Reference to dependencies established in a multiple-*wh* question[*]

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Abstract In discourse, a universal statement establishes a dependency between sets of objects, which can support the evaluation of singular pronouns in a subsequent sentence. Two well-known phenomena involving such reference to a dependency are quantificational subordination and telescoping. This paper argues that a multiple-*wh* question admitting a pair-list answer can support subordination and telescoping, just like universal statements. Accordingly, the relevant phenomena are classified into two kinds of reference to dependencies, called 'question subordination' and 'question telescoping', which exhibit different properties. A dynamic family-of-questions analysis is developed to account for these phenomena. Briefly, 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. Following Dynamic Plural Logic, the family of questions and possible pair-list answers encode different kinds of dependencies. Accessing the dependency encoded in a possible pair-list answer gives rise to question subordination, whereas accessing the dependency encoded in the family of questions gives rise to question telescoping.

Keywords: subordination, telescoping, multiple-*wh* questions, dynamic semantics

1 Introduction

In discourse, a dependency introduced by a quantificational sentence is accessible to a subsequent sentence, as in *quantificational subordination*. In (1) , the first sentence may lead to a boy–book dependency, i.e., each boy bought a different book. The second sentence refers to this dependency for elaboration, i.e., for each boy-book pair retrieved, make sure that the boy sent the book to Ada.[1]

(1)   Every^u boy bought a^v book. Each of them$_u$ sent it$_v$ to Ada.

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[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), *Ada* can also serve as an antecedent of an anaphoric expression, but this proper name does not bear a superscript because it is not referred to in this example.

Crucially, the distributive quantifier *each of them* in the second sentence accesses the boy-book dependency and unfurls it into a set of single boy–book pairs. Within the scope of *each*, the singular pronoun *it* is evaluated relative to each boy–book pair, i.e., for each boy, *it* refers to the book that he bought.

Besides retrieving a dependency with quantificational subordination, another well-documented but less studied strategy is *telescoping* (Roberts 1987). As shown in (2) (Roberts' (35)), in telescoping a singular pronoun looks as if it may be bound by a universal quantifier in the previous sentence.

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

Unlike quantificational subordination, in telescoping the second sentence contains no quantifier. However, the singular pronoun in (2) is still evaluated relative to the previously introduced dependency between chess sets and spare pawns. In addition, telescoping is a rather marked construction, and Roberts has noted various restrictions on its use (see also Wang, McCready & Asher 2006; Keshet 2007).

In this paper, I show that both strategies—quantificational subordination and telescoping—are available for accessing dependencies introduced by multiple-*wh* questions. Specifically, a multiple-*wh* question may have a pair-list reading. As exemplified in (3), this reading admits a pair-list answer, which in this case offers a list of boy–book pairs. This conversation is felicitous in the context where the boys bought one book each. This establishes a dependency between the boys and the books involved: given a boy, we can pick out the book that he bought. The multiple-*wh* question asks for the identification of such a dependency.

(3)   A: Which boy bought which book?
       B: Max bought *Moby Dick*, Kyle *The Great Gatsby*, and Sam *War & Peace*.

The dependency established in (3) can be accessed by pronouns in a subsequent sentence. Consider (4).

(4)   Which^u boy bought which^v book **and** who will **each** of them$_u$ send it$_v$ to?
       Answer: Max bought *Moby Dick*, Kyle *The Great Gatsby*, and Sam *War & Peace*. Each of them will sent the book he bought to Ada.

The second question involves a distributive quantifier. The plural pronoun *them* refers to all the boys in the domain of the *wh*-expression *which boy*, whereas the singular pronoun *it* is evaluated distributively with respect to the boys. In other words, the second question asks to whom each boy sent the book he bought. In section 2, examples like this are shown to share core features with quantificational subordination, an example of which has been provided in (1). So, the pattern shown by (4) is called 'question subordination'.

Besides subordination patterns, the dependency enquired by a multiple-*wh* question can be accessed without a distributive item, with striking resemblance to telescoping. As shown in (5), the multiple-*wh* question in (3) may conjoin with a *wh*-question with two singular pronouns anaphoric to the *wh*-expressions.

(5) Which^u boy bought which^v book **and** who will he$_u$ send it$_v$ to?
Answer: Max bought *Moby Dick*, Kyle *The Great Gatsby*, and Sam *War and Peace*. Each of them will send Ada the book he bought.

In the second question, both singular pronouns are evaluated relative to the dependency: for each boy, *he* refers to the boy and *it* the gift he bought. This pattern is called 'question telescoping'.

Although previous studies have observed these two patterns (van Rooy 1998; Dotlačil & Roelofsen 2019), they have not distinguished between quantificational subordination and telescoping. As argued in this paper, it is important to set these two strategies apart as they access *distinct types of dependencies*.

This paper proposes a dynamic family-of-questions approach to multiple-*wh* questions. Departing from the classical version of this approach (Hagstrom 1998; Willis 2008; Fox 2012; Nicolae 2013; Kotek 2014; a.o.), the derivation of a multiple-*wh* question is dynamicized. Compositionally, the multiple-*wh* question in (3) gives rise to a set of question meanings, like (6). Each question meaning involves one boy. $\llbracket \cdot \rrbracket_d$ is a function mapping a linguistic expression to a dynamic meaning.

(6) $\left\{ \begin{array}{l} \llbracket \text{which}^v \text{ book did Max}^u \text{ buy} \rrbracket_d, \ \llbracket \text{which}^v \text{ book did Kyle}^u \text{ buy} \rrbracket_d, \\ \llbracket \text{which}^v \text{ book did Sam}^u \text{ buy} \rrbracket_d \end{array} \right\}$

This set of question meanings is called 'family of questions'. It can be transformed into a set of possible pair-list answers, as shown in (7). Each member in (7) is derived from connecting possible answers to the questions in (6).

(7) $\left\{ \begin{array}{l} \llbracket \text{Max}^u \text{ bought } MD^v; \text{ Kyle}^u \text{ bought } GG^v; \text{ Sam}^u \text{ bought } WP^v \rrbracket_d, \\ \llbracket \text{Max}^u \text{ bought } WP^v; \text{ Kyle}^u \text{ bought } MD^v; \text{ Sam}^u \text{ bought } GG^v \rrbracket_d, \\ \llbracket \text{Max}^u \text{ bought } WP^v; \text{ Kyle}^u \text{ bought } GG^v; \text{ Sam}^u \text{ bought } MD^v \rrbracket_d, ... \end{array} \right\}$

This paper shows that a family of questions and a pair-list answer encode different kinds of dependencies. Question subordination is derived when the dependency encoded in a family of question is accessed, whereas question telescoping is derived when the dependency encoded in a pair-list answer is accessed.

