A hybrid categorial approach of question composition

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Abstract This paper revisits two fundamental issues in question semantics — what does a question mean, and how is this meaning compositionally derived? Drawn on observations with the distribution of *wh*-words in questions and free relatives as well as quantificational variability effects in question embedding, I argue that the nominal meanings of short answers must be derivable from question denotations, which therefore calls for a categorial approach to define questions. I provide a novel hybrid categorial approach to compose questions. This approach overcomes the problems with traditional categorial approaches in defining bare *wh*-indefinites, composing multi-*wh* questions, and coordinating questions.

Keywords: questions, categorial approaches, short answers, quantificational variability, multi-*wh* questions, question coordinations, free relatives, *wh*-conditionals, mention-some, *wh*-indefinites

1. Introduction

What does a question mean? It is hard to address this issue directly: unlike declaratives, questions can not be defined by truth values or truth conditions — we don't say a question is true or a question is false. Instead, studies on question semantics usually start with the relation between questions, answers, and question-containing or question-like constructions (such as indirect questions, free relatives, and so on). As such, researchers tackle this issue from different entry points and end up with quite different conclusions. Among the classics, starting from the relation between questions and propositional answers, Hamblin-Karttunen Semantics (Hamblin 1973; Karttunen 1977) define a question as a set of propositions, each of which is a possible answer or a true answer of this question. In contrast, starting from the relation between questions and short answers, categorial approaches (Hausser and Zaefferer 1979; Hausser 1983) define questions as lambda (λ-)abstracts, or more precisely, functions over short answers. Motivated by the world dependency relation in interpreting questions under attitudes,[1] Partition Semantics (Groenendijk and Stokhof 1982, 1984) defines questions as partitions of possible worlds.

In the recent studies of question semantics, categorial approaches are less dominant, partially due to their technical deficiencies in composing complex structures, and partially because the relation between questions and short answers can be explained alternatively by syntax. However, independent evidence from the distribution of *wh*-words in free relatives and cases of quantificational variability effects in question-embedding shows that questions much be able to supply predicative or nominal meanings, which leaves λ-abstracts the only possible denotations of questions. Hence, this paper proposes a novel hybrid categorial approach to compose questions. This approach carries forward the advantages of traditional categorial approaches and overcomes their technical deficiencies.

The rest of this paper is organized as follows. Section 2 presents the reasons for pursing categorial approaches. Section 3 discusses the problems with traditional categorial approaches, including defining bare *wh*-indefinites, composing multi-*wh* questions, and getting question coordinations.

[1] Groenendijk and Stokhof (1982, 1984) observe that the interpretation of a question embedded under an attitude predicate is world-dependent. Consider the following indirect question for example: *Jenny knows whether Andy left*. If Andy indeed left, this sentence means that Jenny knows that Andy left. If Andy actually didn't leave, it means that Jenny knows that Andy didn't leave.

Section 4 presents a novel hybrid categorial approach, which overcomes the problems of the traditional categorial approaches. Section 5 shows the advantages of this approach in interpreting *wh*-constructions with predicative or nominal meanings and getting quantificational variability inferences in question-embedding. Section 6 addresses the issue of composing question coordinations, a problem exists in any categorial approaches.

2. Why pursing a categorial approach?

This section will start by reviewing the original motivation of categorial approaches, which is to capture the relation between matrix questions and short answers (§2.1). Over the past few decades, it remains a topic of debate whether this relation should be ascribed to syntax or semantics. Although this paper takes no position on this debate, knowing it helps to understand the relation between λ-abstracts (i.e., the question denotations assumed by categorial approaches) and question denotations proposed by other canonical approaches. Next, I will present two new pieces of evidence for pursuing categorial approaches (§2.2): one is based on a cross-linguistic observation with the distribution gap of *wh*-words in questions and free relatives (§2.2.1), and the other draws on facts about two cases of quantificational variability effects in question-embeddings (§2.2.2).

2.1. The old debate: short answers in discourse

Categorial approaches were originally motivated to capture the relation between matrix questions and their *short answers* in discourse semantically. As exemplified in the following, a *full answer* (also called *clausal answer* or *propositional answer*) is a full declarative, while a short answer is a constituent that specifies only the new information. To be theory-neutral, this paper avoids terms such as *fragment answers* and *elided answers*, which involve the assumption that short answers are derived syntactically by ellipsis.

(1) Who came?
  a. Mary came. (full answer)
  b. Mary. (short answer)

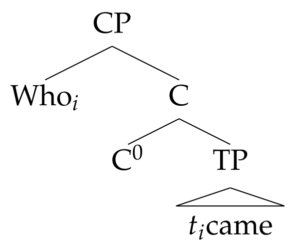
It remains controversial whether a short answer in discourse is bare nominal (Groenendijk and Stokhof 1982, 1984; Stainton 1998, 2005, 2006; Ginzburg and Sag 2000; Jacobson 2016) or covertly clausal (Merchant 2005). If a short answer is bare nominal, it should take a nominal interpretation (i.e., interpreted as an item in the quantification domain of the *wh*-item), which therefore calls for a way to derive such nominal meanings out of a question denotation. Previous works taking this position define the denotations of matrix questions as λ-abstracts, or more precisely, functions that select for the nominal denotation of a short answer as an argument (Groenendijk and Stokhof 1982, 1984; Ginzburg and Sag 2000; Jacobson 2016). In this view, for example, the *wh*-question in (1) denotes the function $\lambda x[\textit{hmn}(x).\textit{came}(x)]$,[2] which can take the human individual *Mary* as an argument. Alternatively, if a short answer is covertly clausal, it should be regarded as an elliptical form of the corresponding full answer and interpreted as a proposition. The ellipsis approach

[2] In this paper, λ-terms with presuppositions are represented in the form of $\lambda v: \beta.\alpha$ or $\lambda v[\beta.\alpha]$ (where β stands for the definedness condition or the presupposition and α stands for the value description), whichever is easier to read. λ-terms without presuppositions are written in the form of $\lambda v.\alpha$ or $\lambda v[\alpha]$.

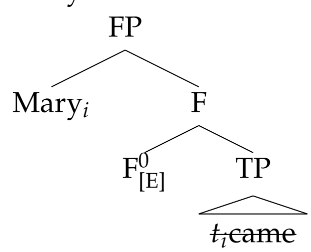
(Merchant 2005) proceeds as follows: first, the focused constituent *Mary* moves to a left-peripheral position, and next, licensed by a linguistic antecedent provided by the *wh*-question, the rest of the clause gets elided.

(2) Ellipsis approach for short answers (Merchant 2005)

a. Who came?



b. Mary.



Different definitions of questions predict different meanings and derivational procedures of short answers in discourse. Categorial approaches (Hausser and Zaefferer 1979; Hausser 1983; Von Stechow and Ede Zimmermann 1984; Guerzoni and Sharvit 2007; Ginzburg and Sag 2000; Jacobson 2016; and among others) define the root denotation of a question as a λ-abstract (or say, a predicate or a set of short answers). Short answers of a question are possible arguments of the λ-abstract denoted by this question, and a full answer is the output of applying this λ-abstract to a short answer.

(3) a. $[\![\text{who came}]\!] = \lambda x[\textit{hmn}(x).\textit{came}(x)]$

b. $[\![\text{who came}]\!]([\![\text{Mary}]\!]) = (\lambda x[\textit{hmn}(x).\textit{came}(x)])(m) = \textit{came}(m)$

In contrast, Hamblin-Karttunen Semantics (Hamblin 1973; Karttunen 1977) and their subsequents (Heim 1995; Cresti 1995; Dayal 1996; Rullmann and Beck 1998; among many others) define the root of a question as a set of propositions, each of which is a possible answer of this question (as assumed by Hamblin) or a true answer of this question (as assumed by Karttunen). Formalizations in (4) exemplify the assumptions of classic Hamblin Semantics. A *wh*-word denotes a set of individuals, as in (4a). A *wh*-question denotes a set of propositions, each of which names an object in the set denoted by the *wh*-word, as in (4b). This set is frequently referred to as a *Hamblin set*. A full answer denotes a singleton set consisting of the proposition named by that answer, as in (4c).

