide an answer that resolves both questions.

(26) Interrogative force (WH_1 and WH_2)

By contrast, in the latter examples, the multiple-*wh* questions and the follow-up declarative sentences must have their own illocutionary forces, as visualized in (27). The speaker only requests the addressee to resolve the involved multiple-*wh* question, but offers additional information by asserting the declarative sentence. In other words, there are two sentence acts.

(27) (Interrogative force (WH_1)) (Declarative force (S_2))

The same kind of contrast also shows up in Q−Q sequences. In (28) and (29), question subordination is still possible, though these Q−Q sequences do not sound perfect for some native speakers.[8]

(28) Context: Annie, Becca, and Cindy bought different books.
A: ?Which^u girl bought which^v book? How much did she$_u$ pay for it$_v$?

(29) Context: Annie, Becca, and Cindy took different courses this term.
A: ?Which^u girl took which^v course? How many credits did she$_u$ get from it$_v$?

However, once the two *wh*-questions are uttered by different conversational participants, the relevant subordination interpretation is clearly degraded, as illustrated in (30) and (31).

(30) Context: Annie, Becca, and Cindy bought different books.
A: Which^u girl bought which^v book?
B: #I'm also wondering how much she$_u$ paid for it$_v$?

(31) Context: Annie, Becca, and Cindy took different courses this term.
A: Which^u girl took which^v course?
B: #I'm also wondering how many credits she$_u$ got from it$_v$?

The Q−Q sequences in (28) and (29) can also be understood to form single interrogative acts, especially when the two questions in the Q−Q sequences are asked together without an apparent pause between them. However, in the conversations (30) and (31), the involved *wh*-questions are distributed in different sentence acts delivered by different speakers.[9]

[8] The judgments on question subordination become more degraded when two *wh*-questions in a Q−Q sequence bear a full *wh*-question intonation (i.e., they end in a falling pitch) (Simon Charlow p.c.), which indicates that the involved *wh*-questions contribute an independent interrogative act. If the intonation-related pattern is further confirmed through prosody experiments in future research, it would also support the contrast we have discussed.

[9] Roelofsen & Dotlačil (2023) notice that question subordination is acceptable between two questions asked by different speakers if the second question is headed by the conjunctor *and*, as shown below.

(i) A: Which^u woman bought which^v dress?
B: **And** how much did she$_u$ pay for it$_v$?

Question subordination is also observed in a *wh*-conjunction where the subsequent question contains only one singular pronoun. In (32) and (33), the singular pronouns are interpreted relative to the *wh*-dependencies established in the first multiple-*wh* questions. It is worth noting that some native speakers perceive it less acceptable when, in a multiple-*wh* question, only the *wh*-subject is referred to by a singular pronoun in a subsequent sentence.[10]

(32) Context: Max, Kyle, and Sam took different courses this term.

A: Which^u boy took which^v course and who taught it$_v$?

B: Max took Algebra taught by Ada, Kyle took Geometry taught by Linda, and Sam took Statistics taught by Sue.

(33) Context: Max, Kyle, and Sam took different courses this term.

A: (?)Which^u boy took which^v course and how many credits did he$_u$ get?

B: Max took Algebra, Kyle took Geometry, and Sam took Statistics. Each of them got three credits.

The same restriction also applies to such cases involving only one *wh*-referring pronoun: if a multiple-*wh* question and a follow-up sentence cannot form a single speech act, the only singular pronoun in the second sentence cannot receive a subordination-like interpretation when referring to a *wh*-expression in the first question, exemplified as follows.

(34) Context: Max, Kyle, and Sam took different courses this term.

A: #Which^u boy took which^v course? I heard it$_v$ was taught by a new teacher.

(35) Context: Max, Kyle, and Sam took different courses this term.

A: #Which^u boy took which^v course? He must have received three credits.

In this example, it is not convincing that the questions uttered by different people form a single speech act. A potential solution is to assume that the appearance of *and* in the follow-up question signals the existence of an elliptical antecedent clause, which would be reconstructed as the same multiple-*wh* question as the previous one.

[10] I would like to thank the editor for pointing out this phenomenon. I have checked intuitions with four native speakers. I presented them with five pairs of sentences following the same patterns as those in (32) and (33). Three of them grew up in California and didn't report perceiving a clear contrast between the two sentences in each pair, but one growing up in Michigan did. Hence, a controlled experiment may be needed to elucidate the contrast. Due to the judgment disparities, I will not offer a full fledged analysis in this paper, but speculate that the contrast between (32) and (33) may be associated with the observation made by Ruys (1992) and Fox (1995) regarding discourse parallelism, as exemplified in (i) and (ii).

(i) *I wonder who^u took what^v from Mary and gave a book to Fred.

(ii) I wonder who^u took what^v from Mary and gave it$_v$ to Fred.

Similar to (32), the *wh*-object in (i) is not referred to by any pronouns in the second conjunct, rendering the sentence unacceptable. It appears that, generally, a coherent subsequent sentence of a multiple-*wh* question should be related to the *wh*-object. While this discourse pattern has not received a complete semantic/pragmatic analysis (cf. Altshuler & Truswell 2022), a potential explanation might be that, in a multiple-*wh* question with a pair-list reading, the *wh*-subject functions like a topic, providing a set of known individuals (Willis 2008), whereas the *wh*-object is in the center of inquiry. As a consequence, the multiple-*wh* question should be followed by a sentence that has some relevance to the *wh*-object.

2.5 Interim summary and the role of conjunction

The empirical findings so far are summarized as follows:

1. A multiple-*wh* question admitting a pair-list answer establishes a dependency between *wh*-expressions, which is accessible in discourse.
2. Quantificational subordination: the dependency established in a multiple-*wh* question can be accessed cross-sententially by a singular pronoun in the scope of a quantifier.
3. Question subordination: the dependency established by a multiple-*wh* question can be accessed by a singular pronoun in a subsequent question that does not contain a quantifier.
4. Question subordination differs from quantificational subordination in that the former is available only when a multiple-*wh* question is possible to form a single interrogative act with a subsequent question.

While this paper is not the first to note that subordination to a *wh*-dependency is possible, it explicitly distinguishes between two types of subordination.

In the following sections, I argue that the two types of subordination emerge as a consequence of accessing two kinds of dependencies. Briefly, a multiple-*wh* question compositionally generates a family of questions, which serves as the basis for constructing pair-list answers. On one hand, a pair-list answer encodes a dependency with the same structure as the one introduced by a quantified statement. Quantifiers hold the key to the accessibility of such a kind of dependency. This results in quantificational subordination. On the other hand, a family of questions encodes a dependency related to answerhood, which can only be accessed when the family of questions is conjoined with a subsequent sentence. This leads to question subordination.

3 A dynamic approach to pair-list readings

3.1 Dynamicizing Hamblin semantics

The core of my proposal is built on a dynamic version of Hamblin semantics (Hamblin 1973), which includes two fundamental assumptions: (a) a *wh*-expression evokes a set of alternative *dynamic* individuals, which introduce drefs, as illustrated in (36); (b) correspondingly, a *wh*-clause denotes a set of *dynamic* propositions, as illustrated in (37).[11]

(36) $[\![\text{who}^u]\!]_d = \{[\![\text{Annie}^u]\!]_d, [\![\text{Becca}^u]\!]_d, [\![\text{Annie and}^u \text{ Becca}]\!]_d\}$

(37) $[\![\text{who}^u \text{ called}]\!]_d = \{[\![\text{Annie}^u \text{ called}]\!]_d, [\![\text{Becca}^u \text{ called}]\!]_d, [\![\text{Annie and}^u \text{ Becca called}]\!]_d\}$

[11] The dynamic Hamblin semantics pursued here is not the only way of dynamicizing alternatives. Other approaches include Murray (2010), Charlow (2014, 2020), Elliott (2020), and Roelofsen & Dotlačil (2023). Comparing with these approaches, my proposal is a relatively direct way of combining DPlL with Hamnblin-Karttunen semantics. It faithfully inherits the semantic structures of the two theories. Section 3.2 will show that the direct combination is sufficient to dynamicize the family-of-questions approach to multiple-*wh* questions. The other approaches aim to handle different empirical phenomena and assume richer semantic structures. On the other hand, the present proposal also borrows insights from Charlow (2014, 2020) and Roelofsen & Dotlačil (2023). Therefore, it can be upgraded to accommodate the semantic structures assumed in these two studies.

The remainder of this subsection provides a relatively informal introduction to the dynamic Hamblin semantics, addressing how dynamic meaning is modeled and how *wh*-expressions support cross-sentential anaphora. The formal definitions and compositional derivations can be found in Appendix A. Note that the domain of a number neutral *wh*-expression includes both atomic individuals and their sums, i.e., plural individuals (see Dayal 1996).

Dynamicness In dynamic semantics, sentence meaning is taken to be a context change potential, a so called 'dynamic proposition', which is formalized to be a function mapping an input context to a corresponding output context. Inspired by Roelofsen & Dotlačil (2023), this paper combines insights from intensionalized update semantics (Heim 1982; Groenendijk et al. 1996) and Dynamic Plural Logic (henceforth, DPlL; van den Berg 1996), modeling a context c as a set of pairs of a possible world w and a set G of assignments, as shown below.

(38) $\quad c := \{(w, G), (w', G'), ...\}$

G	...	u	v	...
g	...	a	b	...
h	...	d	c	...
...	...	...	...	...

As for these pairs, called possibilities in this paper, the possible worlds are used to model intensionality of question meaning and the sets of assignments are responsible for handling dependencies in discourse. The structure of a set of assignments is visualized through the table on the right. The leftmost column lists the assignments (g, g', h, etc.) in the set. Assignments relate drefs (u, u', v, etc.), shown in the the uppermost row, to objects in the model. Each cell in the middle represents a value, i.e., an object that a particular assignment associates with a dref. Each column of these cells then encodes the collective value (a set of entities) of a dref given a set of assignments.

A possibility (w, G) is extended by adding a new dref to the domain of each assignment in G. In DPlL, a dref is either associated with an atomic individual or a plural individual. Following Schwarzschild (1996), the former is modeled as a singleton set of an individual, while the latter a non-singleton set. An example of dref introduction is visualized in (39).

(39)

G	...
g	...
h	...

$\xrightarrow{\quad G^{u \mapsto \mathsf{d}+\mathsf{d}'} \quad}$

G	...	u
$g^{u \mapsto \mathsf{d}}$	...	d
$h^{u \mapsto \mathsf{d}}$	...	d
$g^{u \mapsto \mathsf{d}'}$	...	d′
$h^{u \mapsto \mathsf{d}'}$	...	d′

(40) $\quad G_u := \{g(u) \mid g \in G\}$

G is extended by associating u with a plural individual $\mathsf{d}+\mathsf{d}'$ (i.e., $\{\mathsf{d}, \mathsf{d}'\}$). Essentially, the assignments are associated with d and d' in a point-wise manner.[12] The value of u can be retrieved via G_u, defined as in (40).

Given these basic definitions, the meaning of the declarative sentence *some girls called* can

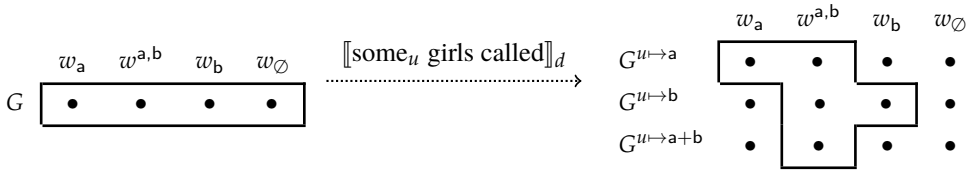
[12] This definition is that of van den Berg's. Alternatively, Brasoveanu (2008) proposes another version of dref introduction, which extends a set of assignments in a cumulative manner, which automatically establish a dependency between drefs. Brasoveanu's definition has an advantage in explaining a donkey sentence where the quantificational restriction contains two indefinites with a dependency, but also encounters challenges, as discussed in detail in Law (2019). Since the present paper does not focus on donkey sentences, I employ van den Berg's definition. However, the dynamic Hamblin semantics proposed in this paper is compatible with Brasoveanu's approach.

be modeled as the dynamic proposition in (41), which updates a context c by extending each of the possibilities (w, G) in c with a dref u pointing to some girls who called in w.

(41) $[\![\text{some}^u \text{ girls called}]\!]_d = \lambda c.\{(w, G^{u\mapsto x}) \mid (w, G) \in c \wedge \textsf{girls}_w(x) \wedge \textsf{called}_w(x)\}$

The update effect of this dynamic proposition is illustrated with the figure in (42).

(42)



This figure is drawn based on a toy model described in (43) below. A context is formulated as a matrix. The uppermost row stores possible worlds, while the leftmost column sets of assignments. Every dot in the middle represents a possibility, i.e., a pair of the world in the corresponding column and the set of assignments in the corresponding row.

(43) Given four worlds w_{a}, w_{b}, $w_{\mathsf{a,b}}$, and $w_{\emptyset}$, and two girls, Annie and Becky:

a. Only Annie called in w_{a};
b. Only Becca called in w_{b};
c. Both Annie and Becca called in $w_{\mathsf{a,b}}$;
d. No one called in $w_{\emptyset}$.

The dynamic proposition in (41) eliminates all the possibilities in the input context where one or more individuals associated with u did not smile in the corresponding world.

Based on theories of the left periphery of a sentence (Rizzi 1997), this paper assumes that beyond the radical of a sentence there is a sentence force operator, which indicates how the sentence meaning is used in communication. Various proposals for sentence force has been made in the literature but I will not dive into them. Sentence force is not crucial to the present analysis of subordination, but serves to mark the sentential boundary. In order to avoid unnecessary complexity, I simply posit that a sentence force operator introduces defined conditions ensuring that a sentence meaning is felicitously used in discourse. For example, the declarative force operator **!** is defined as in (44). Accordingly, a dynamic proposition is asserted only when the speaker is committed to it.

(44) $!(\phi) = \phi$ defined only if the speaker is committed to ϕ.

Question meaning As assumed in Hamblin semantics, a *wh*-expression denotes a set of alternatives, which are modeled as dynamic individuals in the present dynamic setting. A dynamic individual introduces a dref that is associated with the corresponding static individual. At the heart of the composition I propose is a Karttunen semantics (Karttunen 1977; Cresti 1995) in the style of Charlow (2014, 2020). The alternative set denoted by a *wh*-expression is shifted to a generalized quantifier over a set of dynamic propositions by a function $\uparrow$, defined as in (45). The argument f is a function from a dynamic individual χ to a set of dynamic propositions. A lifted

wh-expression takes f, feeds it alternative dynamic individuals χ, and collects the resulting sets into a set of dynamic propositions, i.e., a question meaning.

(45) $$[\![\text{who}^u]\!]^{\uparrow}_d = \lambda f \left(\bigcup \{ f(\chi) \mid \chi \in [\![\text{who}^u]\!]_d \} \right)^{\mathfrak{m}}$$

On one hand, this definition perfectly replicates the essence of Cresti's (1995) implementation of Karttunen semantics, but is grounded in a more general type shifting framework. On the other hand, diverging from Karttunen's (1977) original implementation, a *wh*-expression is distinct from an indefinite. Nevertheless, the relation between *wh*-expressions and indefinites can be captured through specific mappings. I refer readers to Appendix A.2 for details.

In addition to shifting alternative sets to generalized quantifiers, $\uparrow$ brings in an answerhood condition on the resultant question meaning, which is encoded in a function $(\cdot)^{\mathfrak{m}}$, defined as in (46). This function is nothing new but a dynamic version of the Dayal-style answerhood operator (Dayal 1996). Basically, $\mathfrak{m}$ applies to a set Q of dynamic propositions and requires each member ϕ in Q to be the *unique*, maximally informative answer (max-answer, for short). Given this condition, once a dynamic proposition ϕ is selected from Q to update an input context, it must be the most informative member resulting in the output.

(46) $$Q^{\mathfrak{m}} := \Big\{ \underbrace{\lambda c.\ \phi(c) \text{ defined only if } \mathbf{max}_c(Q)(\phi)}_{(\phi)^{\mathfrak{m}}} \ \Big|\ \phi \in Q \Big\}$$

The max-answer is defined through the condition **max** given in (47). In prose, ϕ is the unique dynamic proposition in Q such that it is true and maximally informative relative to the possibilities (w, G) in a context c that support ϕ.