This paper is organized as follows. Section 2 describes question subordination and question telescoping by zooming into their empirical differences. Section 3 presents a dynamicized family-of-questions approach to multiple-*wh* questions, which serves as the backbone of the proposed analysis. Section 4 demonstrates how

the dynamic family-of-questions approach accounts for question subordination and question telescoping. Section 5 concludes. All formal definitions and derivations are deferred to Appendix A.

2 Data

Backcground   It has been observed that *wh*-expressions, like indefinites, can support cross-sentential anaphora, as in (8).

(8)   Which^u boy was late and when did he$_u$ arrive?

The hearer must name the man who was late and specify the time of his arrival. Importantly, the pronoun *he* co-varies with the man 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 discourse referents (drefs, for short), which serve as antecedents for anaphoric expressions (Comorovski 1996; van Rooy 1998; Aloni & van Rooy 2002; Haida 2007; Murray 2010a; Dotlačil & Roelofsen 2018, 2020).

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). In (8), the question *Which^u boy was late* denotes a set of possible answers including *Max^u was late* and *Kyle^u was late*. Both possible answers add a dref *u* for a different boy. As a result, we get different possible outputs. In a conversation, the addressee is directed to decide which output matches the fact.[2] The second question is asked before the first one is resolved. Intuitively, the second question should be interpreted relative to every possible output given by the first question: given that Max was late, he$_u$ refers to Max; given that Kyle was late, *he* refers to Kyle.

A multiple-*wh* question can admit a single-pair answer or a pair-list answer. In the situation where a single-pair answer is admitted, the *wh*-expressions in a multiple-*wh* question can be referred to by singular pronouns, as shown in (9).

(9)   A: Among these boys, only one bought a book as a gift.
         B: Which^u boy bought which^v book and who will he$_u$ send it$_v$ to?
         A: Max bought *Moby Dick* and he will send it to Ada.

Following the common view of the single-pair reading (Dayal 1996; Nicolae 2013;

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2 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.

[Kotek 2014](#); a.o.), the possible single-pair answers are propositions naming a single pair, such as *Max bought Moby Dick*, *Kyle bought The Great Gatsby*, etc. These single-pair answers add the drefs u and v for one boy and one book. They are retrieved by singular pronouns he_u and it_v.

When a multiple-*wh* question admits a pair-list answer, the interrogation is about the dependency between two sets of entities. In this situation, the relevant singular *wh*-expressions can support cross-sentential *plural* anaphora, as in [(10)](#).

(10) Which^u boy bought which^v book and who will they$_u$ send them$_v$ to?
      <u>Answer:</u> Max bought *Moby Dick*, Kyle *The Great Gatsby*, and Sam *War & Peace*. These boys will send the books to Ada.

With a pair-list reading, the multiple-*wh* question allows for possible pair-list answers that specify a proper pairing between the boys and the books. A possible pair-list answer has the effect of adding two drefs u and v for the boys and the books respectively. These possible outputs each create a local context for the subsequent question. For each output, the values stored in u and v are retrieved by the plural pronouns: *they$_u$* refers to the set of boys, while *them$_v$* the set of books.

Question subordination   Now that the background of cross-sentential anaphora to *wh*-expressions has been clarified, we are ready to discuss question subordination, some examples of which are given in [(11)–(ii)](#).

(11) Which^u boy bought which^v book and who will each of them$_u$ send it$_v$ to?
      <u>Answer:</u> Max bought *Moby Dick*, Kyle *The Great Gatsby*, and Sam *War & Peace*. Each boy will send the book he bought to Ada.

As indicated by the pair-list response, the multiple-*wh* question is seeking to identify the dependency between the set of boys and the set of books. In the subsequent question, the plural pronoun *them* restricts the domain of the quantifier *each of them* and is understood to be the set of boys. Intriguingly, 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 the value of *them*: for each boy in the set retrieved by *them*, *it* is interpreted as the book he bought. In this sense, the evaluation of the singular pronoun is subordinated to the dependency established in the antecedent multiple-*wh* question.[3]

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3 Question subordination is also available with other quantifiers like *most/some of them*.

(i) Which^u boy bought which^v book and who will most of them$_u$ send it$_v$ to?
     <u>Answer:</u> Max bought *Moby Dick*, Kyle *The Great Gatsby*, and Sam *War & Peace*. Most of the boys will send the book he bought to Ada.

(ii) Which^u boy wrote which^v paper and would some of them$_u$ like to submit it$_v$ to a journal?
      <u>Answer:</u> Max wrote Tense, Kyle Focus, and Sam Scope. Some of the boys is considering

All of the conjoined questions have a similar configuration to quantificational subordination, which is shown in (12): an antecedent sentence establishes a dependency between two sets of entities and a subsequent sentence contains a universal quantifier that quantifies over one of these sets and scopes over a singular pronoun.

(12)   Every^u boy bought a^v gift and each of them$_u$ sent it$_v$ to his sister.

Question subordination can also be observed when a multiple-*wh* question precedes a declarative sentence or another question without the overt coordinator *and*, as in (13) and (14). In this paper, a sequence of a question and a declarative sentence is referred to as a 'Q–D sequence' and a sequence of two questions is referred to as a 'Q–Q sequence'.[4]

(13)   Which^u boy bought which^v book? Each of them$_u$ might have spent a lot on it$_v$.
        Interpretation: Which boy bought which book? Each of the boys might have spent a lot on the book he bought.

(14)   Which^u boy bought which^v book? Who will each of them$_u$ send it$_v$ to?
        Interpretation: Which boy bought which book? Who will each of the boys send the book he bought to?

In short, subordination is not restricted to universal statements, but is also observed with multiple-*wh* questions.

Question telescoping   Consider (15). As noticed in van Rooy (1998), although no quantifier occurs in (15), the singular pronouns in the second questions still can access the dependency established in the first multiple-*wh* questions, and hence the pair-list answers are felicitous.

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submitting his paper to a journal.

4 More data:

(i)   a.   Which^u boy bought which^v book? I think most of them$_u$ will read it$_v$ immediately.
              Interpretation: Which boy bought which book? I think most of the boys will read the book he bought immediately.
        b.   Which^u boy wrote which^v paper? I heard some of them$_u$ have sent it$_v$ to a journal.
              Interpretation: Which boy wrote which paper? I heard some of the boys have submitted his paper to a journal.

(ii)   a.   Which^u boy bought which^v book? When will most of them$_u$ read it$_v$?
              Interpretation: Which boy bought which book? When will most of the boys read the book he bought?
        b.   Which^u boy wrote which^v paper? Will some of them$_u$ submit it$_v$ to a journal?
              Interpretation: Which boy wrote which paper? Will some of the boys submit his paper to a journal?

(15)   Which^u boy bought which^v book and who will he$_u$ send it$_v$ to?
        <u>Answer:</u> Max bought *Moby Dick*, Kyle *The Great Gatsby* and Sam *War & Peace*. Each of them will send the book he bought to Ada.