(4) a. $[\![\text{who}]\!] = \textit{hmn}$

b. $[\![\text{who came}]\!] = \{\hat{}\textit{came}(x) \mid x \in \textit{hmn}\}$

c. $[\![\text{Mary came}]\!] = \{\hat{}\textit{came}(m)\}$

Given a proposition set (4b)/(4c), it is technically difficult to recover the constituents that make up of the question/answer. More specifically, one won't be able to know that the singleton set (4c) is the interpretation of a declarative made up of a subject *Mary* and a predicate *came*; alternatively, this set can also be the meaning of *Mary came alone or came together with John*, which has a complex predicate *came alone or came together with John*, or the meaning of *The girl among John and Mary came*, which has a complex subject *the girl among John and Mary*. Likewise, one isn't able to know that the Hamblin set (4b) is an interpretation of a question made up of *who* and *came*, or to retrieve the λ-abstract and short answers of a question based on this Hamblin set. As such, Hamblin Semantics predicts that short answers can only be derived syntactically by ellipsis. This problem also exists in Karttunen Semantics and the subsequents of Hamblin-Karttunen Semantics.

For a concrete example of why λ-abstracts and short answers cannot be derived from Hamblin sets, compare the following three questions. Here the context is concerned with only two boys Andy and Billy and one girl Cindy. Noun phrases are interpreted *de dicto*. Abstracts and Hamblin sets of these questions are provided in (a)-formulas and (b)-formulas, respectively. Observe that these three questions yield the very same Hamblin set but different λ-abstracts and short answers.

(5) Did Andy came or Billy came?

a. $\lambda p\colon p \in \{\hat{}\mathsf{came}(a), \hat{}\mathsf{came}(b)\}.p$

b. $\{\hat{}\mathsf{came}(a), \hat{}\mathsf{came}(b)\}$

(6) Which boy came?

a. $\lambda x\colon x \in \{a, b\}.\mathsf{came}(x)$

b. $\{\hat{}\mathsf{came}(a), \hat{}\mathsf{came}(b)\}$

(7) The boy among which people came?

a. $\lambda x\colon x \in \{X \mid \mathsf{hmn}(X) \wedge \exists! y[y \leq X \wedge \mathsf{boy}(y)]\}.\mathsf{came}(\iota y[\mathsf{boy}(y) \wedge y \leq x])$
$= \lambda x\colon x \in \{a \oplus b, a \oplus c\}.\mathsf{came}(\iota y[\mathsf{boy}(y) \wedge y \leq x])$

b. $\{\hat{}\mathsf{came}(\iota y[\mathsf{boy}(y) \wedge y \leq a \oplus c]), \hat{}\mathsf{came}(\iota y[\mathsf{boy}(y) \wedge y \leq b \oplus c])\}$
$= \{\hat{}\mathsf{came}(a), \hat{}\mathsf{came}(b)\}$

The predictions of Partition Semantics (Groenendijk and Stokhof 1982, 1984, 1990) are a bit more complex, because Partition Semantics treats embedded questions and matrix questions differently. One the one hand, Partition Semantics defines matrix questions as λ-abstracts, as exemplified in (8a). Thus, the same as in categorial approaches, the relation between matrix questions and their short answers can be modeled semantically as a function-argument relation. On the other hand, different from categorial approaches, Partition Semantics defines embedded questions as a partitions of possible worlds, as exemplified in (8b).

(8) a. Matrix question
$[\![\text{who came}]\!] = \lambda w \lambda x[\mathsf{hmn}(x).\mathsf{came}_w(x)]$

b. Embedded question (as in *Jenny knows who came*)
$[\![\text{who came}]\!] = \lambda w \lambda w'[\lambda x[\mathsf{hmn}(x).\mathsf{came}_w(x)] = \lambda x[\mathsf{hmn}(x).\mathsf{came}_{w'}(x)]]$

Two world indices belong to the same cell of a partition iff the property denoted by the question nucleus holds for the same set of items in these two worlds. For example, in (8b), w and w' are in the same cell iff the very same set of individuals came in w and w'. With two relevant individuals John and Mary, the partition in (8) is illustrated as in Table 1. Each cell/row stands for a subset of worlds, or equivalently, an exhaustified propositional answer as to *who came*. For instance, the first cell stands for the set of worlds where only John and Mary came, and hence is equivalent to the exhaustified proposition that *only John and Mary came*.

w: only j and m came in w
w: only j came in w
w: only m came in w
w: nobody came in w

Table 1: Partition for *who came*

Since short answers cannot be extracted out of partitions, Partition Semantics predicts that embedded questions cannot provide nominal short answers. However, as to be seen in section 2.2.2, contra this prediction, to capture quantificational variability effects in quantified question-embedding, embedded questions with non-divisive predicates must be able to supply nominal short answers.

To see why short answers cannot be extracted from partitions, consider the following questions. (See Zimmermann (1985) for a formal proof.) These questions have contrasts with respect to number-marking (i.e., whether the *wh*-item is number-marked or not, as (9a, 10a)-vs-(9b, 10b)), polarity (i.e., whether the nucleus is positive or negative, as (9)-vs-(10)), and exhaustivity (i.e., whether the nucleus is exhaustified or not, as (9a, 10a)-vs-(11)). The exhaustified questions (11a-b) are in Mandarin because their English counterparts are ungrammatical).

(9) a. Who came?
b. Which person came?

(10) a. Who didn't come?
b. Which person didn't come?

(11) a. Zhiyou shei lai -le?
only who come -PERF
'Which human x is s.t. only x came?'
b. Zhiyou shei mei lai?
only who not come
'Which human x is s.t. only x didn't come?'

Strikingly, despite of the above contrasts, all of these questions yield the same partition. For a concrete example, compare the two questions in (9). The domain of a singular *wh*-item is a proper subset of that of a bare *wh*-word, namely, the former consists of only atomics while the latter also includes sums (Sharvy 1980; Link 1983). With only two relevant individuals John and Mary, the abstracts and Hamblin sets of these two questions are as follows:

(12) a. Who came?
i. $\lambda x\colon x \in \{j, m, j \oplus m\}.\hat{}\textsf{came}(x)$
ii. $\{\hat{}\textsf{came}(j), \hat{}\textsf{came}(m), \hat{}\textsf{came}(j \oplus m)\}$

b. Which person came?
i. $\lambda x\colon x \in \{j, m\}.\hat{}\textsf{came}(x)$
ii. $\{\hat{}\textsf{came}(j), \hat{}\textsf{came}(m)\}$

The abstract and Hamblin set of the number-neutral question (9a) involve pairs and propositions based on sums, while those of the singular-marked question (9b) do not. However, the two questions in (9) yield the very same partition, as illustrated in Table 2. In both partitions, the first cell for instance stands for the set of worlds where both John and Mary came. In particular, the one yielded by (9a) is the set of worlds w such that the set of atomic/sum individuals who came in w is $\{j, m, j \oplus m\}$, and the one yielded by (9b) is the set of worlds w such that the set of atomic individuals who came in w is $\{j, m\}$. These two sets of worlds are identical.

Partition yielded by (9a)				Partition yielded by (9b)
w: $\{x \mid w \in c(x)\} = \{j, m, j \oplus m\}$		w: only $j \oplus m$ came in w		w: $\{x \mid w \in c(x)\} = \{j, m\}$
w: $\{x \mid w \in c(x)\} = \{j\}$	$=$	w: only j came in w	$=$	w: $\{x \mid w \in c(x)\} = \{j\}$
w: $\{x \mid w \in c(x)\} = \{m\}$		w: only m came in w		w: $\{x \mid w \in c(x)\} = \{m\}$
w: $\{x \mid w \in c(x)\} = \varnothing$		w: nobody came in w		w: $\{x \mid w \in c(x)\} = \varnothing$

Table 2: Partitions for (9a-b)

Hence, abstracts and Hamblin sets cannot be recovered based on partitions. In other words, given the partition of a question, we cannot extract out the possible short/propositional answers or recover the question nucleus.

2.2. Independent arguments for categorial approaches

This paper does not take a position on the syntax or semantics of short answers in discourse. But, the discussion teaches us that the nominal meanings of short answers can only be derived from λ-abstracts. In the rest of this paper, the term "short answer", unless specified, refers to the nominal meaning of a bare short answer. In what follows, I will present two independent arguments for categorial approaches, drawn on observations with free relatives and quantificational variability effects. These observations show that meanings equivalent to the bare nominal denotations of short answers must be derivable from the root denotation of a question.

2.2.1. Caponigro's generalization and free relatives

The meaning of a *wh*- free relative (*wh*-FR henceforth) is systematically equivalent to the nominal meaning of the/a complete true short answer of the corresponding *wh*-question. On the one hand, a *wh*-FR is interpreted exhaustively if the corresponding *wh*-question admits only exhaustive answers. For example in (13a), the FR *what Jenny bought* refers to the exclusive set of items that Jenny bought.[3] On the other hand, a *wh*-FR takes an existential reading if the corresponding *wh*-question admits a "mention-some" reading and can be properly addressed by specifying one of its true answers. For example, in (13b), the FR *where he can get help* refers to one of the places where John could get help. (See more discussions and references on "mention-some" in section 4.1.3.)