(47) $\mathbf{max}_c(Q)(\phi)$ is true iff ϕ is the unique member from Q such that:
- a. ϕ is dynamically true relative to c (i.e., $\phi(c) \neq \emptyset$)
- b. $\forall \psi \in Q : \forall (w, G) \in \{(w', G') \in c \mid \phi\{(w', G')\} \neq \emptyset\}$:
  if ψ is dynamically true in (w, G) (i.e., $\phi\{(w, G)\} \neq \emptyset$), then ϕ entails ψ

In short, a lifted *wh*-expression is not just a generalized quantifier but also responsible for establishing a set including the possible max-answers. Previously, the answerhood condition has commonly been imposed by an independent answerhood operator at the highest position of a question. However, in the present proposal, it is encoded in the denotation of a lifted *wh*-expression. As a consequence, the answerhood condition cannot be severed from the generation of a question meaning. It turns out to be a welcome result when addressing an over-generation problem related to pair-list readings, which I will return to in Section 6.3.[13]

[13] It should be noted that Dayal's answerhood condition does not capture the fact that some *wh*-questions do not admit a max-answer. For example, the question *where can I buy coffee* can be resolved by offering just one coffee shop. Nevertheless, as argued by Xiang (2022), it does not mean that Dayal's answerhood condition should be abandoned. Instead, she proposes that different kinds of answers can uniformly be captured if Dayal's answerhood condition is checked relative to various modal bases. As the semantics of answers is not the main issue of this paper, I will explore how to integrate Xiang's proposal into the present dynamic framework in future research.

The interrogative complementizer $\mathbb{C}$ in a *wh*-question provides a scope position for a lifted *wh*-expression. It is defined as a function putting a dynamic proposition into a set 'container', as shown in (48), which equals to the classical definition: $\lambda\psi\lambda\phi.\psi = \phi$ (see Dayal 2016).

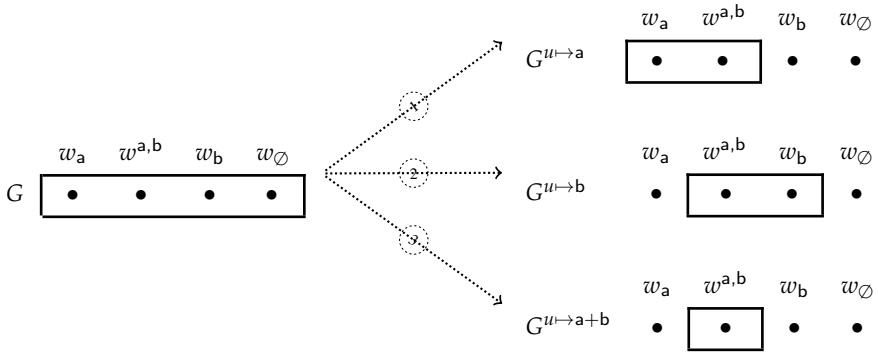
(48) $\quad [\![\mathbb{C}]\!]_d = \lambda\phi.\,\{\phi\}$

Then, the meaning of a *wh*-question is compositionally determined through scoping the *wh*-expression over $\mathbb{C}$. The derivation of *who called* is sketched in (49). but the relevant mechanical issues are set aside until Appendix A.

(49)
$$\begin{aligned}[\![\text{who}^u\ [\mathbb{C}\ [t\ \text{called}]]]\!]_d &= [\![\text{who}^u]\!]_d^{\uparrow}\ \lambda x.[\![\mathbb{C}]\!]_d([\![\text{called}]\!]_d(x)) \\ &= [\![\text{who}^u]\!]_d^{\uparrow}\ \lambda x.\{[\![\text{called}]\!]_d(x)\} \\ &= \{([\![\text{called}]\!]_d(\chi))^{\mathfrak{m}} \mid \chi \in [\![\text{who}^u]\!]_d\} \\ &= \{[\![\text{A}^u\ \text{called}]\!]_d^{\mathbf{m}},\ [\![\text{B}^u\ \text{called}]\!]_d^{\mathbf{m}},\ [\![\text{A and}^u\ \text{B called}]\!]_d^{\mathbf{m}}\} \\ &\qquad\qquad ①\qquad\qquad ②\qquad\qquad ③\end{aligned}$$

The result of the composition in (49) is a set of dynamic propositions, which are assumed to represent possible max-answers to the question. From the perspective of discourse, a *wh*-question provides multiple ways of updating a given context (Farkas & Bruce 2010). In this sense, each dynamic proposition in the resultant set in (49) outputs a potential development of the current context, as shown by the three contexts in (50).

(50)



The outputs capture the weak exhaustive inference of answers (Dayal 1996). Specifically, if a conversational participant knows only that Annie called and is unsure about Becky, they would choose *Annie called* as the answer; whereas, if they know that both Annie and Becca called, they would choose *Annie and Becca called* as the answer.

Similar to a declarative sentence, the root of a *wh*-question is a force layer, where the interrogative act is represented. The interrogative force operator **?** is defined as in (51) (see also Dayal 2023), which is also an identity function with a definedness condition.

(51) $\quad ?(Q) = Q$ **defined only if** the speaker wants the addressee to pick out a member from Q to update the current context. (to be revised)

Cross-sentential anaphora In the dynamic Hamblin semantics, cross-sentential anaphora

to *wh*-expressions is a natural result of conjoining a *wh*-question with a subsequent sentence. Consider (52). Both *wh*-questions denote a set of dynamic propositions. These two sets are conjoined in a point-wise manner, yielding a set of propositional conjunctions.

(52) $[\![\text{which}^u \text{ girl called}]\!]_d\ [\![\text{and}]\!]_d\ [\![\text{what}^v \text{ did she}_u \text{ say}]\!]_d$

$$= \left\{ \begin{array}{l} [\![\text{Annie}^u \text{ called}]\!]^{\mathbf{m}}_d, \\ [\![\text{Becca}^u \text{ called}]\!]^{\mathbf{m}}_d \end{array} \right\} \triangle \left\{ \begin{array}{l} [\![\text{she}_u \text{ said she}_u \text{ was admitted by Cornell}]\!]^{\mathbf{m}}_d \\ [\![\text{she}_u \text{ said she}_u \text{ was admitted by Caltech}]\!]^{\mathbf{m}}_d \end{array} \right\}$$

$$= \left\{ \begin{array}{lll} [\![\text{Annie}^u \text{ called}]\!]^{\mathbf{m}}_d & \triangle & [\![\text{she}_u \text{ said she}_u \text{ was admitted by Cornell}]\!]^{\mathbf{m}}_d, \\ [\![\text{Annie}^u \text{ called}]\!]^{\mathbf{m}}_d & \triangle & [\![\text{she}_u \text{ said she}_u \text{ was admitted by Caltech}]\!]^{\mathbf{m}}_d, \\ [\![\text{Becca}^u \text{ called}]\!]^{\mathbf{m}}_d & \triangle & [\![\text{she}_u \text{ said she}_u \text{ was admitted by Cornell}]\!]^{\mathbf{m}}_d, \\ [\![\text{Becca}^u \text{ called}]\!]^{\mathbf{m}}_d & \triangle & [\![\text{she}_u \text{ said she}_u \text{ was admitted by Caltech}]\!]^{\mathbf{m}}_d \end{array} \right\}$$

In dynamic semantics, the conjunctor *and* denotes dynamic conjunction $\triangle$, which makes the dref introduced in a sentence visible to a subsequent sentence (see Appendix A). In (52), the pronoun in each member of the resulting set retrieves the value of the dref u, which is introduced by a dynamic individual in the set denoted by *which girl*. In other words, the pronoun is interpreted as referring to a girl who called. Its specific identity will be established when both questions are resolved.

Moreover, it is well known that conjunction is cross-categorial. Therefore, conjunction may connect two *wh*-questions at the intra-sentential or inter-sentential level, as visualized in (53).

(53) Intra-sentential conjunction: $\mathbf{?}([\![\text{which}^u \text{ girl called}]\!]_d \triangle [\![\text{what did she}_u \text{ say}]\!]_d)$

Inter-sentential conjunction: $\mathbf{?}[\![\text{which}^u \text{ girl called}]\!]_d \triangle \mathbf{?}[\![\text{what did she}_u \text{ say}]\!]_d$

Intra-sentential conjunction is scoping conjunction under the interrogative force operator **?**. In this case, the speaker is asking the addressee to resolve the two questions with one answer (see Section 2.4). Inter-sentential conjunction is scoping conjunction above **?**. Then, the speaker is asking the addressee to resolve two questions one by one. Since a sentence force operator only introduces definedness conditions in the present analysis, the distinction of intra-sentential and inter-sentential conjunction is trivial in context update. However, this is not always the case. It will be shown in Section 4 that the scope of conjunction holds the key to the account for two types of subordination.

3.2 Dynamic semantics of multiple-*wh* questions

We are now in a position to develop a dynamic analysis for multiple-*wh* questions. The analysis proposed for multiple-*wh* questions follows a widely assumed idea: a multiple-*wh* question with a pair-list reading appears to be a single question about a set of individuals but is in fact a set of sub-questions about each individual (Szabolcsi 1997; Hagstrom 1998; Krifka 2001; Willis 2008; Fox 2012; Nicolae 2013; Constant 2014; Kotek 2014; a.o.), and the pair-list answer is a conjunction of the answers to the sub-questions, as illustrated in (54).

(54) Which girl bought which book? $\rightsquigarrow \left\{ \begin{array}{l} \text{which book did Annie buy,} \\ \text{which book did Becca buy,} \\ \text{which book did Cindy buy} \end{array} \right\}$

Pair-list answer: Annie bought *Sense & Sensibility*, Becca bought *Pride & Prejudice*, and Cindy bought *War & Peace*.

Families of questions The idea sketched earlier has been formalized based on static semantics. Compositionally, a multiple-*wh* clause can give rise to a set of sets of propositions, i.e., a set of question meanings. In this paper, correspondingly, I derive the core meaning of a a multiple-*wh* question as a set of sets of dynamic propositions. The key feature of the proposed composition is that a *wh*-expression scopes over a set of question meanings. Based on Charlow (2014, 2020), I propose that the *wh*-subject in (54) is shifted to a generalized quantifier over higher order alternatives by a function $\Uparrow$, defined as in (55). On one hand, it shares the same schema with $\uparrow$ (see (45)): it feeds the argument f' with every alternative dynamic individuals evoked by the *wh*-subject and collects the results into a set. On the other hand, it differs from $\uparrow$ in that (a) its argument f' is a function to a set of sets of dynamic propositions, i.e., a set of question meanings, rather than a set of dynamic propositions, and (b) it does not apply the answerhood condition to the resultant set.

(55) $[\![\text{which}^u \text{ girl}]\!]_d^{\Uparrow} = \lambda f' \bigcup \{f'(\chi) \mid \chi \in [\![\text{which}^u \text{ girl}]\!]_d\}$

Moreover, the *wh*-object in (54) is lifted by $\uparrow$ and takes scope, too. As a result, the meaning of the multiple-*wh* question is computed as shown in (56). Note that $\mathbb{C}$ applies twice in the computation. It denotes a *polymorphic* function mapping an element x of any type to a singleton set of x. In this example, it puts a question meaning into a set 'container', creating the scope position for the lifted *wh*-subject.

(56) $[\![\text{which}^u \text{ girl bought which}^v \text{ book}]\!]_d$

$= [\![\text{which}^u \text{ girl}]\!]_d^{\Uparrow} \lambda\chi.\, [\![\mathbb{C}]\!]_d \Big([\![\text{which}^v \text{ book}]\!]_d^{\uparrow} \lambda\gamma.\, [\![\mathbb{C}]\!]_d\, ([\![\text{bought}]\!]_d(\gamma)(\chi)) \Big)$

$= [\![\text{which}^u \text{ girl}]\!]_d^{\Uparrow} \lambda\chi.\, [\![\mathbb{C}]\!]_d \{([\![\text{bought}]\!]_d(\gamma)(\chi))^{\mathbf{m}} \mid \gamma \in [\![\text{which}^v \text{ book}]\!]_d\}$

$= [\![\text{which}^u \text{ girl}]\!]_d^{\Uparrow} \lambda\chi.\, \{\{([\![\text{bought}]\!]_d(\gamma)(\chi))^{\mathbf{m}} \mid \gamma \in [\![\text{which}^v \text{ book}]\!]_d\}\}$

$= \{\{([\![\text{bought}]\!]_d(\gamma)(\chi))^{\mathbf{m}} \mid \gamma \in [\![\text{which}^v \text{ book}]\!]_d\} \mid \chi \in [\![\text{which}^u \text{ girl}]\!]_d\}$

$= \{[\![\text{which}^v \text{ book did Annie}^u \text{ buy}]\!]_d, [\![\text{which}^v \text{ book did Becca}^u \text{ buy}]\!]_d\}$

The result is a set of question meanings, which is also known as 'a family of questions'. Essentially, a family of questions establishes a dependency between individuals and answers. In (56), for example, when a different girl is chosen, a different answer may be provided. Moreover, both questions in the family admit a maximally informative answer, leading to a dependent exhaustive inference observed in Fox (2012) and Nicolae (2013), i.e., for each girl, there is a unique book she bought.

It is worth noting that a family of questions generated via $\Uparrow$ is the same as the value of contrastive topic proposed in Büring (2003) and Constant (2014). In this sense, the scope taking facilitated by $\Uparrow$ can be seen as a semantic counterpart of *wh*-topicalization, echoing Willis' (2008) analysis. It means that the lifted *wh*-subject in (56) is topicalized. Cross-linguistically, the topic role is usially assigned to a sentence-initial element, so in a multiple-*wh* question the first *wh*-expression undergoes topicalication instead of the others. This leads to a well-known asymmetry of the *wh*-expressions in (56), whereby the multiple-*wh* question is divided into sub-questions along the domain of girls rather than along the domain of books (Dayal 1996; Kotek 2014; Xiang 2023).

Pair-list answers A family of questions provides a base for the generation of a pair-list answer. Resolving the involved questions gives rise to different answers, which are connected to generate a pair-list answer. This generation process is assumed to be conducted by a covert operator at the top of a multiple-*wh* question.

This paper employs the interrogative force operator **?** to generate pair-list answers.[14] Given that the meaning composition of a multiple-*wh* clause gives rise to a family of questions, which is not the standard question meaning, the definition of **?** must be generalized, as shown in (57), so that this operator can combine with either a single-*wh* or a multiple-*wh* clause (see also Fox 2012). In this paper, the subscript p means that an operator applies in a point-wise manner.

(57) $$\textbf{?}(\mathcal{Q}) := \begin{cases} \mathcal{Q} & \text{if } \mathcal{Q} \text{ is a set of dynamic propositions.} \\ \bigsqcup\!\!\!\!+_{\mathsf{p}} \{Q \mid Q \in \mathcal{Q}\} & \text{if } \mathcal{Q} \text{ is a set of sets of dynamic propositions.} \end{cases}$$

defined only if the speaker wants the addressee to pick out a member from the resultant set to update context

Based on the definition, **?** applies to the family of questions in (56) and connects the questions with the use of a special connective $\uplus\!\!\!+$, defined in (58), in a point-wise manner. This results in a set of dynamic propositions shown in (59).

(58) $\phi \uplus\!\!\!+ \psi := \lambda c.\, \phi(c) \uplus_{\mathsf{p}} \psi(c)$, here

a. $c \uplus_{\mathsf{p}} c' := \{(w, G) \uplus (w', G') \mid (w, G) \in c \wedge (w', G') \in c'\}$

b. $$(w, G) \uplus (w', G') := \begin{cases} (w, G \cup G') & \text{if } w = w' \\ \text{undefined} & \text{if } w \neq w' \end{cases}$$

In prose, when connected by $\uplus\!\!\!+$, ϕ and ψ both update an input context c separately, giving rise to two output contexts c and c', which are collected into the final output by a special union operation $\uplus$. It is important to highlight that $\uplus$ only results in possibilities where both ϕ and ψ are true. According to (98-b), for any possibilities (w, G) and (w', G'), if $w = w'$, a new possibility is formed by pairing the possible world with the union of G and G'; otherwise, it is undefined. As a result, $\phi \uplus\!\!\!+ \psi$ produces possibilities verifying both dynamic propositions (like

[14] It is also feasible to tease apart the generation of pair-list answers from interrogative force. We can posit an interrogative clause type operator that is dedicated to handling the generation of pair-list answers. However, such a complexity is not necessary for the present analysis, so I simply incorporate this function into interrogative force.

intersection) and collecting the relevant assignments (like union).