Departing from question subordination, the coordinator *and* plays an important role in question telescoping. If a multiple-*wh* question is not overtly conjoined with a subsequent sentence, the dependency established in the multiple-*wh* question is not accessible to the singular anaphoric expressions in the subsequent sentence. For example, question telescoping is not allowed in a Q–D sequence, as shown in (16), and is not perfect with a Q–Q sequence, as shown in (17).[5]

(16)   Which^u boy bought which^v book? He$_u$ might have spent a lot on it$_v$.

    a.   <u>Answer:</u> #Max bought *Moby Dick*, Kyle *The Great Gatsby* and Sam *War & Peace*. They indeed spent a lot.
    b.   <u>Answer:</u> Max bought *Moby Dick*. Yeah, this book is not cheap.

(17)   Which^u boy bought which^v book? Who will he$_u$ send it$_v$ to?

    a.   <u>Answer:</u> ??Max bought *Moby Dick*, Kyle *The Great Gatsby* and Sam *War & Peace*. Each of them will send the book he bought to Ada.
    b.   <u>Answer:</u> Max bought *Moby Dick*. He will send this book to Ada.

The use of the singular pronouns in these two examples strongly implies that the multiple-*wh* questions involved here are seeking to identify a single boy and the single book he bought. In other words, the appearance of the singular pronouns rules out the pair-list readings of the antecedent multiple-*wh* questions. The relevant single pair readings remain intact, as evidenced by the acceptability of the single pair answers in both examples.

    Telescoping in multiple-*wh* questions is not exactly the same as that in universal statements. In a universal statement, the availability of telescoping is not conditioned by coordination, but rather some specific rhetorical relations (Roberts 1989; Wang et al. 2006). However, *and* is not needed, such as (18), in which the singular pronouns can still access the dependency established in the previous sentence.

(18)   Each^u degree candidate walked to the stage. He$_u$ took his diploma from the dean and returned to his$_u$ seat.   (Roberts 1989: 717)

On the other hand, even if a universal statement is conjoined with a subsequent sentence, the availability of telescoping is not guaranteed, as evidenced by (19).

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5 The judgement is not agreed by all the native speakers that I have consulted with. To get clear judgements, the two *wh*-questions in each example should bear a full *wh*-question intonation (i.e., they end in a falling pitch, Simon Charlow p.c.), which indicates the questions contribute independent interrogative forces.

(19)   a.   #Every^u boy bought a^v book and he$_u$ sent it$_v$ to Ada.
        b.   #Every^u farmer owns a^v donkey and it$_u$ is fed well.

So far, it's still unclear what role rhetorical relations play in the telescoping phenomenon. 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 in universal statements.

3   A dynamic approach to pair-list readings

The core of my analysis is a compositional derivation of multiple-*wh* questions using a dynamic Hamblin-Karttunen semantics. Based on such a dynamic implementation, the family-of-questions approach to multiple-*wh* questions can be dynamicized in a straightforward way to give rise to two kinds of dependencies.

Theoretical foundation   Building on Hamblin-Karttunen semantics (Hamblin 1973; Karttunen 1977), we assume: (a) *wh*-expressions denote sets of *dynamic* individuals, each of which introduce a dref, as illustrated in (20); (b) *wh*-questions denote sets of *dynamic* propositions, as illustrated in (21).[6]

(20) $\llbracket\text{who}^u\rrbracket_d = \{\llbracket\text{Ada}^u\rrbracket_d, \llbracket\text{Max}^u\rrbracket_d, \llbracket\text{Carl}^u\rrbracket_d\}$

(21) $\llbracket\text{who}^u \text{ was late}\rrbracket_d = \{\llbracket\text{Ada}^u \text{ was late}\rrbracket_d, \llbracket\text{Max}^u \text{ was late}\rrbracket_d, \llbracket\text{Carl}^u \text{ was late}\rrbracket_d\}$

In order to handle dependencies in discourse, I adopt Dynamic Plural Logic (DPlL) proposed by van den Berg (1996) to model dynamic meaning. As in all dynamic settings, the meaning of a sentence radical is viewed as a way of updating an input information state (info-state, for short). The essential feature of DPlL is the assumption

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

that info-states are *sets of assignments*, as shown in the table on the right, instead of single assignments as in a non-plural dynamic semantics. The set G of assignments (g, g', h, etc.) is an info-state. The assignments in G relate drefs (u, u', v, etc.) to objects (a, b, c, etc.) in the model.

Dynamic propositions store information about the values of drefs. For example, the sentence *Ada saw two boys* denotes a dynamic proposition that modifies the input info-state G by adding two drefs u and v. In the outputs, u introduced by the proper name *Ada* invariably stores the girl a, whereas v introduced by the indefinite store

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6 The dynamic Hamblin–Karttunen semantics pursued in this paper is a relatively direct way of combining dynamic semantics with Hamblin-style alternative semantics, but it is not the only way of dynamicizing alternatives. Due to the space limitation, I leave a comparison with other approaches (Murray 2010b; Charlow 2014, 2020; Dotlačil & Roelofsen 2020) for future research.

two boys, collected into sets $\{b, c\}$ or $\{b, t\}$.

(22)

$$
\begin{array}{|c|c|}\hline G & \dots \\\hline g & \dots \\\hline\end{array} \dashrightarrow [\![Ada^u \text{ saw } 2^v \text{ boys}]\!]_d \dashrightarrow \left\{ \begin{array}{|c|c|c|c|}\hline H & \dots & u & v \\\hline g^{u\mapsto a}_{v\mapsto b} & \dots & a & b \\\hline g^{u\mapsto a}_{v\mapsto c} & \dots & a & c \\\hline\end{array}, \begin{array}{|c|c|c|c|}\hline H & \dots & u & v \\\hline g^{u\mapsto a}_{v\mapsto b} & \dots & a & b \\\hline g^{u\mapsto a}_{v\mapsto t} & \dots & a & t \\\hline\end{array} \right\}
$$

A *wh*-question denotes a set of dynamic propositions, as in (23). In other words, a *wh*-question offers possible ways of updating an input info-state.

(23)

Cross-sentential anaphora to *wh*-expressions   Consider (24). Both *wh*-questions denote a set of dynamic propositions. These two sets can be conjoined in a pointwise manner, yielding a set of conjunctions of dynamic propositions.