(13) a. Mary ate [$_{\text{FR}}$ what Jenny bought].
b. John went to [$_{\text{FR}}$ where he could get help].

The similarities between *wh*-FRs and *wh*-questions in meaning and form make it quite appealing to treat these two constructions uniformly. Previous studies have provided two options to unify these two constructions. **Option I** is to assume that *wh*-FRs and *wh*-questions share the same roots and are derived by two independent operations. For example, Partition Semantics assumes that questions and FRs are derived from λ-abstracts via two independent type-shifting (TS) operations. As illustrated in Figure 1a, TS1 turns a λ-abstract into a partition of possible worlds, forming a

[3] Due to the common exhaustive readings, FRs as such are also called "definite FRs", as opposed to "indefinite FRs" which take indefinites-like readings. Unlike the existential FR in (13b), whose non-exhaustive/existential reading is licensed by the presence of a possibility modal, indefinite FRs must be licensed by an external existential operator and usually occur as complements of existential verbs (mainly the equivalents of existential *be* and existential *have*).

question, while TS2 turns a λ-abstract into a nominal element, forming a FR. **Option II** is to treat *wh*-FRs as derivatives of *wh*-questions. As illustrated in (1b), categorial approaches define questions as λ-abstracts, and derive FRs out of questions via one single TS-operation.

(a) Option I

(b) Option II

Figure 1: Options to unify *wh*-questions and *wh*-FRs

Which of the options is more advantageous? A cross-linguistic generalization due to Caponigro (2003, 2004) supports Option II:

(14) **Caponigro's Generalization** (Caponigro 2003, 2004)
If a language uses the *wh*-strategy to form both questions and FRs, the *wh*-words found in FRs are always a subset of those found in questions. Never the other way around. Never some other arbitrary relation between the two sets of *wh*-words.

This generalization was firstly made based on 28 languages from Indo-European, Finno-Ugric, and Semitic families.[4] It also extends to Tlingit and Haida (Cable 2005), Nieves Mixtec and Melchor Ocampo Mixtec (Caponigro et al. 2013), and Chuj (Kotek and Erlewine 2018). For example, cross-linguistically, *how*-words can be used in questions but not in FRs. Language-specifically, Spanish *qué* 'what' and Estonian *millal* 'when' can be used in questions but not in FRs, as seen in (15) and (16), respectively. Sometimes, the use of a *wh*-word is blocked only in particular types of FRs. For example, English *who* can be perfectly used in object-FRs and questions, but is deviant in subject-FRs, as seen in (17).

(15) Spanish *qué* 'what' (Caponigro 2003: ex. 14)

a. Pregunté **qué**/ lo-que cocinaste.
asked.1SG what/ the.N.S-COMP cooked.2SG
'I asked what you cooked.'

b. Comí ***qué**/ lo-que cocinaste.
ate.1SG *what/ the.N.S-COMP cooked.2SG
'I ate what you cooked.'

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[4]The 28 languages attested by Caponigro (2003, 2004) are:

(i) a. INDO-EUROPEAN:
  i. Germanic: Bavarian, Dutch, English, Standard German, Swiss German, West Flemish, Yiddish;
  ii. Romance: Catalan, French, Italian, Brazilian Portuguese, European Portuguese, Romanian, Sardinian, Spanish;
  iii. Slavic: Bulgarian, Macedonian, Polish, Russian, Serbo-Croatian, Slovenian;
  iv. Albanian, Modem Greek

b. FINNO-UGRIC: Estonian, Finnish, Hungarian.

c. SEMITIC: Modem Hebrew, Modem Moroccan Arabic.

(16) Estonian *millal* 'when' (Caponigro 2003: ex. 51)

a. Ma küsisin sult, [$_{\text{Q}}$ **millal** Maria saabus].
I asked you when Maria arrived
'I asked you when Maria arrived.'

b. * Ma lahkusin (siis), [$_{\text{FR}}$ **millal** Maria saabus]
I left then when Maria arrived.
'I left when Maria arrived.'

(17) English *who* (Caponigro 2004: ex. 40)

a. I will marry [$_{\text{FR}}$ who you choose].

b. I don't know [$_{\text{Q}}$ who couldn't sleep enough].

c. ?? [$_{\text{FR}}$ Who couldn't sleep enough] felt tired the following morning.

Caponigro's generalization suggests that the derivational procedure of a *wh*-FR shall be strictly more complex than that of the corresponding *wh*-question; otherwise, there would have been some *wh*-words that could be used in FRs but not in questions (Chierchia and Caponigro 2013).[5]

As such, we shall follow Option II and assume that *wh*-FRs are derived from *wh*-questions. In Figure 1b, Caponigro's Generalization is predicted as long as the TS-operation that turns questions into FRs is partial and is licensed only under particular linguistic or non-linguistic conditions. For example, Cecchetto and Donati (2015: chap. 3) attributes part of the gap to a syntactic operation called "relabeling" (details omitted). Alternatively, an analysis that follows Option I has to stipulate that the operation to derive FRs (TS2) is more strictly distributed than the operation to derive questions (TS1). Although it is hard to knock down this possibility, it is very mysterious why two independently used operations exhibit such distributional patterns.

In conclusion, Caponigro's generalization and the nominal meaning of a *wh*-FR suggest that the nominal meaning of a short answer must be derivable from the root denotation of a question.

2.2.2. Quantificational variability effects

As first observed by Berman (1991), question embeddings modified by a quantity adverbial (e.g., *mostly, partly, for the most part, in part*) are subject to quantificational variability (QV) effects. For example, the sentences in (18a-b) and (19a-b) intuitively imply the quantificational inferences in (18c) and (19c), respectively, which are called "QV inferences".[6]

[5] Chierchia and Caponigro (2013) followed Hamblin-Karttunen Semantics of questions and proposed an analysis of *wh*-FRs in line with Option II. But, as pointed out by Ede Zimmermann (p.c. to Gennaro Chierchia and Ivano Caponigro), this analysis is technically infeasible since it requires to extract abstracts and short answers out of Hamblin sets.

[6] These sentences are ambiguous. For example, (18a-b) can also be interpreted as following:

(i) a. Most of what Jenny knows is the answer to the question 'who came'.
b. What Jenny knows about the question 'who came' is almost complete.

Lahiri (2002) calls (ia) a focus-affected reading, where the matrix quantity adverbial quantifies over propositions compatible with Jenny's knowledge. I'm not aware of any discussions on reading (ib). This reading is true in the following scenario:

> In reality, only Andy came. Jenny knows that either Andy or Billy came. Moreover, based on some reliable clue, she is more inclined to believe that the person who came is Andy.

This paper will not discuss these two readings and will only be interested in the QV reading.

(18) a. Jenny mostly knows who came.
b. For the most part, Jenny knows who came.
c. $\rightsquigarrow$ *For most of the individuals who came, Jenny knows that they came.*

(19) a. Jenny partly knows who came.
b. In part, Jenny knows who came.
c. $\rightsquigarrow$ *For part of the individuals who came, Jenny knows that they came.*

Typically, in paraphrasing a QV inference, the domain of the matrix quantity adverbial can be formed by true atomic propositional answers of the embedded question (Lahiri 1991, 2002; Cremers 2016; compare Beck and Sharvit 2002). As schematized in (20), given a set of propositions, a proposition is atomic iff it does not entail any other propositions in this set. For the question *who came*, the atomic propositional answers are of the form "$^\wedge\textsf{came}(x)$" where x is an atomic human individual. In case that exactly five individuals *abced* came, the quantification domain of the matrix quantity adverbial is the set $\{^\wedge\textsf{came}(x) : x \in \{a,b,c,d,e\}\}$.

(20) Atomic propositions (Cremers 2016: chap. 5)
$\textsc{At}(Q_{\langle st,t\rangle}) = \{p \mid p \in Q \wedge \forall q \in Q[p \subseteq q \rightarrow q = p]\}$

As such, analyses that follow Hamblin-Karttunen Semantics can schematize QV inferences as follows, where $[\![\text{Q}]\!]$ stands for the Hamblin set of the embedded question Q:

(21) The propositional answer-based account (modified from Lahiri (2002))
The QV inference of *Jenny mostly knows Q* is as follows:
$\textsc{Most}\ p\ [w \in p \in \text{AT}([\![\text{Q}]\!])][\textsf{know}(j,q)]$
(For most p such that p is a true atomic proposition in $[\![\text{Q}]\!]$, Jenny knows p.)