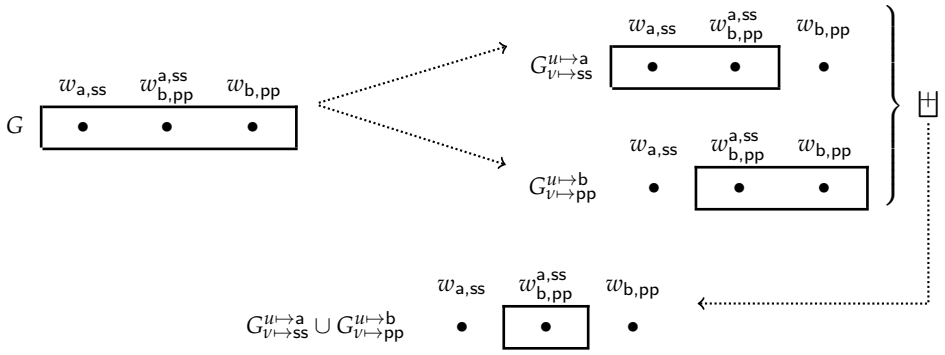
(59) $?\left\{[\![\text{which}^{\nu}\ \text{book did Annie}^{u}\ \text{buy}]\!]_{d},\ [\![\text{which}^{\nu}\ \text{book did Becca}^{u}\ \text{buy}]\!]_{d}\right\}$ (① / ②)

$= \{\phi \uplus \psi \mid \phi \in ① \wedge \psi \in ②\}$

$$= \left\{ \begin{array}{lcl} [\![\text{Annie}^{u}\ \text{bought SS}^{\nu}]\!]^{\mathbf{m}}_{d} & \uplus & [\![\text{Becca}^{u}\ \text{bought PP}^{\nu}]\!]^{\mathbf{m}}_{d}, \\ [\![\text{Annie}^{u}\ \text{bought SS}^{\nu}]\!]^{\mathbf{m}}_{d} & \uplus & [\![\text{Becca}^{u}\ \text{bought SS}^{\nu}]\!]^{\mathbf{m}}_{d}, \\ [\![\text{Annie}^{u}\ \text{bought PP}^{\nu}]\!]^{\mathbf{m}}_{d} & \uplus & [\![\text{Becca}^{u}\ \text{bought SS}^{\nu}]\!]^{\mathbf{m}}_{d}, \\ [\![\text{Annie}^{u}\ \text{bought PP}^{\nu}]\!]^{\mathbf{m}}_{d} & \uplus & [\![\text{Becca}^{u}\ \text{bought PP}^{\nu}]\!]^{\mathbf{m}}_{d} \end{array} \right\}$$

Let me use the first member of the resultant set to illustrate the context update of a pair-list answer. As depicted in (60), the possibilities in the outputs that share the same possible world are the ones involving the possible world $w^{\mathsf{a,ss}}_{\mathsf{b,pp}}$, where Annie bought SS and Becca PP.

(60)



Therefore, the sets of assignments in these possibilities form a union. The details are spelled out in (61). The resultant set of assignments encodes a dependency between u and ν, which are introduced by the *wh*-expressions, i.e., for each girl stored in u, there is a potentially different book stored in ν such that the girl bought the book.

(61) $$\left(w^{\mathsf{a,ss}}_{\mathsf{b,pp}}, \begin{array}{|c|c|}\hline u & \nu \\ \hline \mathsf{a} & \mathsf{ss} \\ \hline \end{array}\right) \uplus \left(w^{\mathsf{a,ss}}_{\mathsf{b,pp}}, \begin{array}{|c|c|}\hline u & \nu \\ \hline \mathsf{b} & \mathsf{pp} \\ \hline \end{array}\right) = \left(w^{\mathsf{a,ss}}_{\mathsf{b,pp}}, \begin{array}{|c|c|}\hline u & \nu \\ \hline \mathsf{a} & \mathsf{ss} \\ \hline \mathsf{b} & \mathsf{pp} \\ \hline \end{array}\right)$$

As a result, the dynamic propositions connected by ⊎ form a possible pair-list answer, which maps an input context to the output where both girls bought a different book. In the same way, the other members in (59) also provide a pair-list answer to the question and give rise to a girl–book dependency with a different value.[15]

In the dynamic family-of-questions analysis, the distinguished feature of a pair-list answer

[15] In the present analysis, a possible pair-list answer consists of multiple dynamic propositions connected by the novel operator ⊔. However, the linguistic expression of a pair-list answer usually involves conjunction. Therefore, it might be more natural if pair-list answers are formed with dynamic conjunction. I will address this issue in Section 6.2. Simply put, dynamic conjunction does not gives rise to a dependency between drefs. In addition, similar to conjunction, the truth condition of $\phi \sqcup \psi$ requires both ϕ and ψ to be true.

is the discourse dependency encoded in this answer, which underlies quantificational subordination. Briefly, the dependencies encoded in pair-list answers are structured in the same way as the one introduced by a universal statement like *every girl bought a book*. In the studies adopting DPlL (van den Berg 1996; Nouwen 2003; Brasoveanu 2010; Henderson 2014; Law 2019; a.o.), the universal statement produces sets of assignments shown in (62), which also encode a dependency between the drefs u and v.

(62) $G \xrightarrow{[\![\text{every}^u \text{ girl bought a}^v \text{ book}]\!]_d}$

u	v
a	ss
b	pp

,

u	v
a	pp
b	ss

,

u	v
a	pp
b	pp

,

u	v
a	ss
b	ss

Because of the similarity between the sets of assignments in (61) and in (62), it is not surprising that the subordination pattern is available for a multiple-*wh* question and a universal statement. We will return to the issue of generating dependencies in Section 6.1, showing that multiple-*wh* questions and universal statements use a general mechanism to establish dependencies. This is the formal reason underlying the surface similarity.[16]

4 Analysis

In the dynamic family-of-questions approach, a multiple-*wh* question denotes a set of possible pair-list answers, which is transformed from a family of questions. A possible pair-list answer encodes a discourse dependency between drefs, while a family of questions an individual–answer dependency. Retrieving these two kinds of dependencies requests two anaphoric strategies, which appear as quantificational subordination and question subordination.

Explaining question subordination As presented in Section 3.1, conjunction can scope above or below a force operator. Therefore, conjunction of a multiple-*wh* question and another question can be under the scope of the **?** operator, as demonstrated in (63). Based on this scope pattern, question subordination is compositionally derived.

(63) $\textbf{?}\left([\![\text{which}^u \text{ girl bought which}^v \text{ book}]\!]_d \mathbin{\triangle} [\![\text{how much did she}_u \text{ paid for it}_v]\!]_d\right)$

In (63), under the scope of **?**, the multiple-*wh* clause denotes a family of questions, which is accessed by the pronouns in the subsequent question, as shown in (64).

[16] This footnote addresses the issue raised by the reviewers regarding the applicability of $\Uparrow$ in single-*wh* questions. Suppose that $\Uparrow$ is utilized to derive the meaning of *who called*, the complementizer $\mathbb{C}$ should be applied twice, as illustrated below. The result is a singleton set of question meaning.

(i) $[\![\text{who}]\!]_d^{\Uparrow}\ \lambda\chi.[\![\mathbb{C}]\!]_d([\![\mathbb{C}]\!]_d([\![\text{called}]\!]_d(\chi))) = \{[\![\text{who called}]\!]_d\}$

Based on the present definition of $\Uparrow$, which lacks the condition of maximal informativity, (i) fails to produce the max-answer. While this issue can be resolved by positing an operator to re-introduce the condition, it leads to a more serious problem: once the force operator **?** is applied, the set in (i), if endowed with the condition of maximal informativity, would be mapped to a set of possible max-answers, which is identical to the denotation derived via $\uparrow$. However, the composition represented in (i) is more complex and hence it should be prevented pragmatically due to the existence of a simpler alternative.

(64) $$\left\{ \begin{array}{l} [\![\text{which}^{\nu} \text{ book did Annie}^{u} \text{ buy}]\!]_{d}, \\ [\![\text{which}^{\nu} \text{ book did Becca}^{u} \text{ buy}]\!]_{d} \end{array} \right\} \mathbin{\triangle} [\![\text{how much did she}_{u} \text{ pay for it}_{\nu}]\!]_{d}$$

Informally, the questions in the family are conjoined with the follow-up question one by one, giving rise to a set including conjunctions of *wh*-questions. This set is equal to a set of sets of propositional conjunctions, as in (65) (see Appendix A.2 for a formal derivation). In every conjunction, the singular pronoun *she* refers to one of the girls ranged over by *which girl*, while the singular pronoun *it* refers to the book this girl bought.

(65) $$\left\{ \begin{array}{lll} [\![\text{which}^{\nu} \text{ book did Annie}^{u} \text{ buy}]\!]_{d} & \triangle & [\![\text{how much did she}_{u} \text{ pay for it}_{\nu}]\!]_{d}, \\ [\![\text{which}^{\nu} \text{ book did Becca}^{u} \text{ buy}]\!]_{d} & \triangle & [\![\text{how much did she}_{u} \text{ pay for it}_{\nu}]\!]_{d} \end{array} \right\}$$

$$= \left\{ \begin{array}{l} \left\{ \begin{array}{lll} [\![\text{Annie}^{u} \text{ bought PP}^{\nu}]\!]^{\mathbf{m}}_{d} & \triangle & [\![\text{she}_{u} \text{ paid \$100 for it}_{\nu}]\!]^{\mathbf{m}}_{d}, \\ [\![\text{Annie}^{u} \text{ bought SS}^{\nu}]\!]^{\mathbf{m}}_{d} & \triangle & [\![\text{she}_{u} \text{ paid \$150 for it}_{\nu}]\!]^{\mathbf{m}}_{d}, \\ [\![\text{Annie}^{u} \text{ bought PP}^{\nu}]\!]^{\mathbf{m}}_{d} & \triangle & [\![\text{she}_{u} \text{ paid \$150 for it}_{\nu}]\!]^{\mathbf{m}}_{d}, \\ [\![\text{Annie}^{u} \text{ bought SS}^{\nu}]\!]^{\mathbf{m}}_{d} & \triangle & [\![\text{she}_{u} \text{ paid \$100 for it}_{\nu}]\!]^{\mathbf{m}}_{d} \end{array} \right\}, \\ \\ \left\{ \begin{array}{lll} [\![\text{Becca}^{u} \text{ bought PP}^{\nu}]\!]^{\mathbf{m}}_{d} & \triangle & [\![\text{she}_{u} \text{ paid \$100 for it}_{\nu}]\!]^{\mathbf{m}}_{d}, \\ [\![\text{Becca}^{u} \text{ bought SS}^{\nu}]\!]^{\mathbf{m}}_{d} & \triangle & [\![\text{she}_{u} \text{ paid \$150 for it}_{\nu}]\!]^{\mathbf{m}}_{d}, \\ [\![\text{Becca}^{u} \text{ bought PP}^{\nu}]\!]^{\mathbf{m}}_{d} & \triangle & [\![\text{she}_{u} \text{ paid \$150 for it}_{\nu}]\!]^{\mathbf{m}}_{d}, \\ [\![\text{Becca}^{u} \text{ bought SS}^{\nu}]\!]^{\mathbf{m}}_{d} & \triangle & [\![\text{she}_{u} \text{ paid \$100 for it}_{\nu}]\!]^{\mathbf{m}}_{d} \end{array} \right\} \end{array} \right\}$$

Since conjoining two dynamic propositions leads to a dynamic proposition, the set in (65) still contains sets of dynamic propositions. **?** is able to operate on this set and transform it into a set of possible pair-list answers, one of which could be *Annie bought PP and paid $100 for it; Becca bought SS and paid $150 for it*.

In short, question subordination is naturally derived when a multiple-*wh* clause is conjoined with another *wh*-clause before **?** applies. Crucially, the interpretation of the subsequent *wh*-clause is subordinated to a family of question meanings denoted by the multiple-*wh* clause. The subordination is achieved through point-wise conjunction. In (65), for example, the subsequent *wh*-clause is interpreted relative to different questions, each of which involves an individual x in the domain of *which girl* and asks which book x bought. As a result, the pronouns in the subsequent *wh*-clause refer to different girls and books.[17]

Explaining quantificational subordination Reference to a *wh*-dependency can also be induced when a quantifier appears. In this case, conjunction scopes over the **?** operator. The scope pattern is demonstrated in (66).

[17] The editor of the first round and a reviewer have raised concerns about the necessity of a family of questions in the present analysis of question subordination. They suggest that the analysis could be simplified by conjoining two sets of dynamic propositions. I defend the present analysis by arguing that the simplified analysis over-generates a pair-list reading for conjunction of single-*wh* questions, like *which girl called and what did she say*, which actually does not admit a pair-list answer. More details are provided in Section 6.3.

(66) $\textbf{?}[\![\text{which}^u \text{ girl bought which}^v \text{ book}]\!]_d \mathbin{\triangle} \textbf{?}[\![\text{how much did each of them}_u \text{ paid for it}_v]\!]_d$

The first multiple-*wh* question denotes a set of alternative pair-list answers, while the second *wh*-question a set of alternative propositional answers. Both sets of answers are point-wisely conjoined, as illustrated in (67).[18]

(67)
$$\left\{ \begin{array}{l} \uplus \left\{ \begin{array}{l} [\![\text{Annie}^u \text{ bought SS}^v]\!]^{\mathbf{m}}_d \\ [\![\text{Becca}^u \text{ bought PP}^v]\!]^{\mathbf{m}}_d \end{array} \right. \\ \uplus \left\{ \begin{array}{l} [\![\text{Annie}^u \text{ bought SS}^v]\!]^{\mathbf{m}}_d \\ [\![\text{Becca}^u \text{ bought SS}^v]\!]^{\mathbf{m}}_d \end{array} \right. \\ \uplus \left\{ \begin{array}{l} [\![\text{Annie}^u \text{ bought PP}^v]\!]^{\mathbf{m}}_d \\ [\![\text{Becca}^u \text{ bought SS}^v]\!]^{\mathbf{m}}_d \end{array} \right. \\ \uplus \left\{ \begin{array}{l} [\![\text{Annie}^u \text{ bought PP}^v]\!]^{\mathbf{m}}_d \\ [\![\text{Becca}^u \text{ bought PP}^v]\!]^{\mathbf{m}}_d \end{array} \right. \end{array} \right\} \mathbin{\triangle} \left\{ \begin{array}{l} [\![\text{each of them}_u \text{ paid \$100 for it}_v]\!]^{\mathbf{m}}_d, \\ [\![\text{each of them}_u \text{ paid \$150 for it}_v]\!]^{\mathbf{m}}_d \end{array} \right\}$$

As a result, the pair-list answers in the first set are cumulatively conjoined with the propositional answers from the second set, forming a set of dynamic conjunctions. (68) is a sample conjunction in the resultant set.

(68)
$$\left(\uplus \left\{ \begin{array}{l} [\![\text{Annie}^u \text{ bought SS}^v]\!]^{\mathbf{m}}_d \\ [\![\text{Becca}^u \text{ bought PP}^v]\!]^{\mathbf{m}}_d \end{array} \right. \right) \mathbin{\triangle} [\![\text{each of them}_u \text{ paid \$100 for it}_v]\!]^{\mathbf{m}}_d$$

Section 3.2 has shown that a pair-list answer maps an input context to an output where every set of assignments encodes a dependency between drefs introduced by *wh*-expressions. In (68), the output context of the pair-list answer is demonstrated as in (69), which can be seen as a summary of the examples from (58) through (61).