(24) $[\![\text{which}^u \text{ boy was late}]\!]_d \ [\![\text{and}]\!]_d \ [\![\text{when did he}_u \text{ arrive}]\!]_d$

$$
= \left\{ \begin{array}{l} [\![\text{Max}^u \text{ was late}]\!]_d, \\ [\![\text{Kyle}^u \text{ was late}]\!]_d \end{array} \right\} [\![\text{and}]\!]_d \left\{ \begin{array}{l} [\![\text{he}_u \text{ arrived at } 10]\!]_d, \\ [\![\text{he}_u \text{ arrived at } 12]\!]_d \end{array} \right\}
$$

$$
= \left\{ \begin{array}{l} [\![\text{Max}^u \text{ was late}]\!]_d \ [\![\text{and}]\!]_d \ [\![\text{he}_u \text{ arrived at } 10]\!]_d, \\ [\![\text{Kyle}^u \text{ was late}]\!]_d \ [\![\text{and}]\!]_d \ [\![\text{he}_u \text{ arrived at } 10]\!]_d, \ \dots \end{array} \right\}
$$

Dynamic conjunction makes the dref introduced in a sentence visible to the subsequent sentences. In (24), 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 boy*.

Dynamic semantics of multiple-*wh* questions   The analysis proposed for multiple-*wh* questions is a dynamic version of the family-of-questions approach defended by Szabolcsi (1997), Hagstrom (1998), Krifka (2001), Willis (2008), Fox (2012), Nicolae (2013), Constant (2014), Kotek (2014), etc. Specifically, I propose that a multiple-*wh* question contains a covert functional morpheme $\mathbb{PL}$, which is responsible for deriving possible pair-list answers.[7]

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7 In addition to the family-of-questions approach, Dayal (1996) follows Chierchia (1993) and proposes a functional approach to pair-list readings of multiple-*wh* questions (Xiang 2020). This approach is

(25)   [$\mathbb{PL}$ [which^u boy bought which^v book]]

Adopting Charlow's (2019) composition of alternatives, the present analysis generates a higher order alternative set for a multiple-*wh* constituent. The official derivation is postponed to Appendix A. Only the result of the derivation is shown here. The multiple-*wh* constituent denotes a set of sets of dynamic propositions, which can be understood as a set of sub-questions, i.e., *a family of questions*. Each sub-question is asking about the gift bought by one boy.

(26)
$$\left\{ \begin{array}{l} \{[\![\text{Max}^u \text{ bgt } MD^v]\!]_d, \ [\![\text{Max}^u \text{ bgt } GG^v]\!]_d, \ [\![\text{Max}^u \text{ bgt } WP^v]\!]_d\}, \\ \{[\![\text{Kyle}^u \text{ bgt } MD^v]\!]_d, \ [\![\text{Kyle}^u \text{ bgt } GG^v]\!]_d, \ [\![\text{Kyle}^u \text{ bgt } WP^v]\!]_d\}, \\ \{[\![\text{Sam}^u \text{ bgt } MD^v]\!]_d, \ [\![\text{Sam}^u \text{ bgt } GG^v]\!]_d, \ [\![\text{Sam}^u \text{ bgt } WP^v]\!]_d\}, \ ... \end{array} \right\}$$

$$= \left\{ \begin{array}{l} [\![\text{which}^v \text{ book did Max}^u \text{ buy}]\!]_d, \\ [\![\text{which}^v \text{ book did Kyle}^u \text{ buy}]\!]_d, \\ [\![\text{which}^v \text{ book did Sam}^u \text{ buy}]\!]_d \end{array} \right\}$$

The family of questions leads an input info-state to three different directions. For each direction, the input info-state is added a different boy and a book that is required to be identified, as demonstrated below:

(27)

$$[\![\text{which}^v \text{ book did Max}^u \text{ buy}]\!]_d \dashrightarrow \left\{ \begin{array}{|c|c|} \hline u & v \\ \hline m & MD \\ \hline \end{array} \right\} \left\{ \begin{array}{|c|c|} \hline u & v \\ \hline m & GG \\ \hline \end{array} \right\} \left\{ \begin{array}{|c|c|} \hline u & v \\ \hline m & WP \\ \hline \end{array} \right\}$$

$$[\![\text{which}^v \text{ book did Kyle}^u \text{ buy}]\!]_d \dashrightarrow \left\{ \begin{array}{|c|c|} \hline u & v \\ \hline k & MD \\ \hline \end{array} \right\} \left\{ \begin{array}{|c|c|} \hline u & v \\ \hline k & GG \\ \hline \end{array} \right\} \left\{ \begin{array}{|c|c|} \hline u & v \\ \hline k & WP \\ \hline \end{array} \right\}$$

$$[\![\text{which}^v \text{ book did Sam}^u \text{ buy}]\!]_d \dashrightarrow \left\{ \begin{array}{|c|c|} \hline u & v \\ \hline s & MD \\ \hline \end{array} \right\} \left\{ \begin{array}{|c|c|} \hline u & v \\ \hline s & GG \\ \hline \end{array} \right\} \left\{ \begin{array}{|c|c|} \hline u & v \\ \hline s & WP \\ \hline \end{array} \right\}$$

The family of questions encodes a dependency between boys and books. The identification of the book depends on which boy is picked up.

The covert morpheme $\mathbb{PL}$ denotes an operator that maps a higher order alternative set to a set of dynamic propositions. Let's demonstrate how $\mathbb{PL}$ works in steps. Given a higher order set $\mathscr{Q}$ that contains sets Q of dynamic propositions, we define an operator **A**, as in (28), to transform $\mathscr{Q}$ into another higher order set. Accordingly, the resulting set of sub-questions in (26) is transformed into (29).

(28)   **A** $\{Q_1, Q_2, ..., Q_n\} := \{\{\phi_1, \ \phi_2, \ ..., \ \phi_n\} \mid \phi_1 \in Q_1, \ \phi_2 \in Q_2, \ ..., \ \phi_n \in Q_n\}$

In prose: for each Q in the set $\{Q_1, Q_2, ..., Q_n\}$, **A** picks out one dynamic propo-

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also dynamicizable. Due to the space limitation, I will compare the present analysis with a dynamic functional approach in another paper.

sition from it. These dynamic propositions are collected into a set. **A** repeatedly generates sets of dynamic propositions in this way, yielding a new set of sets of dynamic propositions.