In the LF derivation, the embedded question moves to the matrix clause, so that the matrix quantity adverbial *mostly* can access the Hamblin set of the embedded question directly (Lahiri 1991, 2002).

(22) [[who came]$_i$ mostly [Jenny knows t_i]]

In addition to the propositional answer-based account, which is only concerned with question-embeddings with responsive predicates (i.e., predicates that admit both interrogative and declarative complements, such as *know* and *remember*), Beck and Sharvit (2002) provide an account using sub-questions. Observing QV effects in question-embeddings with limited cases of rogative predicates (i.e., predicates that admit interrogative complements and reject declarative complements, such as *depends on*, cf. *wonder* and *ask*), Beck and Sharvit argue to define the domain of the matrix quantity adverbial as a set of sub-questions of the embedded questions, paraphrased as in (23b).

(23) For the most part, who will be admitted depends on this committee.
a. $\rightsquigarrow$ *For most individuals x, whether x will be admitted depends on the committee.*
b. $\rightsquigarrow$ *For most Q, Q is a relevant sub-question of the form "whether x will be admitted", Q depends on the committee.*

The sub-question-based account is also compatible with Hamblin-Karttunen Semantics — all one needs to do is to shift each atomic propositional answer of the embedded question into a *whether*-question. Beck and Sharvit define sub-questions of a *wh*-question as *whether*-questions containing a possible atomic answer to this *wh*-question, and assume that whether a sub-question is relevant is determined by the meaning of the question-embedding predicate. In particular, if the question-embedding predicate is veridical, a sub-question is relevant only if it has a true answer to the embedded question. Using the notations in (21), I schematize Beck and Sharvit's account as follows:[7]

(24) Sub-questions-based account (modified from Beck and Sharvit (2002))
The QV inference of *Jenny mostly knows Q* is as follows:
$\textsc{Most}\ Q'\ [\exists p[w \in p \in \text{AT}([\![\text{Q}]\!]) \wedge Q = \textit{whether-}p]][\textit{know}(j, \text{Q}')]$
(For most Q' of the form *whether-p* such that p is a true atomic proposition in $[\![\text{Q}]\!]$, Jenny knows Q'.)

To sum up, the propositional answer-based account and the sub-question-based account are both compatible with Hamblin-Karttunen Semantics. Both accounts link the formation of the domain of the matrix quantity adverbial with the extraction of atomic propositional answers of the embedded question. In particular, in the propositional answer-based account, this domain is directly made up of atomic propositional answers; in the sub-question-based account, this domain is made up of sub-questions defined based on atomic propositional answers. As such, both accounts crucially rely on a proper treatment of atomic propositional answers.

However, there are two challenging cases of getting desired atomic propositional answers. One case is about questions with divisive predicates, and the other is about questions with pair-list readings. The following explains these two challenging cases in details.

Challenge I. questions with non-divisive predicates In a quantified indirect question, if the predicate of the embedded question is non-divisive, as defined in (25), the domain restriction of a matrix quantity adverbial cannot be formed based on propositional answers of the embedded question.

(25) A predicate P is divisive iff $\forall x[P(x) \rightarrow \forall y \leq x[y \in \textsc{Dom}(P) \rightarrow P(y)]]$
(Whenever P holds of something x, it also holds of every subpart of x defined for P.)

Intuitively, for the sentences in (26), the domain of the matrix quantity adverbial is a set of individuals that are atomic subparts of the unique true short answer of the embedded question.[8]

(26) a. Jenny knows for the most part which students formed the bassoon quintet.
b. For the most part, Al knows which soldiers surrounded the fort.
c. Jenny mostly knows which professors formed the committee.

For example, in (26a), if the bassoon quintet was made of five students *abcde*, the unique true short answer of the embedded question is the plural individual $a \oplus b \oplus c \oplus d \oplus e$, and the quantification domain of *for the most part* is the set $\{a, b, c, d, e\}$. The QV inference shall be paraphrased as "for most atomic individual x among *abcde*, Jenny knows that x is in the group of the students who

[7]The original formalization by Beck and Sharvit (2002) is a bit different, since they define an embedded question as Karttunen-intension (of type $\langle s, stt\rangle$), namely, a relation that maps a world to the set of true propositional answers of this question in that world. But this difference is not crucial for this paper.

[8]Examples (26a-b) are taken from Schwarz (1994) and Williams (2000) and have been discussed by Lahiri (2002: 215). I thank Alexandre Cremers (pers. comm.) for bring these data to my attention.

formed the bassoon quintet." Alternatively, if we follow the propositional answer-based definition in (21), the quantification domain would be a singleton set $\{{}^\wedge \textit{f.t.b.q}(a \oplus b \oplus c \oplus d \oplus e)\}$, which is clearly implausible. This problem also applies to the sub-question-based account, because this account requires to define sub-questions based atomic true propositional answers.

Williams (2000) salvages the propositional answer-based account by interpreting the embedded question with a "sub-divisive" reading. He stipulates that the embedded question in (26a) provides propositional answers of a sub-distributive form "x is part of a group that formed the bassoon quintet" where x is an atomic student. Williams derives this reading by assigning the determiner *which* with a collective semantics, as schematized in the following:

(27) John knows which students formed the bassoon quintet.
$\approx$ 'John knows which student(s) x is such that x is part of the group of students who formed the bassoon quintet.'

a. $[\![\text{which}]\!] = \lambda A.\lambda P.\{\lambda w.\exists y \in A[y \geq x \wedge P_w(y)] \mid x \in A\}$

b. $[\![\text{which students}_@ \text{ f.t.b.q.}]\!]$
$= \lambda p.\exists x[{}^*\textit{student}_@(x) \wedge p = \lambda w.\exists y[{}^*\textit{student}_@(y) \wedge y \geq x \wedge \textit{f.t.b.q.}_w(y)]]$
$= \{\lambda w.\exists y[{}^*\textit{student}_@(y) \wedge y \geq x \wedge \textit{f.t.b.q.}_w(y)] \mid x \in {}^*\textit{stdt}_@\}$
($\{x$ is part of a group of students y s.t. y formed the bassoon quintet: x is student(s)$\}$)

Since this approach attributes sub-divisiveness to the lexicon of *which*, it predicts that sub-distributive readings should also be available in matrix *which*-questions. But, contra the prediction, the expected sub-divisive reading is not observed in the corresponding matrix questions. Compare the following sentences:

(28) a. Who is part of the students that formed the bassoon quintet, for example?
b. Which students formed the bassoon quintet, # for example?

(29) a. Who is part of the professors who formed the committee, for example?
b. Which professors formed the committee, # for example?

The use of a partiality-marker *for example* (or alternatively, *give me an example* or *show me an example*) indicates that the speaker is tolerant of incomplete true answers, and thus it presupposes the existence of such an answer. The presupposition is schematized in the following, where $\textsc{Ans}([\![\text{Q}]\!])(w)$ denotes the set of complete true answers of Q in w:[9]

(30) $[\![\text{Q, for example}]\!]^w$ is defined only if there is a proposition p such that

[9] Condition (a) is to exclude answers that are always partial. For example, disjunctive answers like (ia) and negative answers like (ib) are asymmetrically entailed by the complete true answer but are not accepted by the given question.

(i) Who formed a team, for example?
a. # The two girls or the two boys.
b. # Not the two girls.

One might argue that propositions in the Hamblin set of a question are all potentially complete, and therefore that condition (a) can be written more generally as $p \in [\![\text{Q}]\!]$. But, recent studies on *wh*-questions find that some *wh*-questions can have propositional answers formed out of generalized disjunctions (Spector 2007, 2008; Fox 2013) and conjunctions (Xiang 2016: section 1.6). In particular, Xiang (2016: chap. 2) shows that the answer space of the question in (i), where the nucleus is a non-divisive collective predicate, should be closed under boolean conjunction and disjunction.

a. $\exists w'[p \in \textsc{Ans}(\llbracket Q \rrbracket)(w')]$
(p is potentially a complete answer of Q.)

b. $\exists q \in \textsc{Ans}(\llbracket Q \rrbracket)(w)[p \subset q]$
(p is asymmetrically entailed by a complete true answer of Q.)

As seen in (31), the partiality marker *for example* cannot combines with a question that can have only one true answer. The only way to interpret these sentences is to let *for example* quantify over a set of speech acts, read as "for example, tell me which boy came/ whether it is raining/ ...".