(69) $c \dashrightarrow [\![\text{Annie}^u \text{ bought SS}^v]\!]^{\mathbf{m}}_d \uplus [\![\text{Becca}^u \text{ bought PP}^v]\!]^{\mathbf{m}}_d \dashrightarrow$

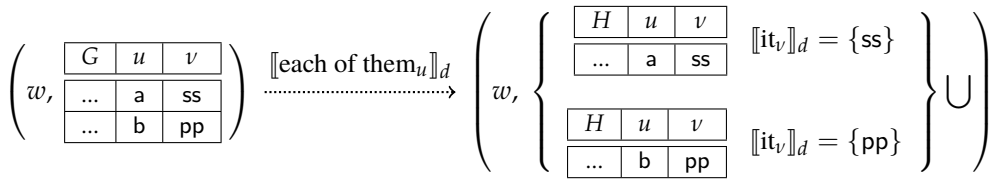
$$\left\{ \left(w,\ G + \begin{array}{|c|c|} \hline u & v \\ \hline \mathsf{a} & \mathsf{ss} \\ \hline \mathsf{b} & \mathsf{pp} \\ \hline \end{array} \right) \;\middle|\; \begin{array}{l} (w, G) \in c \wedge \mathsf{bought}_w(\mathsf{ss})(\mathsf{a}) \\ \wedge\ \mathsf{bought}_w(\mathsf{pp})(\mathsf{b}) \end{array} \right\}$$

Each set of assignments in the output is associated with multiple girls and multiple books and every girl is correlated with a different book. In this sense, there is a girl–book dependency.

[18] It is noted that the second question that involves a distributive quantifier is ambiguous between an individual reading and a pair-list reading (Engdahl 1986). The former expects the answer naming one price, while the latter anticipates the answer providing a list of pairs. The derivation of the individual reading is straightforward, nit the derivation of the pair-list reading is complicated and controversial (see Chierchia (1992), Pafel (1999), Krifka (2001), and Xiang (2023) for details). In order to keep our discussion on track, I only consider the individual reading in this paper and refer interested readers to Li (2020) for a dynamic analysis of the pair-list reading.

The distributive quantifier *each of them* in the second question enables the dependency to be accessible for the singular pronoun *it*. In particular, given the output context in (69), the distributive quantifier divides the set G of assignments in each possibility into subsets H along the values stored in u, as assumed in the standard DPlL analysis (van den Berg 1996; Brasoveanu 2010). In the following figure, the subsets each involve an assignment assigning one girl to u and the corresponding book to v. They provide local contexts for the singular pronoun in the scope of the distributive quantifier.

(70)



Therefore, the singular pronoun *it* retrieves the value assigned to v in each subset of assignments. As a result, the pronoun is understood to be the single book one girl bought. The fact that v in each subset stores only one book also satisfies the atomicity condition of the singular pronoun.

The process presented in (69) and (70) is essentially subordinating the interpretation of a pronoun to a pair-list answer. Crucially, a quantifier is able to unfurl a set G of assignments led by a pair-list answer. As a consequence, a pronoun in the scope of the quantifier is interpreted relative to the subsets of G, rather than G itself. The whole process is actually the same as the one that has been proposed for quantificational subordination.

Subordination in Q−D and Q−Q sequences So far, it has been demonstrated that the divergence between the two types of subordination is rooted in the scopal distinction of *wh*-conjunction. Question subordination is derived through scoping *wh*-conjunction below the **?** operator. In this case, the interpretation of the second *wh*-conjunct is subordinated to a family of question meanings denoted by the first multiple-*wh* conjunct. By contrast, quantificational subordination is induced by scoping *wh*-conjunction over **?**. In this case, the interpretation of the second *wh*-conjunct is subordinated to possible pair-list answers to the first multiple-*wh* conjunct. A prediction of this analysis is that either type of subordination should be disallowed if the corresponding scope pattern of conjunction and **?** is banned.

This prediction is verified by the fact that a quantifier must occur to facilitate reference to a *wh*-dependency when the relevant multiple-*wh* question is followed by a declarative sentence. Consider (71). In dynamic semantics, a sequence of sentences is also understood to be a dynamic conjunction of sentences. Therefore, the structure of (71) can be analyzed as (72).

(71) Context: Annie, Becca, and Cindy bought different books.
A: Which^u girl bought which^v book? Each of them$_u$ might have paid a lot for it$_v$.

(72) **?**[[which^u girl bought which^v book]]$_d$ $\triangle$ **!**[[each of them$_u$ might have paid a lot for it$_v$]]$_d$

Based on the proposed analysis, the follow-up declarative sentence accesses each possible pair-list answer in the set denoted by the first multiple-*wh* question. Therefore, the distributive quan-

tifier functions in the same way as shown in (70) to unfurl the dependency encoded in a pair-list answer, leading to quantificational subordination.[19]

Suppose that a Q−D sequence like (73) could support reference to a *wh*-dependency when no quantifier occurs, the declarative sentence should be under the scope of the **?** operator and hence conjoined with the multiple-*wh* clause denoting a family of questions, as shown in (74).

(73) Context: Annie, Becca, and Cindy bought different books.
A: #Which^u girl bought which^v book? She$_u$ might have paid a lot for it$_v$.

(74) **?** $\left(\llbracket \text{which}^u \text{ girl bought which}^v \text{ book} \rrbracket_d \triangle \llbracket \text{she}_u \text{ might have paid a lot for it}_v \rrbracket_d\right)$

As a result, the declarative sentence would be part of an interrogative act, which goes against the norm that declarative sentence should give rise to a declarative act. In this sense, a declarative sentence cannot be contained in the scope of the interrogative force. Due to the ill-formedness of (74), a subordination-like interpretation is prevented for (73).

Besides, the present analysis can explain the distribution of the subordination-like interpretation in Q−Q sequences. If a person asks a multiple-*wh* and single-*wh* question consecutively, the involved questions may also perform a single interrogative act and require an answer resolving both questions. In this situation, the Q−Q sequence is analyzed as a *wh*-conjunction under the scope of **?**, similar to (63), so reference to *wh*-dependencies is derivable without a quantifier, as shown in (75). Besides, a Q−Q sequence can be understood to be conjunction of two interrogative acts, i.e., conjunction scopes over **?**, similar to (66). As a consequence, reference to *wh*-depdencies is facilitated by a quantifier, as evidenced by (76).

(75) Context: Annie, Becca, and Cindy bought different books.
A: ?Which^u girl bought which^v book? How much did she$_u$ pay for it$_v$?

(76) Context: Annie, Becca, and Cindy bought different books.
A: Which^u girl bought which^v book? How much did each of them$_u$ pay for it$_v$?

By contrast, once two questions are asked consecutively by *different* people in a conversation, like (77), it is implausible to assume that there is just one interrogative act. Therefore, the construal of the involved two questions cannot be a conjunction under interrogative force. Consequently, reference to *wh*-dependencies is not possible.

(77) Context: Annie, Becca, and Cindy bought different books.
A: Which^u girl bought which^v book?
B: #I'm also wondering how much she$_u$ paid for it$_v$?

[19] The most direct way of analyzing the conjunction in (72) is conjoining the multiple-*wh* question with the declarative sentence in a point-wise manner. In other words, they are conjoined in the same way as *wh*-conjunction. However, this analysis misses the fact that a well-formed Q−D sequence is subject to more constraints than *wh*-conjunction (Anna Szabolcsi p.c.). For example, attitude verbs or modals are often required in declarative follow-ups to form coherent Q–D sequences. (72) becomes infelicitous if the modal *might* is omitted. Providing a full-fledged analysis for these constraints of Q−D sequences is significant to understand discourse involving questions, but it is beyond the scope of this paper.

Wrapping up The dynamic family-of-questions approach derives the meaning of a multiple-*wh* question in two steps. First, a family of questions is generated, and then this set is mapped to a set of possible pair-list answers. A possible pair-list answer and a family of questions introduce different kinds of dependencies in discourse. The dependency introduced by a pair-list answer supports quantificational subordination, whereas the dependency introduced by a family of questions supports question subordination.[20]

5 Embedded *wh*-questions

So far, we have not discussed dynamic effects of *wh*-expressions in embedded *wh*-questions. However, it is observed that the *wh*-expression in an embedded *wh*-question can also support cross-sentential anaphora (Haida 2007), as in (78).

(78) Max knows which^{u} girl called and he also knows why she$_{u}$ did.

This subsection shows that the dynamic semantics of questions proposed in this paper can also capture anaphora to embedded *wh*-expressions. Moreover, it presents new data about subordination involving embedded questions and discusses potential analyses.

The standard assumption is that the verb *know* takes a proposition as an argument and, when it embeds a question, the set of propositions denoted by the question has to be shifted to the propositional answer to the question, by a covert answerhood operator $\mathbb{A}$ (Heim 1994; Dayal 1996; Beck & Rullmann 1999; cf. Uegaki 2015; Theiler et al. 2018). In the present dynamic framework, the answerhood condition has been imposed on a *wh*-question through lifting the *wh*-expression to be a generalized quantifier (see (101)) and $\mathbb{A}$ denotes a function $\mathbf{A}$, defined in (79), mapping the *wh*-question to the unique, maximally informative true answer in a specific input context, which is provided by an attitude verb embedding a question. With this assumption in place, the structure of the first sentence in (78) can be represented as (80). Suppose that only Annie called, then the argument of *know* is the dynamic proposition $[\![\text{Annie}^{u}\ \text{called}]\!]^{\mathbf{m}}_{d}$ picked out from the set denoted by the embedded *wh*-question.

(79) $\mathbf{A}(Q) := \lambda c.\phi(c)$ if $\phi \in Q$ and ϕ is dynamically true relative to c.

(80) [Max knows [$\mathbb{A}$ which^{u} girl called]]

Embedding environments do not block anaphoric accessibility. A dref introduced in the scope

[20] One of the reviewers asks if singular pronouns in a polar question are also able to retrieve a *wh*-dependency. According to Li (2023), question subordination is not allowed in the following example.

(i) Scenario: Two girls bought a bunch of clothing from a store. After leaving, the manager comes up to the cashier and wants to know for the purposes of collecting data what the clothing was each of them bought and what they paid with. So the manager says:

Hi! Just collecting data again on that blonde and brunette who just left with the dresses. #Which^{u_1} girl bought which^{u_2} dress and did she$_{u_1}$ pay for it$_{u_2}$ with cash?

Given the present analysis, it is suggested that the multiple-*wh* question and the subsequent polar question cannot constituent a single interrogative act. This is not unreasonable, as the answerhood requirements of *wh*-questions and polar questions are distinct so that it is challenging to address them collectively.

of an attitude verb can still support discourse anaphora (Geach 1967), as evidenced by (81). Therefore, the dref introduced by the *wh*-expression in (80) is also retrievable.[21]

(81) Max knows Annie^{u} called and he also knows why she$_{u}$ did.

Quantificational subordination in embedding environments In addition to the basic cases, reference to *wh*-dependencies can also been observed in embedding environments. Consider (82). The target sentence is felicitous in the given context. According to the context, John has the knowledge of the dependency between the three women and the cities. This dependency is accessible to the singular demonstrative scoping below the distributive quantifier in the subsequent sentence.

(82) Context: Annie was born in New Brunswick, Becca was born in Santa Cruz and Cindy was born in New York. Now, each of them is the mayor of the city in which she was born. John is a journalist who recently reported about these successful women. He not only knows where they were born but also what they are doing now.
John knows which^{u} woman was born in which^{v} city and he also knows what role each of them$_{u}$ is serving in that$_{v}$ city.

Because *know* requires its argument to be propositional, the structure of the first sentence in (82) is analyzed as follows. In this structure, the $\mathbb{A}$ takes as its argument a family of questions, which is delivered by the multiple-*wh* clause, rather than a question meaning, so its denotation must be generalized to operate on either a set of dynamic propositions or a set of sets of dynamic propositions (see also Fox 2012), as shown in (84).

(83) John knows [$\mathbb{A}$ [which^{u} woman was born in which^{v} city]]

(84) $$[\![\mathbb{A}]\!]_{d} = \lambda \mathcal{Q} \begin{cases} \mathbf{A}(\mathcal{Q}) & \text{if } \mathcal{Q} \text{ is a set of dynamic propositions} \\ \biguplus \{\mathbf{A}(Q) \mid Q \in \mathcal{Q}\} & \text{if } \mathcal{Q} \text{ is a set of sets of dynamic propositions} \end{cases}$$

In (83), taking a family of questions, $\mathbb{A}$ applies $\mathbf{A}$ to every member in this family, delivering their max-answers, and connects the resultant answers with $\biguplus$. Based on the definition of $\biguplus$ (see (58)), the clausal complement of *know* is essentially the pair-list answer to the multiple-*wh* question. Consequently, the embedded clause contributes a woman–city dependency in discourse, which is unfurled by the quantifier in the subsequent sentence in (82). Therefore, a subordination-like interpretation is induced.

Clearly, the analysis works only if the attitude verb does not interfere with the subordination-like interpretation. This is independently supported by the fact that reference to quantificational dependencies is also observed in embedded environments, as illustrated in (85).

[21] There are a few dynamic analyses targeting pronominal resolution across clauses embedded by attitude verbs (Geurts 1998; Van Rooy 2000; Dekker & Van Rooy 1998; a.o.). Since anaphora in attitude contexts is not the focus of this paper, I do not review the relevant studies here. Adopting any analysis of attitude verbs that allows the cross-sentential anaphora in (81) enables us to explain how the dref u in (80) is retrieved by a pronoun embedded in a subsequent sentence.

(85) John knows that every^{u} girl bought a^{v} book and he also knows that each of them$_{u}$ paid about \$100 for it$_{v}$.

Question subordination in embedding environments Question subordination is also availanble in embedding environments. Consider (86). The target sentence is acceptable in the same context in (82).

(86) Context: Annie was born in New Brunswick, Becca was born in Santa Cruz and Cindy was born in New York. Now, each of them is the mayor of the city in which she was born. John is a journalist who recently reported about these successful women. He not only knows where they were born but also what they are doing now.
John knows which^{u} woman was born in which^{v} city and he also knows what role she$_{u}$ is serving in that$_{v}$ city.

As presented in Section 4, question subordination is derived when the family of questions denoted by a multiple-*wh* clause is accessible for a subsequent sentence. However, given that the embedded multiple-*wh* question in (86) has the structure like (83), the denotation of the multiple-*wh* clause would be used by $\mathbb{A}$ and inaccessible for the subsequent sentence.

This issue is resolved if the embedded multiple-*wh* clause scopes out of the attitude verb. In particular, the multiple-*wh* clause scopes at the edge of the matrix clause, leaving a variable over question meanings, as visualized in (87). The alternatives in the set denoted by the multiple-*wh* clause feed the function in its scope one by one, yielding a set of dynamic propositions. Note that the scope analysis of embedded questions is not novel and has been justified in the literature (Dayal 1996; Lahiri (2002); Beck & Sharvit 2002; a.o.).

(87) $[\![\text{which}^{u} \text{ woman was born in which}^{v} \text{ city}]\!]_{d}\ \lambda Q.\ [\![\text{know}]\!]_{d}\big([\![\mathbb{A}]\!]_{d}(Q)\big)\big([\![\text{John}]\!]_{d}\big)$

$$= \left\{ \begin{array}{l} [\![\text{which}^{v} \text{ city was Annie}^{u} \text{ born in}]\!]_{d}, \\ [\![\text{which}^{v} \text{ city was Becca}^{u} \text{ born in}]\!]_{d}, \\ [\![\text{which}^{v} \text{ city was Cindy}^{u} \text{ born in}]\!]_{d} \end{array} \right\} \lambda Q.\ [\![\text{know}]\!]_{d}\big([\![\mathbb{A}]\!]_{d}(Q)\big)\big([\![\text{Jhon}]\!]_{d}\big)$$

$$= \left\{ \begin{array}{l} [\![\text{ John knows which}^{v} \text{ city was Annie}^{u} \text{ born in}]\!]_{d}, \\ [\![\text{ John knows which}^{v} \text{ city was Becca}^{u} \text{ born in}]\!]_{d}, \\ [\![\text{ John knows which}^{v} \text{ city was Cindy}^{u} \text{ born in}]\!]_{d} \end{array} \right\}$$

Each member in the resulting set expresses that John knows the answer to a question involving one of the three women. Conjoining them with the subsequent sentence in a point-wise manner gives rise to (88), where each conjoined sentence involves discourse anaphora to a single woman and a single city.