(29)
$$\left\{ \begin{array}{l} \{[\![\text{Max}^u \text{ bgt } MD^v]\!]_d, \quad [\![\text{Kyle}^u \text{ bgt } GG^v]\!]_d, \quad [\![\text{Sam}^u \text{ bgt } WP^v]\!]_d\}, \\ \{[\![\text{Max}^u \text{ bgt } GG^v]\!]_d, \quad [\![\text{Kyle}^u \text{ bgt } WP^v]\!]_d, \quad [\![\text{Sam}^u \text{ bgt } MD^v]\!]_d\}, \\ \{[\![\text{Max}^u \text{ bgt } WP^v]\!]_d, \quad [\![\text{Kyle}^u \text{ bgt } GG^v]\!]_d, \quad [\![\text{Sam}^u \text{ bgt } MD^v]\!]_d\}, \end{array} \right\}$$

Based on (29), we can generate possible pair-list answers that encode dependencies between the drefs u and v. Every set in (29) is mapped by a connective operator $\mathbb{U}$ to the corresponding pair-list answer. The formal definition of $\mathbb{U}$ is given in Appendix A. Informally, it shifts a set of dynamic propositions $\{\phi_1, \phi_2, \phi_3\}$ to one dynamic proposition. The resulting dynamic proposition takes an input info-state and returns output info-states that are produced by the pointwise union ($\sqcup$) of the outputs given by ϕ_1, ϕ_2 and ϕ_3.
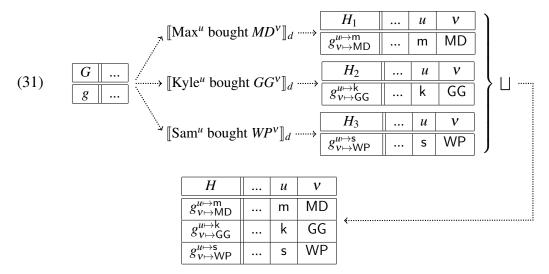
(30) $\mathbb{U} \left\{ \phi_1, \phi_2, \phi_3 \right\}$ gives rise to a dynamic proposition ψ such that, given an input info-state G, ψ produces output info-states as follows:

$$\left. \begin{array}{l} G \dashrightarrow \phi_1 \dashrightarrow \{H_1, H_2\} \\ G \dashrightarrow \phi_2 \dashrightarrow \{H_3, H_4\} \\ G \dashrightarrow \phi_3 \dashrightarrow \{H_5, H_6\} \end{array} \right\} \sqcup = \left\{ H \cup H' \cup H'' \; \middle| \; \begin{array}{l} H \in \{H_1, H_2\} \wedge \\ H' \in \{H_3, H_4\} \wedge \\ H'' \in \{H_5, H_6\} \end{array} \right\}$$

defined only if ϕ_1, ϕ_2, ϕ_3 are dynamically true, i.e., they each map G to a non-empty set.

Take the first set of dynamic propositions in (29) as an example. $\mathbb{U}$ maps this set to a possible pair-list answer, which requires every dynamic propositions in the set to be true dynamically as well as generates a context change potential as depicted in (31).[8] Each dynamic proposition in the set updates an input info-state by adding two drefs u and v, and we get three sets of info-states $\{H_1\}$, $\{H_2\}$ and $\{H_3\}$. Collecting these sets in a pointwise manner gives rise to $\{H_1 \cup H_2 \cup H_3\}$.

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8 This definedness condition is obeyed only if every boy bought a book. This condition gives rise to Dayal's (1996) domain cover effect. However, Xiang (2020) casts doubt on the domain cover effect. She found that the pair-list reading of the question *Which candidate got which job* is fully acceptable in the context where 100 candidates are competing for three jobs. In this context, it's not expected that every candidate will get a job. This example shows that the domain cover effect is cancelable. If Xiang is correct, the definedness condition would be changed to an existential statement: some of the propositions ϕ_1, ϕ_2, and ϕ_3 are dynamically true. This change will not affect the main analysis as well as the domain cover effect is not relevant to the core issue pursued in this paper, so I will leave a detailed discussion on the domain cover effect for future research.

(31)

G	...
g	...

H_1	...	u	v
$g_{v \mapsto MD}^{u \mapsto m}$	...	m	MD

⟦Max^u bought MD^v⟧$_d$ ⤑

H_2	...	u	v
$g_{v \mapsto GG}^{u \mapsto k}$	...	k	GG

⟦Kyle^u bought GG^v⟧$_d$ ⤑

H_3	...	u	v
$g_{v \mapsto WP}^{u \mapsto s}$	...	s	WP

⟦Sam^u bought WP^v⟧$_d$ ⤑

$\bigsqcup$

H	...	u	v
$g_{v \mapsto MD}^{u \mapsto m}$	...	m	MD
$g_{v \mapsto GG}^{u \mapsto k}$	...	k	GG
$g_{v \mapsto WP}^{u \mapsto s}$	...	s	WP

The output encodes a dependency between u and v, i.e., for each boy stored in u, there is a different book stored in v such that u bought v.

Returning to the set (29), we get other possible pair-list answers by applying $\mathbb{U}$ to the rest of the sets. These pair-list answers have different dependencies. Thus, $\mathbb{PL}$ denotes a function mapping a set of sub-questions to a set of pair-list answers.

(32) $\llbracket \mathbb{PL} \rrbracket_d(\mathcal{Q}) := \{\mathbb{U}(A) \mid A \in \mathbf{A}(\mathcal{Q})\}$

Possible pair-list answers are modeled as dynamic propositions in the present analysis, so $\mathbb{PL}$ also plays a role as a type shifter—shifting a set of sets of dynamic propositions to a set of dynamic propositions. The whole multiple-*wh* question asks the addressee to choose a pair-list answer matching the fact.[9]

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. Both the family of questions and a possible pair-list answer encode a dependency between *wh*-expressions. The core of my analysis is that accessing these two kinds of dependencies requests two anaphoric strategies, which appear as question subordination and question telescoping.

The compositional derivation proposed in this paper relies on the cross-categorial nature of conjunction: the coordinator *and* can apply to different syntactic categories

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9 $\mathbb{PL}$ as a meaning shifter is necessary in the family-of-questions approach, because the family of questions denoted by a multiple-*wh* constituent is not a well-defined question meaning in a Hamblin–Karttunen semantics. Hence, in some versions of the family-of-questions approach, such as Hagstrom (1998) and Fox (2012), an answerhood operator is postulated and serves the same role as $\mathbb{PL}$.

of different semantic types. Based on this property, I assume that the coordinator *and* can conjoin a multiple-*wh* question with a subsequent sentence in three ways.

Split CP domain   According to Rizzi (1997, 2001), the CP domain of a sentence is splitted into a series of functional projections.[10] The root of the CP domain is a Force projection ForceP, which marks a speech act. Within the CP domain, there is an interrogative projection IntP that marks the interrogative clause type. Rizzi (2001) argues that in a polar question the IntP is projected by *whether* or *if*, which is usually considered a shifter mapping a proposition p to a question meaning, i.e., a set of p and $\neg p$. In addition, the movement of a *wh*-expression targets a focus projection FocP, which is lower than IntP in the CP domain. Thus, this paper assumes the following syntactic structure for a multiple-*wh* question.

(33) $[_{\text{ForceP}}\ \mathbb{INT}\ [_{\text{IntP}}\ \mathbb{PL}\ [_{\text{FocP}}\ [\text{which boy}]_1\ [_{\text{TP}}\ t_1\ \text{bought which book}]]]]$

The pair-list answer generating operator $\mathbb{PL}$ occupies the Int head. Similar to *whether/if*, $\mathbb{PL}$ shifts a family of questions to a question meaning and hence can be seen as another instance of the interrogative clause type marking.