(31) a. Which boy came, # for example?
b. Is it raining, # for example?
c. Did you vote for Andy or Billy, # for example?
d. Zhiyou shei lai -le, # ju-ge lizi? *Mandarin*
only who come -PERF give-CL example
Intended: 'Which people x is such that **only** x came, # for example?'

Thus, the infelicity of using *for example* in (28b) and (29b) suggests that the embedded questions in (26) admit only collective readings and have only one true answer. The seeming sub-divisive meaning in their QV inferences should come from the entire question-embedding constructions, not from the embedded questions.

Challenge 2. ***wh*-questions with pair-list readings** This challenge is theory-internal to Dayal (1996, 2017), who follows Hamblin-Karttunen Semantics and defines single-*wh* questions and multi-*wh* questions uniformly as sets of propositions. As seen in (32), multi-*wh* questions are ambiguous between single-pair readings and pair-list readings. Under a single-pair reading, the question in (32) presupposes that there is exactly one boy-invite-girl pair and asks the addressee to specify this pair. Under a pair-list reading, it expects that there are multiple boy-invite-girl pairs and requests the addressee to list all these pairs.

(32) Which boy invited which girl?
a. Andy invited Mary. (single-pair)
b. Andy invited Mary, Billy invited Julia, Charlie invited Daphne. (pair-list)

Dayal (1996, 2017) analyzes the single-pair reading of a multi-*wh* question as denoting a set of atomic propositions, as in (33a), while the pair-list reading as denoting a set of conjunctive propositions, as in (33b). In particular, for the pair-list reading, she proposes a function-based approach and derives these conjunctive propositions based on functions from atomic boys to atomic girls. For example, the conjunctive answer $\mathsf{invt}(b1, g1) \wedge \mathsf{invt}(b2, g1) \wedge \mathsf{invt}(b3, g1)$ is based on the function $f = [b1 \to g1, b2 \to g1, b3 \to g1]$. (See Xiang (2016: chap. 5) for a review.)

(33) a. $\llbracket$which boy invited which girl$\rrbracket_{\text{single-pair}}$
$$= \left\{ \begin{array}{lll} \mathsf{invt}(b1, g1), & \mathsf{invt}(b2, g1), & \mathsf{invt}(b3, g1), \\ \mathsf{invt}(b1, g2), & \mathsf{invt}(b2, g2), & \mathsf{invt}(b3, g2), \\ ... & & \end{array} \right\}$$

b. $[\![\text{which boy invited which girl}]\!]_{\text{pair-list}}$
$$= \left\{ \begin{array}{l} \textit{invt}(b1, g1) \wedge \textit{invt}(b2, g1) \wedge \textit{invt}(b3, g1) \\ \textit{invt}(b1, g1) \wedge \textit{invt}(b2, g2) \wedge \textit{invt}(b3, g1) \\ \ldots \end{array} \right\}$$

Compared with competing approaches, especially family-of-question approaches (Hagstrom 1998, Fox 2012, Nicolae 2013, Kotek 2014) which analyzes the single-pair reading of a multi-*wh* question as sets of proposition sets, Dayal's approach manages to keep the semantic type of multi-*wh* questions low (uniformly of type $\langle st, t\rangle$), and thus advantageously leaves space to tackle with more complex structures (such as *wh*-triangles, which have more than two *wh*-items).

However, Lahiri (2002) points out that the use of conjunction in deriving pair-list readings has unwelcome consequences in predicting QV effects. In (34), the quantification adverbial *mostly* in the matrix clause intuitively quantifies over the set of true propositions of the form 'boy x invited girl y'.

(34) Jenny mostly knows which boy invited which girl.
$\rightsquigarrow$ *For most p such that p is a true proposition of the form 'boy x invited girl y', Jenny knows p.*

To predict this QV inference, the atomic propositions must be kept alive and should not be mashed under conjunction — once two propositions are conjoined, there is no way to retrieve them back.[10]

In contrast, using categorial approaches, we can define the QV inferences easily. Treating the multi-*wh* question as a function from boy-girl pairs to propositions, analyses that follow categorial approaches can define the quantification domain of *mostly* as a set of boy-girl pairs and paragraph the QV inference as follows:

(35) Jenny mostly knows which boy invited which girl.
$\rightsquigarrow$ *For most boy-girl pairs $\langle x, y\rangle$ such that x invited y, Jenny knows that x invited y.*

3. Traditional categorial approaches and their problems

3.1. Assumptions of traditional categorial approaches

Traditional categorial approaches (Hausser and Zaefferer 1979; Hausser 1983, Von Stechow and Ede Zimmermann 1984, Guerzoni and Sharvit 2007, Ginzburg and Sag 2000, among others) define questions as λ-abstracts, as in (36), the *wh*-determiner as a λ-operator, as in (37a), and *wh*-phrases as functions from predicates to partial predicates, as in (37b-d).

(36) *Wh*-questions
a. $[\![\text{who came}]\!] = \lambda x_e \colon \textit{hmn}(x).\textit{came}(x)$
b. $[\![\text{who bought what}]\!] = \lambda x_e \lambda y_e \colon \textit{hmn}(x) \wedge \textit{thing}(y).\textit{bought}(x, y)$

(37) *Wh*-determiner and *wh*-phrases
a. $[\![\text{wh-}]\!] = \lambda A_{\langle e,t\rangle} \lambda P_{\langle e,t\rangle} \lambda x_e \colon A(x).P(x)$
b. $[\![\text{who}]\!] = \lambda P_{\langle e,t\rangle} \lambda x_e \colon \textit{hmn}(x).P(x)$

[10] In a colloquium talk at MIT, Dayal (2016) removes conjunctive closure and analyzes the root denotation of a multi-*wh* question as a family of proposition sets, in the same spirit of family-of question approaches. This revision manages to keep the atomic propositions alive, but sacrifices the advantage of keeping the semantic type of questions low.

c. $[\![\text{what}]\!] = \lambda P_{\langle e,t \rangle} \lambda x_e \colon \textit{thing}(x).P(x)$

d. $[\![\text{which student}]\!] = \lambda P_{\langle e,t \rangle} \lambda x_e \colon \textit{stdt}(x).P(x)$

Traditional categorial approaches do not attempt to derive the meaning of a question compositionally. But, by the assumed question denotations and *wh*-lexicons, single-*wh* question can be composed by standard functional application. As illustrated in (38), *who* moves to the specifier of CP. Applying *who* to a total predicate denoted by its sister node returns a partial predicate defined only for human individuals, which are simply possible short answers of this question. Since traditional categorial approaches are not interested in the extension/intension distinction, here the sister node of the *wh*-word is defined extensionally as a predicate.

(38) Who came?

CP
$\lambda x_e \colon \textit{hmn}(x).\textit{came}(x)$

- who
  $\lambda P_{\langle e,t \rangle} \lambda x_e \colon \textit{hmn}(x).P(x)$
- $\lambda x_e.\textit{came}(x)$
  - λx
  - IP
    - x came

3.2. Problems of traditional categorial approaches

In the recent studies of question semantics, categorial approaches are less commonly used than the alternative approaches (especially Hamblin-Karttunen Semantics) due to the their deficiencies in defining *wh*-indefinites and composing complex structures.

3.2.1. Problem 1: Bare *wh*-indefinites

First of all, defining the *wh*-determiner as a λ-operator, categorial approaches cannot account for the indefinite use of *wh*-expressions, especially for languages that use bare *wh*-words as indefinites.

Cross-linguistically, *wh*-words are often used to form indefinites, henceforth called *wh*-indefinites. As reported by Haspelmath (1997: pp. 174), 64 languages out of his 100-language sample have *wh*-indefinites. In principle, languages with *wh*-indefinites can be classified into the following four types, on the basis of the morphological forms of their *wh*-words in questions and existential statements:

Language type	Are *wh*-words morphologically marked in ...		Representatives
	... interrogatives?	... existential statements?	
I	No	Yes	Hebrew, Japanese
II	No	No	Dutch, Chuj
III	Yes	No	(unattested)
IV	Yes	Yes	(unattested)

Table 3: Language-type by morphological forms of *wh*-words in questions and existential statements

In reality, natural languages with *wh*-indefinites mostly fall into Type I and II. *Wh*-indefinites in Type

I languages are formed out of *wh*-words together with additional morphology, henceforth called "complex *wh*-indefinites", while those in Type II languages have a bare form, henceforth called "bare *wh*-indefinites". Type III and IV languages, where *wh*-words are morphologically complex when used in interrogatives, are unattested.[11]

Previous studies on the semantic relation between *wh*-words and *wh*-indefinites mostly draw on observations with complex *wh*-indefinites in Type I languages. For example, as seen in (39), Hebrew uses *mi* as 'who' and *ma* as 'what' in questions, but *mi-Sehu* as 'someone' and *ma-Sehu* as 'something' in existential statements. This affixation pattern is also found in Romanian, Bulgarian, Basque, and many other languages.