(88) $$\left\{ \begin{array}{lll} [\![\text{J knows which}^{v} \text{ city A}^{u} \text{ ... }]\!]_{d} & [\![\text{and}]\!]_{d} & [\![\text{he knows ... she}_{u} \text{ ... that}_{v} \text{ city}]\!]_{d}, \\ [\![\text{J knows which}^{v} \text{ city B}^{u} \text{ ... }]\!]_{d} & [\![\text{and}]\!]_{d} & [\![\text{he knows ... she}_{u} \text{ ... that}_{v} \text{ city}]\!]_{d}, \\ [\![\text{J knows which}^{v} \text{ city C}^{u} \text{ ... }]\!]_{d} & [\![\text{and}]\!]_{d} & [\![\text{he knows ... she}_{u} \text{ ... that}_{v} \text{ city}]\!]_{d} \end{array} \right\}$$

Because the sentence in (86) is declarative, the set in (88) should be closed. (86) expresses that, for each woman, John knows in which city she was born and which role she is serving in that city, so I follow Rawlins (2013) and postulate that the set is closed by conjunction, i.e., all the dynamic propositions in the set are conjoined, resulting in one dynamic proposition. Therefore, the meaning of the whole sentence in (86) is represented as follows:

(89) ϕ_1 $[\![\text{and}]\!]_d$ ϕ_2 $[\![\text{and}]\!]_d$ ϕ_3, in which $\phi_1, \phi_2, \phi_3 \in$ (88)

The conjunction closure is inserted only when the declarative force operator combines with an alternative set. It is noted that sentence force is constrained syntactically. In English, *wh*-movement only supports interrogative force, which operates on alternative sets and hence will never trigger the insertion of the conjunction closure.

The present analysis predicts that question subordination should be disallowed if a multiple-*wh* question cannot scope beyond an embedding verb. According to the same set of studies, i.e., Moltmann & Szabolcsi (1993), Lahiri (2002), and Beck & Sharvit (2002), it is difficult for questions embedded by the verb *wonder* to move out. Correspondingly, some native speakers found that the example lacking quantifiers in (90) is marginal.[22] As a comparison, the example involving a quantifier is acceptable for them.

(90) Context: Annie, Becca, and Cindy each came from a different city but they all became very successful in New York. Peter as a journalist would like to report about these women. He needs to find out where they were born and when they left there.

a. ??Peter wonders which^u woman was born in which^v city, but he also wonders when she$_u$ left that$_v$ city. (Question subordination)

b. Peter wonders which^u woman was born in which^v city, but he also wonders when each of them$_u$ left that$_v$ city. (Quantificational subordination)

In addition, it predicts that question subordination should always be available in the embedding environment exemplified by (86), no matter what the second embedded clauses are and what the second embedding verbs are. Consider the following examples. In (91), the verb *know* embeds a declarative sentence in the second sentence, whereas in (91) the question is embedded by the verb *wonder*, which only takes a question as the complement.

(91) Context: Annie was born in New Brunswick, Becca was born in Santa Cruz, and Cindy was born in New York. Now, each of them is the mayor of the city in which she was born. John is a journalist who recently reported about these successful women. He not only knows where they were born but also what they

[22] Not all of my informants consider (90) unacceptable. In addition, one of the reviewers points out that the marginal acceptability of the first example in (90) is due to discourse incoherence. They notice that the examples in (90) sound much better if *but* is replaced with *and* or if the attitude verb in the second conjuncts is substituted with *know*. It may echo the observation in Beck & Sharvit (2002). They find that questions embedded by *wonder* can take wide scope in some specific contexts and trigger the quantificational variability effect. In other words, the scope taking of questions embedded by *wonder* is not always disallowed.

are doing now.
?John knows which^{u} woman was born in which^{v} city, and he also knows she$_{u}$ is serving mayor in that$_{v}$ city.

(92) Context: Annie was born in New Brunswick, Becca was born in Santa Cruz, and Cindy was born in New York. Now, each of them is the mayor of the city in which she was born. Peter met these women in college and learned where they were born. After graduation, he went abroad to work and did not stay in touch with them. Recently, he heard that each of these women has become an important person in the city that she was born. He is very curious about what they are doing now.
(??)Peter knows which^{u} woman was born in which^{v} city, but he wonders what role she$_{u}$ is serving in that$_{v}$ city.

As for both examples, the same derivational process as the one from (87) through (88) enables every question in the set generated by the embedded multiple-*wh* question to serve as an antecedent for the second sentence. So, subordination should be allowed without the help of quantifiers. Nevertheless, the empirical judgments are far from clear. Of the five native speakers I interviewed, all of them accepted (91) in the given context, but four of them found it a bit harder to get as compared with (86). In addition, three of them accepted (92) in the given context, but the other two rejected it. It is unclear at this point what is behind the individual variation, which may benefit from a controlled experiment and is left for future study.[23]

6 Discussion

This section is devoted to discussions on theoretical and empirical issues raised in the dynamic family-of-question approach. First of all, the proposed way of deriving pair-list answers is compared with universal quantification in DPlL. The comparison shows that the present derivation of pair-list answers is not radical but reflects a general device of building discourse dependency. Additionally, it is shown that deriving the pair-list reading based on a family of questions has an advantage in avoiding an over-generation problem related to the uniqueness requirement of *wh*-questions in discourse. Last but not least, it is demonstrated that question subordination

[23] A reviewer points out that question subordination is allowed between two sentences that embed questions but are not adjacently conjoined, as exemplified below.

(i) John knows which woman was born in which city. That's good. He also knows what role she is serving in that city. That's where the problems begin.

The present analysis can capture question subordination in (i) as follows: (a) the embedded question in the first sentence denotes a family of questions, which scopes over the matrix clause, leading to a set of propositional meanings; (b) each proposition is subsequently conjoined with the following sentences; (c) the resultant set of conjoined propositions is further closed by conjunction. However, this analysis is not adequate because it leaves aside the references of the demonstratives in (i). Based on native speakers' intuitions, the first demonstrative may refer to the fact that John has knowledge about the pair-list answer to the embedded question. It indicates that the pair-list answer may have been generated when the second sentence is uttered. So, addressing this issue calls for a fine-grained analysis of demonstrative reference, which is beyond the scope of this paper and left for future research.

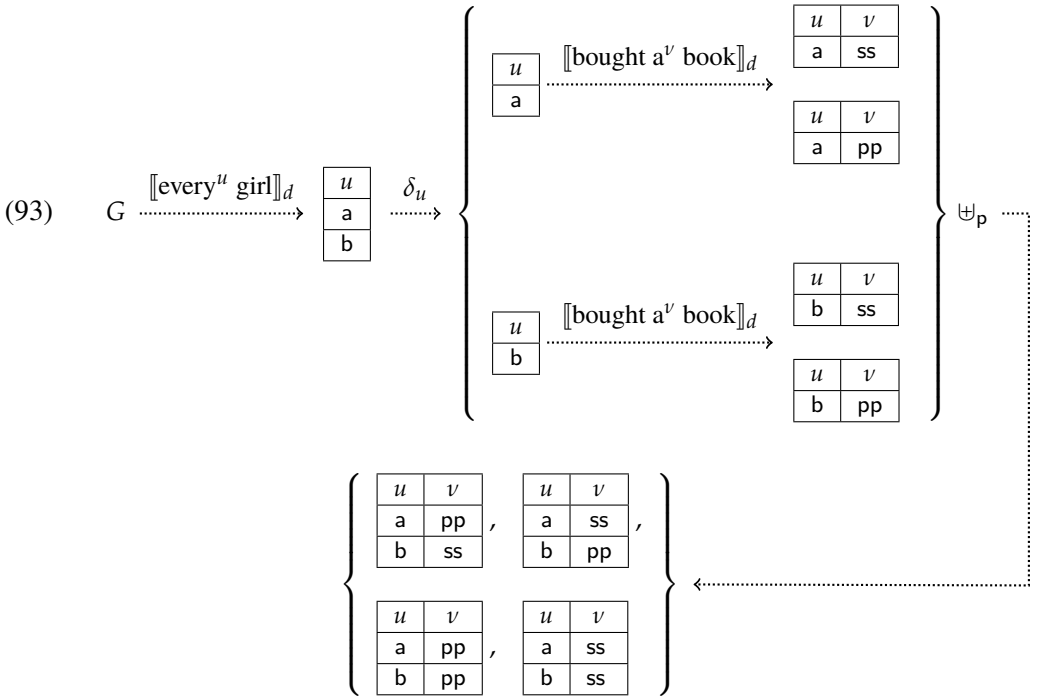
challenges the E-type analysis, supporting the necessity of dynamic semantics.

6.1 Building discourse dependencies

The backbone of the present analysis is a dynamicized version of the well known family-of-questions approach. The main innovation lies in the manner of generating pair-list answers. Crucially, a pair-list answer to a multiple-*wh* question encodes a dependency between drefs introduced by the *wh*-expressions, which is retrievable in discourse. The dependency shares the same structure with the one introduced by a universal statement in DPlL. I show here that the similarity of these two kinds of dependencies originates in the formal uniformity of deriving these dependencies. This is the underlying reason why both multiple-*wh* questions and universal statements support subordination.

In DPlL, a universal quantifier is commonly decomposed into a maximal, plural entity and a distributive operator δ. For concreteness, the update process of the sentence *every*^{u} *girl bought* *a*^{v} *book* can be depicted as in (93). For simplicity, I omit intensionality here and only presents updates of assignments. The formal definition of δ is provided in Appendix A.

(93)



The universal quantifier introduces a dref u storing all girls (a and b) in the model. Then, δ_u splits the resultant set of assignments along its u-dimension, giving rise to two subsets, both of which associate u with one girl. They are updated by the formula in the scope of the universal quantifier. In particular, the indefinite adds to both subsets another dref v associating with a book. The outputs are collected into the final output through $\uplus$ in a point-wise manner. In the resultant context, the possibilities involve girl–book dependencies.

Returning to multiple-*wh* questions, a pair-list answers is derived by applying **?** to a family

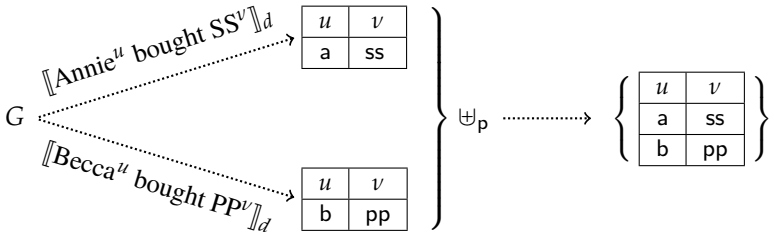
of questions. As shown in (94), the resultant set includes possible pair-list answers, each of which is formed by connecting with $\uplus$ possible answers to the questions in the relevant family.

(94) $?[\![\text{which}^u \text{ girl bought which}^v \text{ book}]\!]_d = ? \left\{ \begin{array}{l} [\![\text{which book did Annie buy}]\!]_d, \\ [\![\text{which book did Becca buy}]\!]_d \end{array} \right\}$

$$= \left\{ \begin{array}{lll} [\![\text{Annie}^u \text{ bought SS}^v]\!]^{\mathbf{m}}_d & \uplus & [\![\text{Becca}^u \text{ bought PP}^v]\!]^{\mathbf{m}}_d, \\ [\![\text{Annie}^u \text{ bought SS}^v]\!]^{\mathbf{m}}_d & \uplus & [\![\text{Becca}^u \text{ bought SS}^v]\!]^{\mathbf{m}}_d, \\ [\![\text{Annie}^u \text{ bought PP}^v]\!]^{\mathbf{m}}_d & \uplus & [\![\text{Becca}^u \text{ bought SS}^v]\!]^{\mathbf{m}}_d, \\ [\![\text{Annie}^u \text{ bought PP}^v]\!]^{\mathbf{m}}_d & \uplus & [\![\text{Becca}^u \text{ bought PP}^v]\!]^{\mathbf{m}}_d \end{array} \right\}$$

Based on the definition of $\uplus$, the output of a pair-list answer results from collecting the outputs of the propositional answers with $\uplus$ in a point-wise manner. Take the top member of the resultant set in (94) as an example. Its update process is pictured in (95). It is shown that the output of the pair-list answer also involves a girl-book dependency.

(95)



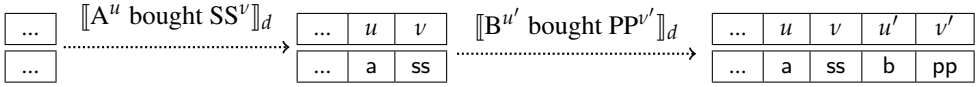
Now, we have two operators that can establish discourse dependency—δ_u and **?**. Although they operate on different objects, their operations have a *uniform* scheme. Both are constructed by applying $\uplus$ to a set of output contexts in a point-wise manner. The difference is how the set of contexts is produced. As for **?**, this set is generated by updating an input context with propositional answers. As for δ_u, this set is generated by dividing a set of assignments into subsets based on the values in u and feeding these subsets each to the formula in its scope. As a consequence, the dependencies established in universal quantification and multiple-*wh* questions share the same structure, and hence reference to these dependencies can be achieved in the same way.

6.2 Dynamic vs. static pair-list answers

In a static framework, the generation of pair-list answers is built on conjunction. For example, a point-wise answerhood operator A^{pw} posited in Fox (2012) maps a family of questions to a pair-list answer by applying a Dayal-style answerhood operator A to each question in the family and then conjoining all the resultant true answers in w. A simplified definition is provided in (96) to fit the present discussion. The spirit behind the definition in (96) is shared by major analyses in the family-of-questions approach (Hagstrom 1998; Nicolae 2013; Kotek 2014) but implemented in different ways.

(96) $\mathsf{A}^{\text{pw}}_w(\mathcal{Q}) = \cap\{\mathsf{A}_w(Q) \mid Q \in \mathcal{Q}\}$

The dynamic **?** operator defined in this paper maintains the spirit of A^{pw} on one hand, but essentially differs from it on the other hand. As previously emphasized, **?** also applies to a family of questions and connects the max-answers to the involved questions into a pair-list answer. This operation is similar to that performed by A^{pw}. However, **?** differs from A^{pw} in that it connects max-answers with a specific operator $\uplus$, rather than conjunction. This is because dynamic conjunction cannot establish a dependency in discourse. Consider (97). The two dynamic propositions are conjoined. They successively introduce drefs to an input context.

(97) 

As a result, the output context does not encode non-trivial dependencies between drefs. No variation is observed for the value stored in u (or u') and, correspondingly, no variation is observed for the one stored in v (or v'). If the pair-list answer to a multiple-*wh* question were generated via dynamic conjunction, we would not get a *wh*-dependency.

Although **?** does not apply conjunction to the dynamic propositions it connects, it also require all of these dynamic propositions to be true in at least one world. This consequence is led by the definition of the connective $\uplus$. I repeat the relevant definitions below:

(98) $\phi \uplus \psi := \lambda c.\, \phi(c) \uplus_{\mathsf{p}} \psi(c)$, here

a. $c \uplus_{\mathsf{p}} c' := \{(w, G) \uplus (w', G') \mid (w, G) \in c \wedge (w', G') \in c'\}$

b. $(w, G) \uplus (w', G') := \begin{cases} (w, G \cup G') & \text{if } w = w' \\ \text{undefined} & \text{if } w \neq w' \end{cases}$

Given (98), two dynamic propositions connected by $\uplus$ would deliver an empty set if there is no world where they are both true. Returning to (95), the constructed pair-list answer is dynamically true iff Annie bought SS and Becca PP. Thus, a pair-list answer derived in the present analysis gives rise to a dependency as well as retains the spirit of conjunction.[24,25]

[24] One of the reviewers and Simon Charlow (p.c.) both notice that subordination is also observed in conjunction of sentences, as exemplified below.

(i) Annie bought *Sense & Sensibility*, Becca *Pride and Prejudice*, and Cindy *War & Peace*. And each of them read it immediately.

This suggests that the conjunction of sentences should establish a girl–book dependency akin to a universal statement or a multiple-*wh* question. Consequently, re-defining conjunction with the use of $\uplus$ may be necessary. However, crafting a full fledged analysis for conjunction is beyond the scope of this paper and left for future research.