Conjoining FocPs   Given the structure in (33), ForcePs, IntPs, and FocPs can be conjoined by *and*. If a conjunction of a multiple-*wh* question and another question is analyzed as a FocP coordination, as illustrated in (34), the composition based on this structure yields question telescoping.

(34) $[_{\text{ForceP}}\ \mathbb{INT}\ [_{\text{IntP}}\ \mathbb{PL}\ [_{\text{FocP}}\ [_{\text{FocP}}\ \text{which}^u\ \text{boy bought which}^v\ \text{book}]$
              and $[_{\text{FocP}}\ \text{who will he}_u\ \text{send it}_v\ \text{to}]]]]$

According to the last section, the first FocP denotes a family of questions, which is semantically conjoined with the set of propositions denoted by the second FocP, as shown in (35). Informally, the *wh*-questions in the first set are conjoined with the follow-up *wh*-question one by one, giving rise to a set including conjunctions of *wh*-questions. For each conjunction of questions, *he* refers to a boy, while *it* refers to the book bought by the boy.

(35) $\left\{ \begin{array}{l} [\![\text{which}^v\ \text{book did Max}^u\ \text{buy}]\!]_d, \\ [\![\text{which}^v\ \text{book did Kyle}^u\ \text{buy}]\!]_d, \\ [\![\text{which}^v\ \text{book did Sam}^u\ \text{buy}]\!]_d \end{array} \right\}\ [\![\text{and}]\!]_d\ [\![\text{who will he}_u\ \text{send it}_v\ \text{to}]\!]_d$

$= \left\{ \begin{array}{lll} [\![\text{which}^v\ \text{book did Max}^u\ \text{buy}]\!]_d & [\![\text{and}]\!]_d & [\![\text{who will he}_u\ \text{send it}_v\ \text{to}]\!]_d, \\ [\![\text{which}^v\ \text{book did Kyle}^u\ \text{buy}]\!]_d & [\![\text{and}]\!]_d & [\![\text{who will he}_u\ \text{send it}_v\ \text{to}]\!]_d, \\ [\![\text{which}^v\ \text{book did Sam}^u\ \text{buy}]\!]_d & [\![\text{and}]\!]_d & [\![\text{who will he}_u\ \text{send it}_v\ \text{to}]\!]_d \end{array} \right\}$

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10 The split CP analysis is also adopted in many semantic studies, such as Farkas & Roelofsen (2017), Hoeks (2018), and Dotlačil & Roelofsen (2020).

Since the resulting set in (35) is also a set of questions, $\mathbb{PL}$ is able to operate on this set and transform it into a set of possible pair-list answers.

The derivation in (35) accounts for question telescoping. Crucially, the subsequent question accesses the dependency encoded in the family of questions, which gives rise to different directions of information update. Each direction involves one of the boys and the issue of identifying the book he bought. The resolution of the issue depends on which boy is involved and leads to a local context for the subsequent question. These local contexts each contain one boy and one book. Through conjunction, these contexts are accessed by the subsequent question. Consequently, the singular pronouns in the subsequent question retrieve a different boy and a different book relative to each local context.

Conjoining IntPs If *and* connects IntPs, rather than FocPs, in (33), question subordination is derived. Specifically, the relevant example is analyzed as in (36).

(36) $[_{\text{ForceP}} \; \mathbb{INT} \; [_{\text{IntP}} \; [_{\text{IntP}} \; \mathbb{PL} \; [_{\text{FocP}} \; \text{which}^u \; \text{boy bought which}^v \; \text{book}]]$
$\qquad\qquad$ **and** $[_{\text{IntP}} \; [_{\text{FocP}} \; \text{who will each of them}_u \; \text{send it}_v \; \text{to}]]]]$

The first IntP consists of $\mathbb{PL}$ and the FocP. The latter denotes a family of questions, which is shifted by $\mathbb{PL}$ to a set of possible pair-list answers, as shown in (37). For the convenience of discussion, I assign each pair-list answer a number.

(37) $\left\{ \begin{array}{l} \uplus \{ [\![\text{Max}^u \text{ bgt } MD^v]\!]_d, \quad [\![\text{Kyle}^u \text{ bgt } GG^v]\!]_d, \quad [\![\text{Sam}^u \text{ bgt } WP^v]\!]_d \}, \; \boxed{1} \\[4pt] \uplus \{ [\![\text{Max}^u \text{ bgt } GG^v]\!]_d, \quad [\![\text{Kyle}^u \text{ bgt } WP^v]\!]_d, \quad [\![\text{Sam}^u \text{ bgt } MD^v]\!]_d \}, \; \boxed{2} \\[4pt] \uplus \{ [\![\text{Max}^u \text{ bgt } WP^v]\!]_d, \quad [\![\text{Kyle}^u \text{ bgt } GG^v]\!]_d, \quad [\![\text{Sam}^u \text{ bgt } MD^v]\!]_d \}, \; \boxed{3} \dots \end{array} \right\}$
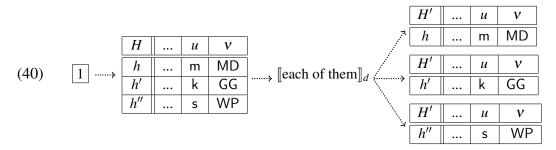
The second IntP has the same denotation as FocP, i.e., a set of propositions. The Int head may denote a function mapping a question meaning to the identical question meaning $(\lambda Q.Q)$. Each member in the set involves a distributive quantifier. The meaning of the IntP coordination is computed in the way shown in (38). The result is a set containing conjunctions of dynamic propositions.

(38) $\left\{ \begin{array}{c} \boxed{1}, \\[4pt] \boxed{2}, \\[4pt] \boxed{3}, \dots \end{array} \right\} \; [\![\text{and}]\!]_d \left\{ \begin{array}{l} [\![\text{each of them}_u \text{ will send it}_v \text{ to Ada}]\!]_d, \\[4pt] [\![\text{each of them}_u \text{ will send it}_v \text{ to Eva}]\!]_d, \\[4pt] [\![\text{each of them}_u \text{ will send it}_v \text{ to Mia}]\!]_d \end{array} \right\}$

(39) is a member of the resulting set. Each possible pair-list answer leads to an output info-state that encodes the dependency between the drefs u and v. The distributive quantifier *each of them* enables the dependency encoded in the pair-list answer to be accessible to the singular pronoun *it*.