(39) Hebrew *mi* 'who' (Itai Bassi p.c.)

a. **Mi** ba?
who come
'Who is coming?'

b. **Mi-Sehu** ba.
who-SEHU come
'someone is coming.'

c. **Ma** hu mevi?
what he bring
'What is he bringing?'

d. Hu mevi **ma-Sehu**.
he bring what-SEHU
'he is bringing something.'

In some other languages with complex *wh*-indefinites, *wh*-questions need some extra morphology. For example, in Japanese, the *-ka* morpheme in *wh*-indefinites such as *dare-ka* is also presented in questions, as seen in (40b). But, here the *-ka* morpheme is not attached to the *wh*-word but rather to the entire interrogative CP. It is also used in polar questions, as in (40c). Hence, Japanese *wh*-words per se are morphologically unmarked in questions. See a uniform analysis of *-ka* in Uegaki (2018) and references therein.

(40) Japanese *dare* 'who' (Uegaki 2018: ex. 2 and ex. 34)

a. [$_{DP}$ **dare-ka**] -ga hashitta.
who-KA -NOM ran
'Someone ran.'

b. [$_{Q}$ **dare**-ga hashitta-**ka**] oshiete.
who-NOM ran-KA tell
'Tell me who ran.'

c. Hanako-ga hashitta-**ka**?
Hanako-NOM ran-KA
'Did Hanako come?'

For those complex *wh*-indefinites in Type I languages, it is plausible to attribute their existential meaning to operations external to the lexicons of the corresponding *wh*-words. A derivational path of *wh*-indefinites is as illustrated in Figure 2: an existential (Ex-)operator shifts a *wh*-words into an existential indefinite.

[11] The only known example of Type III languages is Esperanto, a constructed international auxiliary language created in the late 19th century. For example, Esperanto uses *kiu* and *kio* for 'who' and 'what' while *iu* and *io* for 'someone' and 'something'. Since Esperanto is not a natural language, it is not interesting to consider it in discussing the typology of *wh*-indefinites.

$$\begin{tikzcd} \textbf{Indefinites} \\ \textbf{\textit{Wh}-words} \arrow[u, "\text{Ex-operator}"] \end{tikzcd}$$

Figure 2: The derivation of complex *wh*-indefinites

For example, Bittner (1994) defines the root of a *wh*-phrase as a set-denoting item and derives its quantificational meaning via employing an $\exists$-quantifier, as schematized in (41). Alternatively, if *wh*-words are defined following categorial approaches, the derivation of complex *wh*-indefinites can be as in (42): a *wh*-expression denotes a function from total predicates to partial predicates, and is shifted into an existential quantifier via the application of an $\mathcal{E}$-operator.

(41) a. $[\![\text{who}]\!] = \textsf{\textit{hmn}}$
  b. $\exists = \lambda D \lambda P.\exists x \in D[P(x)]$
  c. $\exists([\![\text{who}]\!]) = \lambda P_{\langle e,t\rangle}.\exists x \in \textsf{\textit{hmn}}[P(x)]$

(42) a. $[\![\text{who}]\!] = \lambda P \lambda x\colon \textsf{\textit{hmn}}(x).P(x)$
  b. $\mathcal{E} = \lambda \pi_{\langle et,et\rangle} \lambda P_{\langle e,t\rangle}.\exists x \in \text{Dom}(\pi(P))[\pi(P)(x)]$
  c. $\mathcal{E}([\![\text{who}]\!]) = \lambda P_{\langle e,t\rangle}.\exists x \in \textsc{Dom}(\lambda x[\textsf{\textit{hmn}}(x).P(x)])[\textsf{\textit{hmn}}(x).P(x)]$
  $= \lambda P_{\langle e,t\rangle}.\exists x \in \textsf{\textit{hmn}}[P(x)]$

Other than defining *wh*-indefinites as generalized existential quantifiers, a similar line of thinking is to place the existential-closure at a clausal level. Representatives include Beck (2006), Shimoyama (2006), Kotek (2014), and Uegaki (2018). These works adopt Hamblin Semantics in defining and composing questions and sentences.

However, the indefinite use of *wh*-words in Type II languages shall be derived differently. In these languages, *wh*-words use a bare form in both interrogatives and existential statements. This language type is widespread in Haspelmath's 100-language sample. As Haspelmath (1997: chap. 7) reports, out of the studied 64 languages whose indefinites are morphologically similar to their *wh*-words, there are 31 languages whose *wh*-words use a bare form when functioning as indefinites in non-interrogative sentences. Moreover, based on an aggregate survey of approximately 150 languages, Gärtner (2009) compiled a list of 62 languages showing interrogative-vs-indefinite ambiguity. Since one of the goals in this paper is to unify the meaning and derivation of FRs and questions, it is particularly interesting to look at languages with both bare *wh*-indefinites and (definite) *wh*-FRs. Representatives include Dutch, German, Russian, Slovene, and Chuj.

(43) Dutch *wat* 'what'
  a. **Wat** heb je gegeten?
  what have you eaten
  'What have you eaten?'
  b. Je hebt **wat** gegeten.
  You have what eaten
  'You have eaten something.'

c. Ik heb gegeten [$_{\text{FR}}$ **wat** jij gekookt had].
I have eaten what you cooked had
'I have eaten what you cooked.'

(44) Chuj *mach* 'who' (Kotek and Erlewine 2018, to appear)

a. **Mach** ix-/ø-ulek'-i?
who PRFV-B3-come-ITV
'Who came?'

b. Ol-/ø-w-il **mach**.
PROSP-B3-A1s-see who
'I will see someone.'

c. Tato tz-/ø-/ø-il **mach**, /ø-/ø-al t'a hin.
if IMPF-B3-A2s-see who B3-A2-say PRFV B1s
'If you see someone, let me know.'

d. Ix-/ø-in-mak [$_{\text{FR}}$ **mach** ix-/ø-ulek'-i].
PRFV-B3-A1s-hit who PRFV-B3-come-ITV
Intended: 'I hit the person who came.'

Bare *wh*-indefinites in Type II languages pose a great challenge to traditional categorial approaches — "It is extremely unlikely that zero-grammaticalization should happen so often, and so systematically." (Haspelmath 1997: pp. 174) Hence, for these bare *wh*-indefinites, the existential meaning shall be part of their lexicons, not obtained by an additional type-shifting operation or the application of a covert operator. In other words, in languages with bare *wh*-indefinites, the interrogative meaning of a *wh*-word shall be essentially identical to the existential indefinite meaning. Definitions of *wh*-words proposed by traditional categorial approaches cannot capture this relation.

So far, we have discussed three *wh*-constructions: *wh*-questions, *wh*-FRs, and existential statements with *wh*-indefinites. The following summarizes the relationship of these three constructions and the involved *wh*-expressions:

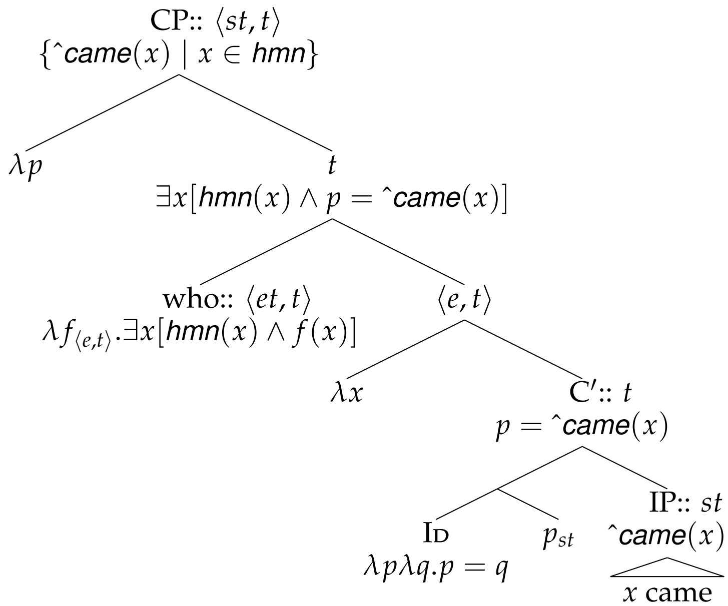
***Wh*-questions versus *wh*-FRs:** The similarities between *wh*-questions and *wh*-FRs in meaning (especially on the distribution of mention-some/existential readings) and Caponigro's Generalization on the distributional gap of *wh*-words suggest that *wh*-FRs are derivatives of *wh*-questions. This is a CP-level relation. To capture this relation, we shall define *wh*-questions as abstracts and hence pursue a categorial approach.