[25] A^{pw} and **?** both capture Dayal's (1996) domain exhaustivity effect, which requires each element in the domain of the c-commanding *wh*-expression to be paired with at least one element in the domain of the c-commanded *wh*-expression. In a family-of-question analysis, this effect essentially means that every question in the family should have a true answer. However, Xiang (2023) casts doubt on the domain cover effect. She notices that the pair-list reading of the multiple-*wh* question in (i) is fully acceptable in the given context, unlike the question with a universal quantifier in (i). In this context, it's not expected that each kid will sit on one of the three chairs. Hence, the domain cover effect is not hardwired in the meaning of multiple-*wh* questions.

(i) Context: Four kids are playing Musical Chairs and are competing for three chairs.

a. Guess which one of the four kids will sit on which one of the three chairs.

b. #Guess which one of the three chairs each of the four kids will sit on. (Xiang 2023: 434)

6.3 Uniqueness requirements

In the present analysis, question subordination is possible when cross-sentential anaphora to *wh*-expressions is achieved before pair-list answers are built. In this sense, as pointed out by reviewers, it may not be necessary to adopt the family-of-question approach. The spirit of the present analysis can be retained even if a multiple-*wh* clause just denotes an ordinary question meaning. A concrete example is given in (99). Both *wh*-clauses denote a set of dynamic propositions. Conjoining these sets in a point-wise manner leads to a set of conjoined dynamic propositions, where the singular pronouns refer to one girl and one book.

(99) $[\![\text{which}^u \text{ girl bought which}^v \text{ book}]\!]_d\ [\![\text{and}]\!]_d\ [\![\text{how much did she}_u \text{ pay for it}_v]\!]_d$

$$= \left\{ \begin{array}{l} [\![\text{Annie}^u \text{ bought SS}^v]\!]_d, \\ [\![\text{Annie}^u \text{ bought PP}^v]\!]_d, \\ [\![\text{Becca}^u \text{ bought SS}^v]\!]_d, \\ [\![\text{Becca}^u \text{ bought PP}^v]\!]_d \end{array} \right\} [\![\text{and}]\!]_d \left\{ \begin{array}{l} [\![\text{she}_u \text{ paid \$100 for it}_v]\!]_d, \\ [\![\text{she}_u \text{ paid \$120 for it}_v]\!]_d \end{array} \right\}$$

Although the resultant set does not provide possible pair-list answers, it is not hard to define a novel question operator $?'$ to re-organize the resultant set and generate possible pair-list answers. Similar analyses sharing this spirit have been proposed by Haida (2007) and Roelofsen & Dotlačil (2023).[26] Since defining $?'$ is not crucial to the present study, I leave it for readers.

Although the analysis sketched above sounds simple regarding composition, it leads to overgeneration: conjunction of two single-*wh* questions would have unattested pair-list readings. Consider (100), which denotes a set of conjoined dynamic propositions.

(100) $[\![\text{which}^u \text{ girl called}]\!]_d\ [\![\text{and}]\!]_d\ [\![\text{what}^v \text{ did she}_u \text{ say}]\!]_d$

$= \{\phi\ [\![\text{and}]\!]_d\ \psi \mid \phi \in [\![\text{which}^u \text{ girl called}]\!]_d \wedge \psi \in [\![\text{what}^v \text{ did she}_u \text{ say}]\!]_d\}$

The resultant set is of the same type as the one in (99). As a consequence, if there were a question operator $?'$ shifting the set in (99) to a set of pair-list answers, it would apply to (100) and generate pair-list answers. For concreteness, the *wh*-conjunction could be resolved by an answer like *Annie called and she said she was admitted by Cornell; Becca called and she said she was admitted by Caltech*. However, a pair-list answer is actually not admitted.

Intuitively, the lack of a pair-list reading in (100) is because of the uniqueness requirements that the involved *wh*-questions have. Comorovski (1996), Dayal (1996), and others have observed that a question with a singular *which*-expression is generally constrained by a unique-

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In order to resolve this issue, the definition $?$ can be revised: it applies $\boxed{+}_{\mathsf{p}}$ to the subsets of a family of questions and then collects the results into a set (recall (58)), as shown below.

(ii) Given that $\mathcal{Q}$ is a family of questions, $?(\mathcal{Q}) := \bigcup \left\{ \boxed{+}_{\mathsf{p}} \{Q \mid Q \in \mathfrak{Q}\} \;\middle|\; \mathfrak{Q} \subseteq \mathcal{Q} \right\}$

(iii) $\boxed{+}_{\mathsf{p}} \{Q_1, Q_2, ..., Q_n\} := \{\phi_1 \amalg \phi_2 \amalg ... \amalg \phi_n \mid \phi_1 \in Q_1 \wedge \phi_2 \in Q_2 \wedge ... \wedge \phi_n \in Q_n\}$

Since this paper does not delve into the semantics of questions with quantifiers, it is not possible to sketch an account for the domain exhaustivity effect attested in (i-b). Interested readers are referred to Li (2020) for a dynamic analysis.

[26] Their analyses do not adopt Hamblin semantics. However, they both assume that a multiple-*wh* clause denote the same meaning as a single-*wh* clause and attribute the generation of pair-list readings to a question operator.

ness requirement. For example, the first question in (100) presupposes that there is a unique girl calling. The uniqueness presupposition prohibits the possibility that the whole *wh*-conjunction receive a pair-list interpretation.

Nevertheless, the over-generation problem cannot be avoided by simply assuming that any questions with singular *which*-expressions have such a uniqueness requirement. In fact, the same uniqueness presupposition is not observed in a question with multiple singular *which*-expressions, like the one in (99), which admits a pair-list answer involving multiple girls and books. In (100), the *wh*-conjunction can also be seen as a multiple-*wh* clause, as it contains two *wh*-expressions. If its denotation were of the same type as a multiple-*wh* question, as shown in (99) and (100), any analysis that explains the absence of the uniqueness presupposition in (99) would wrongly wipe out the uniqueness presupposition attested in (100).

Overall, the over-generation problem is rooted in the hypothesis that the core meaning of a multiple-*wh* question is a set of propositions, as what conjunction of two single-*wh* questions denotes. This hypothesis does not hold in the family-of-question approach, where a typical multiple-*wh* question compositionally delivers a set of sets of propositions, so it has a potential to resolve the over-generation problem.

In the present analysis, the uniqueness requirement is brought in by a lifted *wh*-expression. The relevant definitions are repeated below.

(101) $[\![\text{which}^u\ \text{girl}]\!]_d^{\uparrow} = \lambda f\left(\bigcup\{f(\chi)\mid \chi\in[\![\text{which}^u\ \text{girl}]\!]_d\}\right)^{\mathbf{m}}$

(102) $Q^{\mathbf{m}} := \Big\{ \underbrace{\lambda c.\,\phi(c)\text{ defined only if }\mathbf{max}_c(Q)(\phi)}_{(\phi)^{\mathbf{m}}} \;\Big|\; \phi\in Q\Big\}$

(103) $\mathbf{max}_c(Q)(\phi)$ is true iff ϕ is the unique member from Q such that:

a. ϕ is dynamically true relative to c (i.e., $\phi(c)\neq\emptyset$)

b. $\forall\psi\in Q:\forall(w,G)\in\{(w',G')\in c\mid\phi\{(w',G')\}\neq\emptyset\}:$
if ψ is dynamically true in (w,G) (i.e., $\phi\{(w,G)\}\neq\emptyset$), then ϕ entails ψ

As a consequence, composing the meaning of a single-*wh* question always gives rise to a set of dynamic propositions, each of which serve as the unique max-answer in some possibilities of an input context. So, the first single-*wh* question in (100) denotes a set as shown in (104).

(104) $[\![\text{which}^u\ \text{girl}]\!]_d^{\uparrow}\lambda\chi.[\![\mathbb{C}]\!]_d([\![\text{called}]\!]_d(\chi)) = \{[\![\text{Annie}^u\ \text{called}]\!]_d^{\mathbf{m}},\ [\![\text{Becca}^u\ \text{called}]\!]_d^{\mathbf{m}}\}$

Since *which girl* ranges over atomic girls, every member in the resultant set only involves an atomic individual. Given the informative maximality condition imposed by **m**, this question is felicitous only if the speaker believes that only one girl called. Hence, a pair-list reading is prevented for (100).

By contrast, there is an asymmetry in scope taking of *wh*-expressions. For concreteness, the meaning of the multiple-*wh* question in (99) is derived as in (105). The *wh*-subject is lifted by $\Uparrow$, which does not bring in the answerhood condition, while the *wh*-object is lifted by $\uparrow$ and hence constrained by the uniqueness requirement.

(105) $[\![\text{which}^u \text{ girl}]\!]_d^{\Uparrow} \lambda\chi.\, [\![\mathbb{C}]\!]_d \Big([\![\text{which}^v \text{ book}]\!]_d^{\uparrow} \lambda\gamma.\, [\![\mathbb{C}]\!]_d\,([\![\text{bought}]\!]_d(\gamma)(\chi)) \Big)$
$= \{[\![\text{which}^v \text{ book did Annie}^u \text{ buy}]\!]_d, [\![\text{which}^v \text{ book did Becca}^u \text{ buy}]\!]_d\}$

The result is a family of questions, which has a dependent exhaustive inference, according to Section 3.2. That is, for each girl, there is a unique book she bought. In other words, the uniqueness requirement is checked relative to different questions, so it is not prevented that more than one girl bought a unique book. When it is conjoined with another question, a pair-list reading is still allowed.[27]

6.4 E-type anaphora and question subordination

After elucidating a series of consequences stemming from the present dynamic analysis, I proceed to address a long-standing issue: is dynamic meaning necessary? Regarding discourse anaphora, Evans (1977) has argued that this phenomenon can be captured by a static, E-type analysis, which is further developed by Heim (1990), Büring (2004), Elbourne (2005), and so on. Essentially, in the E-type analysis, a pronoun is interpreted as a definite expression. For example, the sentence in (106) is interpreted as (107). The conditional quantifies over minimal situations that contain one farmer, one donkey, the ownership, and nothing else. Given such a minimal situation, the pronouns in the consequent clause are interpreted as *the unique farmer* and *the unique donkey* in the situation.

(106) If a farmer owns a donkey, he feeds it well.

(107) For every tuple of a farmer x, a donkey y, and a minimal situation s, if x owns y in s, then there is a situation s' extended from s such that the unique farmer x in s feeds the unique donkey y in s well in s'.

The success of the E-type analysis weakens the necessity of dynamic semantics, which becomes possible but not necessary to handle discourse anaphora.

However, Dekker (2004) and Schlenker (2011) have defeneded dynamic semantics with the help of 'bishop' sentences and sign language data. Alongside them, I show that question sub-

[27] One of the reviewers raised a valid question: Can the analysis in (100) avoid the over-generation problem through incorporating the fundamental idea behind (105)? A straightforward way to achieve this is to assume that both *wh*-expressions in (105) normally take scope, but only the second one bears the condition of maximal informativity, as shown in (i). Then, the meaning of the multiple-*wh* question in (105) would be derived as in (ii).

(i) a. $[\![\text{which}^u \text{ girl}]\!]_d^{\dagger} = \lambda f \bigcup \{f(\chi) \mid \chi \in [\![\text{which}^u \text{ girl}]\!]_d\}$
b. $[\![\text{which}^v \text{ book}]\!]_d^{\uparrow} = \lambda f \left(\bigcup \{f(\chi) \mid \chi \in [\![\text{which}^v \text{ book}]\!]_d\}\right)^{\mathfrak{m}}$

(ii) $[\![\text{which}^u \text{ girl}]\!]_d^{\dagger} \lambda\chi.\, [\![\text{which}^v \text{ book}]\!]_d^{\uparrow} \lambda\gamma.\, [\![\mathbb{C}]\!]_d\,([\![\text{bought}]\!]_d(\gamma)(\chi))$
$= \{[\![\text{Ann}^u \text{ bought SS}^v]\!]_d^{\mathbf{m}}, [\![\text{Becca}^u \text{ bought PP}^v]\!]_d^{\mathbf{m}}, \ldots\}$

Since the condition of maximal informativity yields a possible max-answer rather than a maximal individual, the resultant set in (ii) still includes possible max-answers, indicating that only one girl bought exactly one book. The pair-list reading would be eliminated. The root of this problem is that the interpretation derived in (ii) lacks sufficient structure, preventing the condition of maximal informativity from being evaluated relative to each girl.

ordination provides additional support for the dynamic analysis over the E-type analysis. As the editor notes, question subordination is degraded if the involved *wh*-expressions are linked to singular definite expressions, as shown in (108). The degradedness of definite expressions in question subordination may not be due to a competition between definite expressions and pronouns. In fact, they do not compete with each other when the antecedent multiple-*wh*-question inquires about a single pair, as exemplified by (109).

(108) Context: Annie, Becca, and Cindy bought different books.
A: Which girl bought which book and how much did { ??the girl (who bought a book) / she } pay for { ??the book (that she bought) / it }?

(109) Context: Only one of the girls in Classroom 21 bought a book from the store.
A: Which girl bought which book and how much did { the girl (who bought a book) / she } pay for { the book (that she bought) / it }?

Based on the contrast in (108) and (109), the infelicity of the definite expressions in the former may be due to their uniqueness presuppositions not satisfied in the context where multiple girls bought multiple books. As a consequence, it casts doubt for the hypothesis that a pronoun is derived from a definite expression: if a singular pronoun were interpreted as a definite expression, question subordination would not be acceptable, contrary to fact.

It should be noted that the uniqueness presupposition of a definite expression does not always project globally. As discussed in Mandelkern & Rothschild (2019), when a definite expression is anaphoric to an indefinite, the uniqueness presupposition is filtered. For example, in (110), the definite expression is felicitously altered with a pronoun, even when John actually met several women at the party.

(110) John met a woman at the party and John liked { the woman / her }.

However, this filtering effect is not triggered by reference to *wh*-expressions, as evidenced by (108), where only the pronouns can receive a subordination-like interpretation. As a result, Lewis's (2022) recent account for the filtering effect, which is compatible with the E-type analysis, does not apply to question subordination. Certainly, the contrast between (108) and (110) also needs to be explained in a dynamic framework, but this calls for a full analysis of definite expressions, which is beyond the scope of this paper and left for future research.

7 Conclusion

This paper takes up cross-sentential anaphora to *wh*-dependencies established in multiple-*wh* questions. Building on a dynamicized Hamblin semantics, it also propose a dynamic family-of-questions approach to the pair-list reading of multiple-*wh* questions. In brief, the core of a multiple-*wh* question is a family of sub-questions, whose answers are connected to generate a pair-list answer. Under the specific dynamic framework adopted in this paper, a pair-list answer and a family of questions encode a *wh*-dependency constructed in a different way. The *wh*-dependency of a pair-list answer is cross-sententially retrievable to a singular pronoun only

when the pronoun is in the scope of a quantifier; by contrast, the dependency encoded in a family of questions is cross-sententially retrievable to a singular pronoun only when a multiple-*wh* question can form a single interrogative act with a follow-up sentence.

A Formal analysis

A.1 Dynamics

Update semantics enriched with sets of assignments (Roelofsen & Dotlačil 2023) is taken as the basis of the dynamic setup assumed in this paper, while the compositional mechanism essentially follows Chierchia's (1992) and Charlow's (to appearb) Montagovian setting. The basic types are entities (type e), possible worlds (type s), assignments (type g) and truth (type t). For convenience, I define the following type abbreviations:

- $\{a\} ::= a \to \mathsf{t}$ for sets of type-a elements, in which a is a variable over types.
- $\mathbf{s} ::= \mathsf{s} \times \{\mathsf{g}\}$ for possibilities, which are pairs of a possible world and a set of assignments.
- $\mathbf{c} ::= \{\mathbf{s}\}$ for contexts, which are sets of possibilities.
- $\mathbf{t} ::= \mathbf{c} \to \mathbf{c}$ for dynamic propositions, which are context change potentials.
- $\mathbf{e} ::= (\mathsf{e} \to \mathbf{t}) \to \mathbf{t}$ for dynamic individuals, which are dynamic generalized quantifiers.