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(39)   1   ⟦and⟧$_d$ ⟦each of them$_u$ will send it$_v$ to Ada⟧$_d$

The pair-list answer is the first dynamic proposition in (37), whose output is given in (40). The output is divided by ⟦each of them$_u$⟧$_d$ into sub info-states 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 sub info-states each involve an assignment assigning one boy to u and the corresponding book to v. Then, these sub info-states are taken as inputs by the formula in the scope of the distributive quantifier, i.e., ⟦will send it$_v$ to Ada⟧$_d$, one by one.

(40)   1   ⟶

H		...	u	v
h		...	m	MD
h'		...	k	GG
h''		...	s	WP

⟶ ⟦each of them⟧$_d$ ⟶

H'		...	u	v
h		...	m	MD

H'		...	u	v
h'		...	k	GG

H'		...	u	v
h''		...	s	WP

The singular pronoun *it* retrieves the value assigned to v in the input sub info-state. As a result, the pronoun is understood to be the single book. The fact that v in each sub info-state stores only one book also satisfies the atomicity condition of the singular pronoun. The whole process of retrieving the dependency between u and v is the same as the one that has been proposed for quantificational subordination.
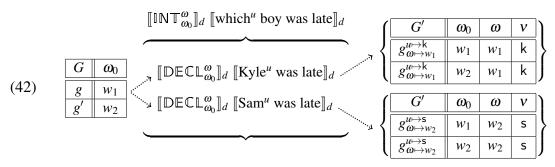
   In this case, a pair-list answer outputs a context where involves multiple boys and the books they bought. Hence, a singular pronoun cannot retrieve the boys or the books, unless the local context is unfurled by a quantifier. Thus, the dependency encoded in a pair-list answer only supports question subordination.

Conjoining ForcePs   So far, it has been demonstrated that question subordination and question telescoping are related to two different kinds of dependencies, i.e., the dependency encoded in a pair-list answer and the one encoded in a family of questions. A prediction is that, if only one kind of dependency is available for the sentence following a multiple-*wh* question, either question subordination or question telescoping will be blocked. This prediction is verified by the fact that question telescoping is disallowed when a multiple-*wh* question is not overtly conjoined with another sentence, as described in Section 2.

   Let's consider Q–D sequences (i.e., a multiple-*wh* question and a declarative are sequenced) first. The structure of a Q–D sequence is analyzed as follows.

(41)   [$_{ForceP}$ [$_{ForceP}$ $\mathbb{INT}$ [$_{IntP}$ $\mathbb{PL}$ [$_{FocP}$ which^u boy bought which^v book]]]
         and   [$_{ForceP}$ $\mathbb{DECL}$ [$_{TP}$ each of them$_u$ might spend a lot on it$_v$]]]

The structural analysis relies on the following assumptions that have been argued independently. **(a)** In a dynamic setting, a sequence of sentences is construed as conjunction of the relevant sentences. In (41), therefore, I assume that the two sentences are connected by a covert coordinator and, whose denotation is the same as its overt counterpart. **(b)** The multiple-*wh* question and the subsequent declarative sentence give rise to two different speech acts, i.e., an interrogative speech act and an assertive speech act. $\mathbb{INT}$ and $\mathbb{DECL}$ are force operators. The former shifts a question meaning, i.e., a set of dynamic propositions, to an interrogative speech act, whereas the latter shifts a dynamic proposition, to an assertive speech act. **(c)** Following previous studies, speech acts are conjoinable (Szabolcsi 1997; Krifka 2001, Hoeks 2018; a.o.). Semantically, the Q–D sequence in (41) denotes a conjunction of speech acts.

Following Brasoveanu (2010) and AnderBois, Brasoveanu & Henderson (2015), a force operator introduces a dref ω for possible worlds. Specifically, the dref ω introduced by $\mathbb{DECL}$ stores a set of possible worlds that are chosen from a local context and verify a dynamic proposition. The meaning of $\mathbb{INT}$ is built on $\mathbb{DECL}$: $\mathbb{INT}$ takes a set of dynamic propositions and feeds these dynamic propositions to $\mathbb{DECL}$ one by one. The process is depicted in (42). Suppose that Kyle was late in w_1 and Sam was late in w_2, then the set of possible worlds in the input may be reduced to $\{w_1\}$ or $\{w_2\}$. In a conversation, the addressee needs to choose one member from the set in (42) as the updated context. Basically, this process preserves the spirit of Farkas & Bruce's (2010) view of the interrogative force.

(42)

$$[\![\mathbb{INT}^{\omega}_{\omega_0}]\!]_d \; [\![\text{which}^u \text{ boy was late}]\!]_d$$

G	ω_0
g	w_1
g'	w_2

$[\![\mathbb{DECL}^{\omega}_{\omega_0}]\!]_d \; [\![\text{Kyle}^u \text{ was late}]\!]_d$

$[\![\mathbb{DECL}^{\omega}_{\omega_0}]\!]_d \; [\![\text{Sam}^u \text{ was late}]\!]_d$

G'	ω_0	ω	v
$g^{u\mapsto k}_{\omega\mapsto w_1}$	w_1	w_1	k
$g^{u\mapsto k}_{\omega\mapsto w_1}$	w_2	w_1	k

G'	ω_0	ω	v
$g^{u\mapsto s}_{\omega\mapsto w_2}$	w_1	w_2	s
$g^{u\mapsto s}_{\omega\mapsto w_2}$	w_2	w_2	s

Returning to (41), and coordinates ForcePs, and hence scopes over both the force operators as well as $\mathbb{PL}$. As a consequence, the subsequent declarative sentence only accesses the set of possible pair-list answers given by the multiple-*wh* question. In particular, the denotation of the first ForceP is derived by applying $\mathbb{INT}$ to the set of possible pair-list answers, i.e., the denotation of IntP. According to the derivation in (42), ForceP denotes (43), where every possible pair-list answer in (37), i.e., the denotation of IntP in (41), is shifted to the corresponding declarative sentence.

(43) $\left\{ [\![\mathbb{DECL}^{\omega}_{\omega_0}]\!]_d(\phi) \mid \phi \in (37) \right\}$

$\mathbb{DECL}$ introduces a dref that stores possible words verifying the pair-list answer in its scope. Hence, the dependencies encoded in these possible pair-list answers are preserved in (43). For example, the output of the declarative sentence $[\![\mathbb{DECL}^{\omega}_{\omega_0}]\!]_d(\boxed{1})$ from (43) is shown as the table on the right. The

H	ω_0	ω	u	v
h	w_1	w_1	m	MD
h	w_2	w_1	k	GG
h	w_3	w_1	s	WP

output is successfully produced iff, against the context set $\{w_1, w_2, w_3\}$, Max bought *Moby Dick*, Kyle *the Great Gatsby*, and Sam *War & Peace* in w_1. The dependency between u and v is still encoded in this info-state. Recall that accessing such a dependency requires the occurrence of a quantifier, which can unfurl the dependency into a set of single boy–book pairs. Therefore, in (41), the distributive quantifier occurring in the declarative sentence enables the singular pronoun to retrieve the boy–book dependency established in the previous interrogative sentence.