***Wh*-words versus bare *wh*-indefinites:** The morphological equivalence between *wh*-words in questions and bare *wh*-indefinites in existential statements suggests that *wh*-words shall be semantically equivalent to or close to *wh*-indefinites. This is a word-level relation. To capture this relation, for languages with bare *wh*-indefinites, we shall treat the existential meaning as part of the lexicon of a *wh*-word.

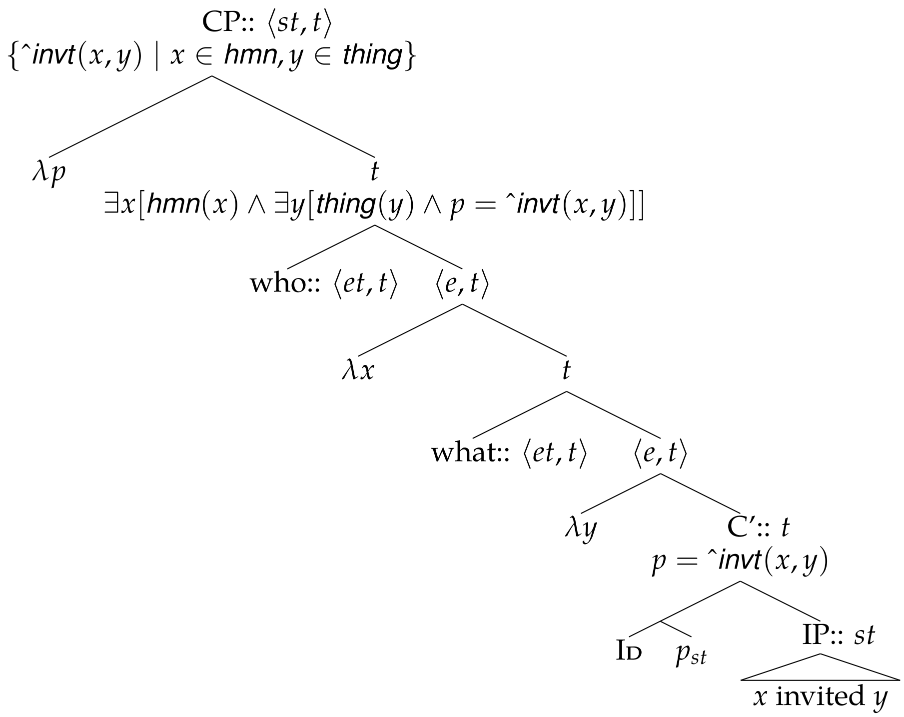
3.2.2. Problem 2: Composing multi-*wh* questions

As seen in (32) in section 2.2.2, multi-*wh* questions are ambiguous between single-pair readings and pair-list readings. While the derivation of a pair-list reading is known to be challenging, the composition of a single-pair reading is straightforward in most canonical approaches of question semantics. For example, for Heim (1995), who transports Karttunen Semantics into Government and Binding (GB-)style LFs, the compositions of the single-*wh* question (45) and the multi-*wh* question (46) proceed uniformly. In both derivations, the *wh*-words, which are defined as existential generalized quantifiers (of type $\langle et, t\rangle$), undertake *wh*-movement and combine with sister nodes of type $\langle e, t\rangle$ via Functional Application.

(45) Who came?



(46) Who bought what?



In categorial approaches, the composition of a single-*wh* question also involves *wh*-movement and Functional Application. In (47) (repeated from (38)), *who* moves to [Spec, CP], applies to a total predicate (of type $\langle e, t\rangle$) denoted by the remnant CP, and returns a partial predicate defined only for human individuals. However, it is difficult to extend this simple derivation to the composition of a multi-*wh* question. For example, the composition of the LF in (48) suffers type mismatch: the higher-*wh* *who* selects for an argument of type $\langle e, t\rangle$, while its sister node is of type $\langle e, et\rangle$. These two nodes cannot be combined via Functional Application or Predicate Modification. (See George 2011: §2.4.2 for a solution using *tuple types*.)

(47) Who came?

$$[_{\text{CP}: \lambda x_e[\mathit{hmn}(x).\mathit{came}(x)]}\ [\text{who}:: \langle et, et\rangle]\ [_{\lambda x_e.\mathit{came}(x)}\ \lambda x\ [_{\text{IP}}\ x \text{ came}]]]$$

(48) Who bought what?

$$[_{\text{CP}: \text{TYPE MISMATCH!}}\ [\text{who}:: \langle et, et\rangle]\ [_{\langle e, et\rangle}\ \lambda x\ [_{\langle e,t\rangle}\ [\text{what}:: \langle et, et\rangle]\ [_{\langle e,t\rangle}\ \lambda y\ [_{\text{IP}}\ x \text{ bought } y]]]]]$$

3.2.3. Problem 3: Coordinations of questions

Conjunction and disjunction are standardly defined as *meet* '$\sqcap$' and *join* '$\sqcup$', which operate on meanings of the same *conjoinable type* (also called *t-reducible type*) (Partee and Rooth 1983, Groenendijk and Stokhof 1989). (In the formalizations, the symbols '$\wedge$' and '$\vee$' are reserved for truth values, and A' stands for the interpretation of a syntactic expression A.)

(49) a. **Conjoinable types**

i. t is a conjoinable type.

ii. If τ is a conjoinable type, then $\langle \sigma, \tau \rangle$ is a conjoinable type for any type σ.

b. **Meet**

$$A' \sqcap B' = \begin{cases} A' \wedge B' & \text{if } A' \text{ and } B' \text{ are of type } t \\ \lambda x.A'(x) \sqcap B'(x) & \text{if } A' \text{ and } B' \text{ are of some other conjoinable type} \\ \text{undefined} & \text{otherwise} \end{cases}$$

c. **Join**

$$A' \sqcup B' = \begin{cases} A' \vee B' & \text{if } A' \text{ and } B' \text{ are of type } t \\ \lambda x.A'(x) \sqcup B'(x) & \text{if } A' \text{ and } B' \text{ are of some other conjoinable type} \\ \text{undefined} & \text{otherwise} \end{cases}$$

See the following expressions for simple illustration. An intransitive verb (of type $\langle e, t\rangle$) cannot be coordinated with a transitive verb (of type $\langle e, et\rangle$), as seen in (50a-b). A proper name *Jenny* (of type e) can be shifted into be of type $\langle et, t\rangle$ via Montague-lift and hence can be coordinated with a generalized quantifier *every student* (of type $\langle et, t\rangle$), as in (50c). But, it cannot be coordinated with a common noun such as *student* (of type $\langle e, t\rangle$) because proper names and common nouns are of different types regardless of the application of Montague-lift, as in (50d).

(50) a. jump and run — $\mathit{jump}_{\langle e,t\rangle} \sqcap \mathit{run}_{\langle e,t\rangle}$

b. * jump and look for — $\#\mathit{jump}_{\langle e,t\rangle} \sqcap \mathit{look\text{-}for}_{\langle e,et\rangle}$

c. Jenny and every student — $\textsc{Lift}(\mathit{Jenny})_{\langle et,t\rangle} \sqcap \mathit{every\ student}_{\langle et,t\rangle}$

d. * Jenny and student — $\#\textsc{Lift}(\mathit{Jenny})_{\langle et,t\rangle} \sqcap \mathit{stdt}_{\langle e,t\rangle}$

$\#\mathit{Jenny}_e \sqcap \mathit{stdt}_{\langle e,t\rangle}$

Assigning different semantic types to different questions, categorial approaches have difficulties in getting coordinations of question. As shown in (51), the single-*wh* question *who came* and the multi-*wh* question *who bought what* can be naturally conjoined or disjoined and embedded under an interrogative-embedding predicate. But, categorial approaches treat these two questions as of type $\langle e, t\rangle$ and $\langle e, et\rangle$, respectively. This treatment conflicts the standard view that only items of the same conjoinable type can be coordinated.

(51) a. John asked Mary [[who came] and/or [who bought what]].
b. John knows [[who came] and/or [who bought what]].