The domain of entities includes atomic and non-atomic entities. Following Schwarzschild (1996), atomic entities are construed as singleton sets of entities, while non-atomic ones are constructed as non-singleton sets. The domain is mereologically structured. The part-of relation is modeled in terms of subset-hood, i.e., $x \leq y := x \subseteq y$.[28]

Lexical relations Lexical relations are functions from sequences of arguments to dynamic propositions. For example, the denotation of the transitive verb *buy* is defined in (111).

(111) $\mathbf{buy} := \lambda x \lambda y \lambda c.\, \{(w, G) \in c \mid \mathsf{buy}_w(x)(y)\}$ Type: $\mathsf{e} \to \mathsf{e} \to \mathbf{t}$

Accordingly, a dynamic lexical relation is built on the corresponding static one. The static predicate buy is distributive and hence is closed cumulatively: if $\mathsf{buy}(x)(y)$ and $\mathsf{buy}(x')(y')$, then $\mathsf{buy}(x \cup x')(y \cup y')$.

Drefs Drefs are variables ($\mathcal{V} ::= \{\, u, v, \ldots \,\}$). Dref introduction is assignment modification, defined in (112). A set of assignments G is extended by adding a new dref to the domain of each assignment in G. The value stored in a dref can be retrieved, as shown in (113). The dref introducer $\mathbf{E}$ is defined in (114).

(112) $G^{u \to x} := \{g^{u \mapsto d} \mid g \in G \wedge d \in x\}$

(113) $G_u := \{g_u \mid g \in G\}$, where $g_u := g(u)$

(114) $\mathbf{E}^u := \lambda P \lambda c.\, \{(w, G^{u \mapsto x}) \mid (w, G) \in P(x)(c)\}$ Type: $\mathbf{e}$

[28] Suppose that our model contains three people, Annie, Becca, and Cindy, then $D_e = \wp\{\mathsf{a}, \mathsf{b}, \mathsf{c}\} - \emptyset$.

Dynamic conjunction Dynamic conjunction $\between$ amounts to composition of CCPs, defined in (115). The second conjunct takes the output produced by the first conjunct as the input.

(115) $\phi \between \psi := \lambda c.\psi(\phi(c))$

Dynamic individuals Proper names, indefinites, pronouns, and quantifiers are all dynamic individuals. In terms of types, they are also dynamic generalized quantifiers.

Proper names and indefinites introduce drefs, defined as in (116) and (117). A proper name associates a set of assignments with one entity, generating a *deterministic* update (notationally, the atomic entity $\mathsf{a} := \{\text{ada}\}$), whereas an indefinite associates a set of assignments with a set of entities, giving rise to a *non-deterministic* update.

(116) $[\![\text{Annie}^u]\!]_d = \lambda P \lambda c.\{(w, G^{u \mapsto \mathsf{a}}) \mid (w, G) \in P(\mathsf{a})(c)\}$ Type: $\mathbf{e}$

(117) $[\![\text{some}^u \text{ books}]\!]_d = \lambda P \lambda c.\{(w, G^{u \mapsto x}) \mid (w, G) \in [\mathbf{books}(x) \between P(x)](c)\}$ Type: $\mathbf{e}$

Pronouns retrieve the values of drefs. Following Brasoveanu (2008), a singular pronoun contributes an atomicity condition ($|G_u| = 1$), which requires that only one value is stored in u, as shown in (118). A plural pronoun does not have such a condition, as shown in (119).

(118) $[\![\text{it}_u]\!]_d = \lambda P \lambda c. \bigcup \{P(G_u)\{(w, G)\} \mid (w, G) \in c \wedge |G_u| = 1\}$ Type: $\mathbf{e}$

(119) $[\![\text{they}_u]\!]_d = \lambda P \lambda c. \bigcup \{P(G_u)\{(w, G)\} \mid (w, G) \in c\}$ Type: $\mathbf{e}$

Quantifiers are defined based on the classical generalized quantifier theory (Barwise & Cooper 1981), following van den Berg (1996). Roughly speaking, a quantifier introduces two drefs for two *maximal* sets of entities, A and B, as well as expresses a relation of A and B. Based on van den Berg, I assume a schematic lexical entry, as given in (120), for a quantificational determiner (see also Brasoveanu 2010).

(120) $[\![D^{u,v}]\!]_d = \lambda P \lambda P'.\mathbf{M}_u(\mathbf{E}^u(\mathbf{D}_u(P))) \between \mathbf{M}_v(\mathbf{E}^v(\mathbf{D}_v(P)) \between (\mathbf{D}_v(P'))) \between \mathcal{R}_{u,v}$ Type: $(\mathsf{e} \to \mathbf{t}) \to (\mathsf{e} \to \mathbf{t}) \to \mathbf{t}$

The two arguments of the determiner are operated on by the distributive operator $\mathbf{D}_u$, defined in (121) and (122). It takes every possibility p in an input context and splits the set of assignments in p into subsets. Each subset is associated with one value stored in u (i.e., $G|_{u=x}$) and forms a new context with the possible world in p. These new contexts are distributively updated with a dynamic predicate P. A successful update requires that every individual x has the property P (i.e., $\forall x \in G_u : P(x)\{(w, G|_{u=x})\} \neq \emptyset$). The outputs are collected into a context through $\uplus$ in a point-wise manner. The same update process applies to every possibility in c and all the outputs are collected into the final new context.

(121) $\mathbf{D}_u := \lambda P \lambda c. \bigcup \{\delta_u(P)\{(w, G)\} \mid (w, G) \in c\}$ Type: $\mathbf{e}$

(122) $\delta_u(P)\{(w,G)\} := \biguplus_{\mathsf{p}} \{P(x)\{(w,G|_{u=x})\} \mid x \in G_u\}$

$$\textbf{if } \forall x \in G_u : P(x)\{(w,G|_{u=x})\} \neq \emptyset; \textbf{ else } \emptyset$$

(123) $G|_u := \{g \mid g \in G \wedge g_u = x\}$

The maximal operator $\mathbf{M}$, defined in (124), ensures that the individuals stored in u are the maximal one with P.

(124) $\mathbf{M}_u(\phi) := \lambda c.\{(w,G) \in \phi(c) \mid \neg\exists (w,H) \in \phi(c) : G_u \subset H_u\}$

Accordingly, $\mathbf{M}_u(\mathbf{E}^u(\delta_u(P)))$ introduces a dref u storing all the individuals that have the property P, whereas $\mathbf{M}_v(\mathbf{E}^v(\delta_v(P)) \triangle (\delta_v(P')))$ introduces a dref v storing all the individuals that have the properties P and P'. Finally, $\mathcal{R}_{u,v}$, defined in (125), requires the individuals stored in u and the ones in v to satisfy the relation R of set, for example $\textbf{every} := A \subseteq B$, $\textbf{some} := A \cap B = \emptyset$, $\textbf{most} := |A \cap B| > |A - B|$, etc. Based on these definitions, the denotation of a universal quantifier can be exemplified as in (126).

(125) $\mathcal{R}_{u,v} := \lambda c.\{(w,G) \in c \mid R(G_u, G_v)\}$

(126) $[\![\text{every}^{u,v}\ \text{girl}]\!]_d = \lambda P.\mathbf{M}_u(\mathbf{E}^u(\mathbf{D}_u(\textbf{girl}))) \triangle \mathbf{M}_v(\mathbf{E}^v(\mathbf{D}_v(\textbf{girl})) \triangle \mathbf{D}_v(P)) \triangle \textbf{every}_{u,v}$

Composition A verb combines with dynamic individuals via Hendricks's (1993) Argument Raising, defined in (127). Accordingly, the interpretation of the verb *buy* can be shifted by raising the types of its arguments, as exemplified in (128) and (129).

(127) Argument Raising
Let f be any function of type $\vec{a} \to \mathsf{e}_n \to \vec{b} \to \mathbf{t}$. $\vec{a}$ and $\vec{b}$ are sequences of semantic types (of any number, including none). e_n is the n-th argument of type e.
Then $f^{\mathbf{r}_n}$ is a function of type $\vec{a} \to \mathbf{e}_n \to \vec{b} \to \mathbf{t}$, where

$$f^{\mathbf{r}_n} := \lambda\vec{z}\lambda\chi\lambda\vec{y}.\chi\left(\lambda x.f(\vec{z})(x)(\vec{y})\right)$$

(128) $\left([\![\text{buy}]\!]_d^{\mathbf{r}_1}\right)^{\mathbf{r}_2} = [\![\text{buy}]\!]_d^{\mathbf{r}_{(1,2)}} = \lambda\chi\lambda\gamma.\gamma(\lambda y.\chi(\lambda x.[\![\text{buy}]\!]_d(x)(y)))$ (Surface scope)

(129) $\left([\![\text{buy}]\!]_d^{\mathbf{r}_2}\right)^{\mathbf{r}_1} = [\![\text{buy}]\!]_d^{\mathbf{r}_{(2,1)}} = \lambda\chi\lambda\gamma.\chi(\lambda x.\gamma(\lambda y.[\![\text{buy}]\!]_d(x)(y)))$ (Inverse scope)

With the Argument Raising rule, the meaning of the sentence *Annie bought some books* is derived as in (130), which is a dynamic proposition.

(130) $[\![\text{Annie bought some books}]\!]_d$

$= [\![\text{bought}]\!]_d^{\mathbf{r}_{(1,2)}}\left([\![\text{some}^v\ \text{book}]\!]_d\right)\left([\![\text{Annie}^u]\!]_d\right)$

$= [\![\text{Annie}^u]\!]_d\ \left(\lambda y.\ [\![\text{some}^v\ \text{books}]\!]_d\ \left(\lambda x.[\![\text{bought}]\!]_d(x)(y)\right)\right)$

$= \lambda c.\{(w, G^{u\to\mathsf{a}}_{v\to x}) \mid (w,G) \in c \wedge \mathsf{book}_w(x) \wedge \mathsf{bought}_w(x)(\mathsf{a})\}$

A.2 Compositional dynamic semantics of questions

The dynamic Hamblin semantics can be made compositional in the same way that the static version can be. The composition I am pursuing in this paper is built on Charlow's (2014, 2020) monadic conception of enriched meanings, but the essence is just along the line of Karttunen (1977) and Cresti (1995). A *wh*-expression evokes a set of alternative dynamic individuals. The formal definition is given in (131).

$$(131)\qquad [\![\text{who}^u]\!]_d = \left\{ \lambda P \lambda c. \left\{ (w, G^{u \mapsto y}) \;\middle|\; \begin{array}{l} y = x \wedge \mathsf{human}_w(y) \wedge \\ (w, G) \in P(x)(c) \end{array} \right\} \;\middle|\; x \in D_e \right\}$$

Type : $\{\mathbf{e}\}$

In the composition of a question meaning, a *wh*-expression takes scope via combining with the shifter $\uparrow$, which also brings in the max-answer condition (see Section 3.1). Correspondingly, the interrogative complementizer $\mathbb{C}$ maps a sentence meaning into a singleton set including it, creating a scope position for a lifted *wh*-expression. The relevant definitions are repeated below.

$$(132)\qquad \uparrow := \lambda A \lambda f \left(\bigcup \{ f(\chi) \mid \chi \in A \} \right)^{\mathfrak{m}} \qquad \text{Type: } \{\mathbf{e}\} \to (\mathbf{e} \to \{\mathbf{t}\}) \to \{\mathbf{t}\}$$

$$(133)\qquad [\![\mathbb{C}]\!]_d = \lambda \phi . \{\phi\} \qquad \text{Type: } \mathbf{t} \to \{\mathbf{t}\}$$

The operations $\uparrow$ and $[\![\mathbb{C}]\!]_d$ constitute something known as 'monad' in mathematics or computer science. A monad really is a way of composing enriched meanings in terms of natural language semantics. The most direct way of combining Hamblin semantics with dynamic semantics is putting dynamic meanings into a set 'container'. For example, the meaning of a *wh*-expression is a set containing dynamic individuals. $\uparrow$ and $[\![\mathbb{C}]\!]_d$ provides instructions on how to compose these set-containing dynamic meanings, as exemplified in (134).

$$(134)\qquad \begin{aligned} [\![\text{who}^u]\!]_d^{\uparrow}\, \lambda\chi.[\![\mathbb{C}]\!]_d([\![\text{called}]\!]_d^{\mathbf{r}_1}(\chi)) &= [\![\text{who}^u]\!]_d^{\uparrow}\, \lambda\chi.[\![\mathbb{C}]\!]_d \{[\![\text{called}]\!]_d^{\mathbf{r}_1}(\chi)\} \\ &= \{[\![\text{called}]\!]_d^{\mathbf{r}_1}(\chi) \mid \chi \in [\![\text{who}^u]\!]_d\} \end{aligned}$$

This monad facilitated composition is actually the same as the Karttunen-style composition of question meanings in static semantics, because the latter is also built on the same monadic operations (Charlow 2020). Therefore, although question meaning is dynamicized, the way of deriving it remains unchanged. Given that the Karttunen-style composition underlies many studies of questions, the merits of these studies are largely inherited in the present dynamic framework, including the generation of the pair-list reading.

Connection to indefinites In many dynamic frameworks of questions (Aloni & van Rooy 2002; Haida 2007; Roelofsen & Dotlačil 2023), a *wh*-expression is assumed to have the same denotation with the corresponding indefinite, as Karttunen (1977) posits. However, in the present analysis, a lifted *wh*-expression takes scope distinctly from an indefinite: the former scopes over a set of dynamic propositions, while the latter a dynamic proposition (see (117)). Empirically, this distinction yields a welcomed consequence—*wh*-expressions do not behave exactly like indefinites. For example, while a multiple-*wh* question gives rise to a pair-list reading, no

such reading is evoked when a *wh*-expression co-occurs with another indefinite, as evidenced in (135). This is because the indefinite as a dynamic existential quantifier does not induce a set of dynamic propositions under the scope of the *wh*-expression. Given the present analysis, no higher-order alternatives are generated and question subordination is thus impossible in (135).

(135) Which^u girl bought a^v book and how much did she$_u$ pay for it$_v$?

However, it does not imply that the present analysis disregards the connection between *wh*-expressions and indefinites, which is attested cross-linguistically (Haspelmath 1997; Haida 2007; a.o.). In the current setting, an indefinite can be mapped to a *wh*-expression by the shifter $+$, as defined in (136); whereas a *wh*-expression can be mapped to an indefinite by the shifter $-$, as defined in (137).

(136) $[\![\text{someone}^u]\!]_d^+ = \{\lambda P.\, [\![\text{someone}^u]\!]_d(P) \triangle u = y \mid y \in D_e\}$

(137) $[\![\text{who}^u]\!]_d^- = \lambda P \lambda c. \bigcup \{\chi(P)(c) \mid \chi \in [\![\text{who}^u]\!]_d\}$

A dynamic family-of-questions analysis In the family-of-questions analyses (Hagstrom 1998; Willis 2008; Fox 2012; Nicolae 2013; Constant 2014; Kotek 2014; a.o.), one *wh*-expression in a multiple-*wh* question scopes over the whole question meaning, delivering a higher order value, i.e., a set of question meanings. Based on monads, this scope taking is conducted in a uniform way. The key feature of monadic operations is polymorphism. In particular, $\uparrow$ and $[\![\mathbb{C}]\!]_d$ are instances of two polymorphic functions—$\star$ and η, which place no restrictions on the sorts of sets it can apply to, or on the sorts of sets it ultimately returns, as shown in (138) and (139).[29]

(138) $\star := \lambda A \lambda f. \bigcup \{f(x) \mid x \in A\}$ Type: $\{a\} \to (a \to \{b\}) \to \{b\}$

(139) $\eta := \lambda x.\{x\}$ Type: $a \to \{a\}$

Accordingly, $\star$ can shift a *wh*-expression to be a generalized quantifier scoping over a set of sets of dynamic propositions, which is of type $\{\{\mathbf{t}\}\}$. This is exactly what the shifter $\Uparrow$ defined in Section 3.2 does. Moreover, $[\![\mathbb{C}]\!]_d$ is able to map a set of dynamic propositions to a singleton set including this set. The definitions are repeated as follows.

(140) $\Uparrow := \lambda A \lambda f' \bigcup \{f'(\chi) \mid \chi \in A\}$ Type: $\{\mathbf{e}\} \to (\mathbf{e} \to \{\{\mathbf{t}\}\}) \to \{\{\mathbf{t}\}\}$

(141) $[\![\mathbb{C}]\!]_d = \lambda Q.\{Q\}$ Type: $\{\mathbf{t}\} \to \{\{\mathbf{t}\}\}$

Consequently, the core of the family-of-approach is retained in the present dynamic framework, as visualized in (142).