Moreover, $\mathbb{INT}$ has to scope over $\mathbb{PL}$. $\mathbb{INT}$ denotes a function shifting a question meaning to a speech act, and cannot combine with a set of question meanings due to type mismatch. Hence, $\mathbb{PL}$ must apply first and transform a set of question meanings to a question meaning before the application of $\mathbb{INT}$. Consequently, in (41), the subsequent declarative sentence cannot access the family of questions denoted by FocP. Thus, question telescoping, which involves reference to the dependency encoded in a family of questions, is not observed in conjunction of speech acts, as shown below.

(44)　Which^u boy bought which^v book? He$_u$ might have spent a lot on it$_v$.
　　　Interpretation: #Which^u boy bought which^v book? Each of the boys might have spent a lot on the book he bought.

This analysis can be extended to Q–Q sequences. As discussed in Section 2, the questions in a Q–Q sequence bear the full interrogative intonation, indicating that these questions elicit relatively independent inquiries. Similar to a Q–D sequence, a Q–Q sequence is analyzed as ForceP coordination. As a consequence, the subsequent question in a Q–Q sequence can only access the dependencies encoded in possible pair-list answers, which are preserved at the ForceP level. So, only question subordination is observed in a Q–Q sequence.

5　Conclusion

This paper takes up cross-sentential anaphora to dependencies established by multiple-*wh* questions. Building on the Hamblin–Karttunen semantics and DPlL, I have proposed a dynamic family-of-questions approach, which 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. Under DPlL, 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 question subordination, whereas the dependency introduced by a family of questions supports question telescoping.

A Formal analysis

Types: The basic types are entities (type e), possible worlds (type w), assignments (type g) and truth (type t).

Type abbreviations: $\{a\} ::= a \to t$ for sets of type-a elements; $t ::= \{w\} \to \{g\} \to (\{g\} \to t)$ for dynamic propositions; $e ::= (e \to t) \to t$ for dynamic individuals; $c ::= \{g\} \to (\{g\} \to t)$ for context change potentials.

Type shifters: $\eta(\alpha) := \{\alpha\}$ $\quad\quad m^{\Uparrow} := \lambda f. \bigcup \{f(x) \mid x \in m\}$ $\quad\quad$ (Charlow 2014)

Dynamic conjunction: $\Phi \wedge \Psi := \lambda G. \bigcup \{\Psi(G') \mid G' \in \Phi(G)\}$

$[\![A \text{ and } B]\!]_d = [\![A]\!]_d \triangle [\![B]\!]_d$ if $[\![A]\!]_d$ and $[\![B]\!]_d$ are of type c;
$\quad\quad\quad\quad \lambda\alpha.[\![A]\!]_d(\alpha) \triangle [\![B]\!]_d(\alpha)$ if $[\![A]\!]_d$ and $[\![B]\!]_d$ are of type $a \to c$

Pair-list answer generating operator: $[\![\mathbb{PL}]\!]_d = \lambda \mathscr{Q}.\{\mathbb{U}(A) \mid A \in \mathbf{A}(\mathscr{Q})\}$

$\mathbb{U}(A) := \lambda p \lambda G. \bigsqcup \{\phi(p)(G) \mid \phi \in A\}$ if $\forall \phi \in A : \exists H \in \phi(p)(G)$ else $\emptyset$

$\bigsqcup\{A_1, ... A_n\} := \{S_1 \cup ... \cup S_n \mid S_1 \in A_1, ... S_n \in A_n\}$

Speech act operators:

$[\![\mathbb{DECL}^{\omega}_{\omega_0}]\!]_d = \lambda \phi \lambda G. \bigcup \{\phi(p)(G^{\omega \mapsto p}) \mid p \subseteq G_{\omega_0}\}$ $\quad\quad\quad\quad\quad\quad$ Type: $t \to c$

Nominal and verbal expressions

- $[\![\text{Ada}^u]\!]_d = \lambda P \lambda p \lambda G.P(\mathsf{a})(p)(G^{u \mapsto \mathsf{a}})$ $\quad\quad\quad\quad\quad\quad\quad\quad\quad$ Type: e
- $[\![\text{which}^u \text{ boy}]\!]_d = \{\lambda P \lambda p \lambda G.P(x)(p)(G^{u \mapsto x}) \mid x \in \text{boy}_{w_0}\}$ $\quad\quad$ Type: $\{e\}$
- $[\![\text{buy}]\!]_d = \lambda x \lambda y \lambda p \lambda G.\{G\}$ if $\forall w \in p : \text{buy}_w(x)(y)$ else $\emptyset$ $\quad$ Type: $e \to e \to t$

Derivation: Multiple-*wh* questions
$[\![\text{which}^u \text{ boy bought which}^v \text{ book}]\!]_d$
$= [\![\text{which}^u \text{ boy}]\!]_d^{\Uparrow} \lambda\beta.\eta([\![\text{which}^u \text{ book}]\!]_d^{\Uparrow} \lambda\beta'.\eta(\beta \; \lambda y.(\beta' \; \lambda x.[\![\text{buy}]\!]_d(x)(y))))$
$= [\![\text{which}^u \text{ boy}]\!]_d^{\Uparrow} \lambda\beta\{\{\beta \; \lambda y.[\beta' \; \lambda x.[[\![\text{buy}]\!]_d(x)(y)]] \mid \beta' \in [\![\text{which}^v \text{ book}]\!]_d\}\}$
$= \{\{\beta \; \lambda y.[\beta' \; \lambda x.[[\![\text{buy}]\!]_d(x)(y)]] \mid \beta' \in [\![\text{which}^v \text{ book}]\!]_d\} \mid \beta \in [\![\text{which}^u \text{ boy}]\!]_d \}$

Derivation: Conjunction of questions
$[\![\text{who}^u \text{ was late and when did he}_u \text{ arrive}]\!]_d$
$= [\![\text{who}^u \text{ was late}]\!]_d^{\Uparrow} (\lambda\phi.[\![\text{when}^v \text{ did he}_u \text{ arrive}]\!]_d^{\Uparrow} (\lambda\psi\lambda p.\eta(\phi(p) \triangle \psi(p))))$

Derivation: Question telescoping
$[\![\text{which}^u \text{ boy bought which}^v \text{ book and who did he send it to}]\!]_d$
$= [\![\text{wh-boy ... wh-book}]\!]_d^{\Uparrow} (\lambda Q.\eta(Q^{\Uparrow}(\lambda\phi.[\![\text{who ...}]\!]_d^{\Uparrow} (\lambda\psi\lambda p.\eta(\phi(p) \triangle \psi(p))))))$

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