(142) $[\![\text{which}^u\ \text{girl}]\!]_d^{\Uparrow}\ \lambda\chi.\ [\![\mathbb{C}]\!]_d \Big([\![\text{which}^v\ \text{book}]\!]_d^{\uparrow}\ \lambda\gamma.\ [\![\mathbb{C}]\!]_d \Big([\![\text{bought}]\!]_d^{\mathbf{r}^{(1,2)}}(\gamma)(\chi) \Big) \Big)$

$= [\![\text{which}^u\ \text{girl}]\!]_d^{\Uparrow}\ \lambda\chi.\ [\![\mathbb{C}]\!]_d \Big\{ \Big([\![\text{bought}]\!]_d^{\mathbf{r}^{(1,2)}}(\gamma)(\chi) \Big)^{\mathbf{m}} \mid \gamma \in [\![\text{which}^v\ \text{book}]\!]_d \Big\}$

$= [\![\text{which}^u\ \text{girl}]\!]_d^{\Uparrow}\ \lambda\chi.\ \Big\{ \Big\{ \Big([\![\text{bought}]\!]_d^{\mathbf{r}^{(1,2)}}(\gamma)(\chi) \Big)^{\mathbf{m}} \mid \gamma \in [\![\text{which}^v\ \text{book}]\!]_d \Big\} \Big\}$

[29] $\uparrow$ can also been understood as a composition of $\star$ and a function from sets of propositions to sets of propositions.

$$= \left\{ \left\{ (\llbracket \text{bought} \rrbracket_d(\gamma)(\chi))^{\mathbf{m}} \mid \gamma \in \llbracket \text{which}^{\nu} \text{ book} \rrbracket_d \right\} \middle| \ \chi \in \llbracket \text{which}^{u} \text{ girl} \rrbracket_d \right\}$$

***Wh*-conjunction** Given the polymorphic nature, the meaning of *wh*-conjunction can also be derived through $\star$ and η, as shown in (143) and (144). The former shows how two sets of dynamic propositions are conjoined, while the latter demonstrates how a set of sets of dynamic propositions is conjoined with a set of dynamic propositions. Hence, it is unnecessary to posit a point-wise conjunction.

(143) $\llbracket \text{which}^{u} \text{ girl called and what did she}_{u} \text{ say} \rrbracket_d$

$= \llbracket \text{which}^{u} \text{ girl called} \rrbracket_d^{\star} \lambda\phi.\llbracket \text{what did she}_{u} \text{ say} \rrbracket_d^{\star} \lambda\psi.\eta\,(\phi \mathbin{\triangle} \psi)$

$= \llbracket \text{which}^{u} \text{ girl called} \rrbracket_d^{\star} \lambda\phi.\,\{\phi \mathbin{\triangle} \psi \mid \psi \in \llbracket \text{what did she}_{u} \text{ say} \rrbracket_d\}$

$= \{\phi \mathbin{\triangle} \psi \mid \phi \in \llbracket \text{which}^{u} \text{ girl called} \rrbracket_d \wedge \psi \in \llbracket \text{what did she}_{u} \text{ say} \rrbracket_d\}$

(144) $\llbracket \text{which}^{u} \text{ girl bought which}^{\nu} \text{ book and how much did she}_{u} \text{ pay for it}_{\nu} \rrbracket_d$

$= \llbracket \text{wh.girl ... wh.book} \rrbracket_d^{\star} \lambda\phi.\eta\left(\llbracket \text{how.much ...} \rrbracket_d^{\star} \lambda\psi.\eta\,(\phi \mathbin{\triangle} \psi)\right)$

$= \llbracket \text{wh.girl ... wh.book} \rrbracket_d^{\star} \lambda\phi.\eta\,\{\phi \mathbin{\triangle} \psi \mid \psi \in \llbracket \text{how.much ...} \rrbracket_d\}$

$= \llbracket \text{wh.girl ... wh.book} \rrbracket_d^{\star} \lambda\phi.\,\{\{\phi \mathbin{\triangle} \psi \mid \psi \in \llbracket \text{how.much ...} \rrbracket_d\}\}$

$= \{\{\phi \mathbin{\triangle} \psi \mid \psi \in \llbracket \text{how.much ...} \rrbracket_d\}\ \phi \in \llbracket \text{wh.girl ... wh.book} \rrbracket_d\}$

B Comparison

This appendix compares the present analysis with the previous approaches to the subordination patterns with multiple-*wh* questions. While these attempts provide valuable insights and have influenced the present analysis more or less, they are only successful in addressing one kind of subordination, leaving the other unresolved. In addition to the analyses explicitly targeting reference to *wh*-dependencies, Roelofsen & Dotlačil (2023) and Nakamura (2023) utilize Dynamic Inquisitive Semantics to develop dynamic analyses for pair-list answers, which can be extended to the phenomena addressed in this paper. However, these analyses also fall short empirically. Due to the space limitations, the present comparison does not cover Roelofsen & Dotlačil (2023) and Nakamura (2023), but interested readers are referred to Li (2023) for a discussion on how Dynamic Inquisitive Semantics is challenged by reference to *wh*-dependencies.

B.1 Inherent distributivity in question meaning

To my knowledge, van Rooy (1998) is the first to observe reference to dependencies established in multiple-*wh* questions. His study is concerned only with quantificational subordination. In his own words, van Rooy considers his analysis 'just a generalization of van den Berg's analysis of dependencies of quantifiers [i.e., quantificational subordination]'. The essential piece of van Rooy's implementation is that every question involves a distributive operator in its semantic representation. As a result, any anaphoric expression occurring in a question must be evaluated distributively relative to a set of assignments. Given this feature, it can account for question

subordination. For example, the meaning of the conjunction of questions in (145) can be represented as (146). Note that van Rooy implements the operators and the lexical entries in (146) in a slightly different way from this paper. However, these formal differences are not essential for the present discussion, so we do not go into the details here.

(145) Which^u girl bought which^v book and how much did she$_u$ pay for it$_v$?

(146) $\mathbf{Q}(\mathbf{max}^u([\![\text{girl}]\!]_d) \mathbin{\underline{\wedge}} \mathbf{max}^v([\![\text{book}]\!]_d) \mathbin{\underline{\wedge}} \delta_{u,v}([\![\text{bought}]\!]_d(v)(u))) \mathbin{\underline{\wedge}}$
$\mathbf{Q}(\mathbf{max}^{u'}([\![\text{price}]\!]_d) \mathbin{\underline{\wedge}} \delta_{u,v,u'}([\![\text{she}_u \text{ pay for it}_v]\!]_d)(u'))$

Within the scope of the $\mathbf{Q}$ operator[30], a maximal set of girls and a maximal set of books are introduced by the *wh*-expressions, and crucially, a distributive operator occurs in the scope of the *wh*-expressions. As for the first multiple-*wh* question, the representation except $\mathbf{Q}$ is similar to universal quantification in DPlL. Therefore, it can establish a girl–book dependency. In the second *wh*-question, the distributive operator scopes over two singular pronouns, so it enables the pronouns to be evaluated relative to the previously introduced girl–book dependency.

However, assuming that questions have distributive operators in their semantic representations leads to over-generation problems. First of all, question subordination should be allowed when a question follows a universal statement. Consider (147).

(147) I know every^u girl bought a^v book, but how much did { #she$_u$ / each of them$_u$ } pay for it$_v$?

Without a distributive quantifier, the singular pronouns occurring in the subsequent question cannot access the girl–book dependency established in the universal statement. If the question itself contributed a distributive operator, a distributive quantifier should not be needed. However, it is not the case.

In addition, a broader but related issue is that under this assumption a pair-list reading should emerge when a singular *wh*-expression co-occurs with an indefinite. Specifically, the meaning of the sentence in (148) could be represented as (149).

(148) Which^u girl bought a^v book?

(149) $\mathbf{Q}(\mathbf{max}^u([\![\text{girl}]\!]_d) \mathbin{\underline{\wedge}} \delta_u([\![\text{bought a book}]\!]_d(u)))$

Given that the indefinite possibly falls within the scope of the distributive operator, the question may presuppose that a group of girls each bought a book and ask about the girl–book dependency. However, this is also contrary to fact. (148) only presupposes that a single, unique girl bought a book.

[30] $\mathbf{Q}$ introduces an abstract in the sense of Groenendijk & Stokhof (1982), which determines a partition of possible worlds and generates a question meaning in the partition semantics (Groenendijk & Stokhof 1984). van Rooy does not spell out how the introduced abstract is used in his paper and this is not important for the analysis of question subordination, so it is left open here.

B.2 Dynamic partition semantics

Haida (2007) proposes an alternative way to derive the pair-list reading of a multiple-*wh* question. His analysis combines the partition semantics of questions (Groenendijk & Stokhof 1984) and Dynamic Predicate Logic (DPL) (Groenendijk & Stokhof 1991) by adding the biconditional operator $\Leftrightarrow$, defined in (150), to DPL. This operator is used to indicate that two formulas of DPL are equivalent iff they have the same context change potential. DPlL, the framework adopted in this paper, is an enrichment of DPL. The difference is that DPL operates on assignments, instead of sets of assignments.

(150) $\quad \Phi \Leftrightarrow \Psi := \lambda g.\{g \mid \forall k.k \in \Phi(g) \leftrightarrow k \in \Psi(g)\}$

Wh-expressions share the same denotation with indefinites, i.e., dynamic existential quantifiers, illustrated as in (151). The interrogative interpretation is modeled by the question operator $\mathbf{Q}$, as in (152). This operator takes a dynamic proposition ϕ and returns another dynamic proposition that specifies an equivalence relation on the sets of possible worlds as well as updates the input context with the extension of ϕ.

(151) $\quad [\![\text{who}^u]\!]_d = [\![\text{someone}^u]\!]_d$

(152) $\quad \mathbf{Q}_{w_0} := \lambda\phi\lambda w.\big(\phi(w_0) \Leftrightarrow \phi(w)\big) \triangle \phi(w_0)$

In Haida's analysis, the multiple-*wh* question *which*^{u} *boy bought which*^{v} *book* denotes (153) (the restrictors of the *wh*-expressions are omitted for simplicity). The two *wh*-expressions are embedded by the bi-conditional, which lends universal quantificational force to the existential quantifiers in its scope, as what a dynamic conditional does in DPL (see Groenendijk & Stokhof (1991) and Haida (2007) for the concrete proofs).

(153) $\quad \lambda w.\left[\begin{array}{r} [\![\text{some}^u \text{ boy bgt some}^v \text{ book}]\!]_d(w_0) \Leftrightarrow [\![\text{some}^u \text{ boy bgt some}^v \text{ book}]\!]_d(w) \\ \triangle\, [\![\text{some}^u \text{ boy bgt some}^v \text{ book}]\!]_d(w_0) \end{array}\right]$

$$= \lambda w\lambda g.\left\{ g^{u\mapsto x}_{v\mapsto y} \;\middle|\; \mathsf{buy}_w(y)(x) \wedge \forall x', y' \in D_e \left[\begin{array}{l} \mathsf{buy}_{w_0}(y')(x') \leftrightarrow \\ \mathsf{buy}_w(y')(x') \end{array}\right] \right\}$$

In (153), the bi-conditional component characterizes a set of possible worlds in which every boy bought a book. Suppose that Max bought *Moby Dick* and Kyle *the Great Gatsby*, then the information offered by the answer to the question should be equivalent to the real world, i.e., Max bought *Moby Dick* and Kyle *the Great Gatsby*.

Although (153) seems to derive a pair-list answer, it does not establish a dependency between u and v at the discourse level. As defined in (150), $\Leftrightarrow$ is not externally dynamic and the information established in the biconditional component does not pass down to subsequent sentences. As a result, it is not clear how this analysis can explain question subordination, which is similar to quantificational subordination. As argued in Krifka (1996) and van den Berg (1996), DPL cannot capture quantificational subordination without extra assumptions.

B.3 A potential functional approach

Besides the family-of-questions approach, an alternative functional approach is proposed to handle the pair-list reading of a multiple-*wh* question. In the functional approach, a multiple-*wh* question with a pair-list reading is assumed to request the identification of a skolemized function f (Engdahl 1986; Chierchia 1993; Dayal 1996; Xiang 2023; a.o.). Following Dayal (1996), the meaning of the question *which boy bought which book* is represented as in (154).

(154) $\{\cap\{\lambda w.\mathsf{buy}_w(f(x))(x) \mid x \in \mathsf{boy}\} \mid f \in [\mathsf{boy} \mapsto \mathsf{book}]\}$

The *wh*-object introduces a set of functions f mapping boys to books, written as $[\mathsf{boy} \mapsto \mathsf{book}]$. Given the boys ranged over by the *wh*-subject, a function f maps each boy to the book he bought. In this approach, the set of f-s naturally represents the non-deterministic boy–book dependency.

As pointed out by Heim (2018), a skolemized function, which encodes a functional dependency between sets, can replace plural info-states assumed in DPlL to capture reference to dependencies. If a skolemized function f is introduced as a dref, the dependency encoded in f becomes accessible in discourse. Therefore, the functional approach to multiple-*wh* questions also has the potential to model reference to dependencies established in a multiple-*wh* question. However, it is not as straightforward as one might have hoped. The functional approach has to overcome some difficulties in order to become a tenable account.

In place of sets of assignments, we may posit that a *wh*-expression introduces a skolemized function f as a dref in a multiple-*wh* question. Consider (155). Following the standard assumption, the *wh*-subject behaves like an indefinite and introduces a dref u storing some atomic boy x. Crucially, the *wh*-object is anaphoric to u and introduces a dref $\int$ associating with various skolemized functions f from boys to books. Given these assumptions, the static meaning in (154) can be dynamisized as in (156).

(155) Which^u boy bought which$^{\int}_u$ book and who will each$^\nu$ of them$_u$ send it$_{\int,\nu}$ to?

(156) $$\left\{ \underline{\sqcup} \left\{ \begin{array}{r} \lambda g \lambda h \lambda w.\mathsf{buy}_w(f(x))(x) \wedge \\ h = g^{u \mapsto x}_{\int \mapsto f} \end{array} \;\middle|\; x \in \mathsf{boy}_{w_0} \right\} \;\middle|\; f \in [\mathsf{boy}_{w_0} \mapsto \mathsf{book}_{w_0}] \right\}$$

In the subsequent question, the pronoun *it* is double indexed and accesses $\int$ and ν. The latter is introduced by the distributive quantifier and stores an atomic part of the boys ranged over by *which boy*. The value of the pronoun results from applying the function stored in $\int$ to the entity stored in ν. That is, for each boy, *it* refers to the book he bought. Consequently, the subsequent question can be understood as: 'for each boy, who did he sent the book he bought to'.

A tricky issue raised by this analysis is how to interpret the plural pronoun *them*. Crucially, it must refer to all boys ranged over by *which boy*; otherwise, the functional dependency involved in $\int$ would be trivially used. Specifically, if *them* directly retrieved the value stored in u, which is just one atomic boy, the subsequent question in (155) would be interpreted as a question asking who some boy sent his book to. This does not capture the subordination pattern.

The editor in the second round suggests resolving this problem by linking *them* to the domain of $\int$. Additionally, Zhang (2024) proposes that *which* introduces a plural individual for

a dref, which is then distributively evaluated. While either way may save the dynamic functional approach when explaining quantificational subordination, they both encounter a similar challenge when applied to question subordination. Consider (157). The singular pronoun *he* may not refer to the plural domain of $\int$ or the plural individual introduced by *which* due to the number mismatch.

(157) Which boy bought which book and who will he send it to?

If the singular pronoun was linked to an atomic boy, the subsequent question would just ask to whom one of the relevant boys sent the book he bought.

Of course, the problem can be addressed if the dynamic functional approach is also integrated with Dynamic Plural Logic, as Dynamic Inquisitive Semantics (Roelofsen & Dotlačil 2023) does. However, this integration would compromise the simplicity of the assumption about information states. Moreover, Dynamic Inquisitive Semantics is not adequate to explain question subordination. I refer interested readers to Li (2023) for more details.

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