Moreover, even if the coordinated questions are of the same conjoinable type, traditional categorial approaches do not predict the correct reading. Consider the sentence in (52) for example. Categorial approaches define Q_1 as the set of individuals who voted for Andy, and Q_2 as the set of individuals who voted for Billy, as in (52a-b). By the standard definition of conjunction, the meet of these two sets is their intersection, namely, the set of individuals who voted for both Andy and Billy, as in (52c). In consequence, categorial approaches incorrectly predict (52) to mean that Jenny knows who voted for both Andy and Billy.[12]

(52) Jenny knows [$_{Q_1}$ who voted for Andy] and [$_{Q_2}$ who voted for Billy].

a. $[\![Q_1]\!] = \lambda x.\textsf{vote-for}(x, a)$
b. $[\![Q_2]\!] = \lambda x.\textsf{vote-for}(x, b)$
c. $[\![Q_1]\!] \sqcap [\![Q_2]\!] = (\lambda x.\textsf{vote-for}(x, a)) \sqcap (\lambda x.\textsf{vote-for}(x, b))$
$= (\lambda x.\textsf{vote-for}(x, a)) \wedge (\lambda x.\textsf{vote-for}(x, b))$
$= [\![\text{who voted for Andy and Billy}]\!]$

4. A hybrid categorial approach

Previous sections have presented motivations for pursing a categorial approaches and problems with traditional categorial approach. This section proposes a novel hybrid categorial approach to compose the semantics of *wh*-questions. This approach not only achieves the advantages of traditional categorial approaches in retrieving short answers but also overcomes their technical problems. I will firstly sketch out the basic components of this approach (§4.1) and next extend this approach to multi-*wh* questions with pair-list reading (§4.2). Discussions on coordinations of questions is postponed to section 6, because the solution applies to any categorial approach.

[12] Hamblin-Karttunen Semantics also has this problem: if questions are defined as proposition sets, and conjunction is treated standardly as meet, the conjunction of two questions would be analyzed as the intersection of two proposition sets. This prediction is clearly incorrect. For example, in (52), the two coordinated questions have no propositional answer in common. A common solution of this problem is to allow the conjunction to be applied point-wise, as defined in (i): a point-wise conjunction of two proposition sets returns a set of conjunctive propositions.

(i) **Point-wise conjunction $\cap_{\text{PW}}$**
Given two sets of propositions α and β, then $\alpha \cap_{\text{PW}} \beta = \{a \cap b \mid a \in \alpha, b \in \beta\}$

Inquisitive Semantics restores the standard treatment of conjunction. See details in Ciardelli et al. (2013), Ciardelli and Roelofsen (2015) and Ciardelli et al. (To appear).

4.1. Basics

To present a hybrid categorial approach, I begin by explaining how to define and compose simple *wh*-question (including single-*wh* questions and multi-*wh* questions with single-pair readings), and how to derive answers out of this question denotation. Discussions on these issues also address the problems with traditional categorial approaches in defining *wh*-words and composing multi-*wh* questions with single-pair readings.

4.1.1. Question denotation

I define the root denotation of a question as a *topical property*, namely, a λ-abstract ranging over propositions.[13] For example, the topical property of the question in (53) is a function that maps an atomic student *Jenny* to the proposition that *Jenny came*.

(53) Which student came? Jenny.

a. $\boldsymbol{P} = \lambda x\colon \mathit{stdt}_{@}(x) = 1.\hat{}\mathit{came}(x)$

b. $\boldsymbol{P}(j) = \hat{}\mathit{came}(j)$

Short answers, propositional answers, and partitions can be easily derived out of topical properties. Let $\boldsymbol{P}$ stand for a topical property. Short answers are elements in the domain of $\boldsymbol{P}$. Propositional answers are propositions obtained by applying $\boldsymbol{P}$ to its possible arguments. Partition is a relation between worlds such that the true short answers of this question are identical in these worlds.[14]

(54) Given a question Q with a topical property $\boldsymbol{P}$, we have:

a. Short answers of Q
$\mathrm{Dom}(\boldsymbol{P})$

b. Propositional answers of Q
$\{\boldsymbol{P}(\alpha) \mid \alpha \in \mathrm{Dom}(\boldsymbol{P})\}$

c. Partition of possible worlds of Q
$\lambda w \lambda w'.\boldsymbol{P}_w = \boldsymbol{P}_{w'}$, where $\boldsymbol{P}_w = \{\alpha \mid w \in \boldsymbol{P}(\alpha)\}$

For example, for the singular-marked question in (53), two worlds w and w' are in the same cell iff the very same set of atomic students came in w and w'. With two relevant students Jenny and Mary, the partition of (53) is illustrated as in Table 4. For instance, the first cell stands for the set of worlds where only Jenny and Mary came, or equivalently, where the true short answers of the question *which student came* include only the two atomic individuals *Jenny* and *Mary*.

---

[13] The term "topical property" was firstly used by Chierchia and Caponigro (2013) to describe the meaning of a *wh*-FR derived out of a question root. This way of calling something a 'property' is a bit unconventional. Standardly, property is a meaning of type $\langle s, et\rangle$, a function from possible worlds to predicates (viz., sets of entities).

[14] The partition can also be defined based on propositional answers or complete true answers. See section 4.1.3 for definitions of answerhood-operators $\textsc{Ans}$ and $\textsc{Ans}^S$.

(i) a. Defining partition based on true propositional answers
$\lambda w \lambda w'.Q_w = Q_{w'}$, where $Q_w = \{\boldsymbol{P}(\alpha) : \alpha \in \mathrm{Dom}(\boldsymbol{P}) \wedge w \in \boldsymbol{P}(\alpha)\}$

b. Defining partition based on complete true short answers
$\lambda w \lambda w'.\textsc{Ans}^S(\boldsymbol{P})w = \textsc{Ans}^S(\boldsymbol{P})w'$

c. Defining partition based on complete true propositional answers
$\lambda w \lambda w'.\textsc{Ans}(\boldsymbol{P})w = \textsc{Ans}(\boldsymbol{P})w'$

w: only j and m came in w		$=$	w: $\{\alpha \mid w \in \boldsymbol{P}(\alpha)\} = \{j, m\}$
w: only j came in w			w: $\{\alpha \mid w \in \boldsymbol{P}(\alpha)\} = \{j\}$
w: only m came in w			w: $\{\alpha \mid w \in \boldsymbol{P}(\alpha)\} = \{m\}$
w: nobody came in w			w: $\{\alpha \mid w \in \boldsymbol{P}(\alpha)\} = \varnothing$

Table 4: Partition for *which student came*

As such, any information that is derivable from the Hamblin set or the partition of a question is also derivable from the topical property of this question. Hence, defining questions as topical properties, we can still capture the objective of Hamblin-Karttunen Semantics in modeling the relationship between questions and propositional answers, as well as the objective of Partition Semantics in modeling world-dependency in question-embeddings.

4.1.2. Question composition

Observe in (53a) that the domain of the topical property $\boldsymbol{P}$ is equivalent to the extensional value of the *wh*-complement, namely, the set of atomic students in the actual world $\textit{stdt}_{@}$.[15] This domain can be extracted out of the *wh*-item as follows: first, following Karttunen (1977) and Heim (1995), I define *wh*-items as existential indefinites; next, I extract out the set $\textit{stdt}_{@}$ by applying the type-shifter Be (Partee 1986) to *which student*. As shown in the following, the type-shifter Be shifts an existential quantifier to its quantification domain:

(55) Extracting the domain of an $\exists$-quantifier

a. $[\![\text{which student}_{@}]\!] = \lambda f_{\langle e,t\rangle}.\exists x \in \textit{stdt}_{@}[f(x)]$ (To be revised in (79))

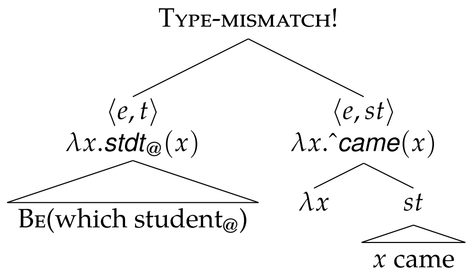
b. $\text{BE} = \lambda \mathcal{P} \lambda z.\mathcal{P}(\lambda y.y = z)$

c. $$\begin{aligned}\text{BE}([\![\text{which student}_{@}]\!]) &= \lambda z[(\lambda f_{\langle e,t\rangle}.\exists x \in \textit{stdt}_{@}[f(x)])(\lambda y.y = z)] \\ &= \lambda z.\exists x \in \textit{stdt}_{@}[(\lambda y.y = z)(x)] \\ &= \lambda z.\exists x \in \textit{stdt}_{@}[x = z] \\ &= \{z \mid z \in \textit{stdt}_{@}\} \\ &= \textit{stdt}_{@}\end{aligned}$$

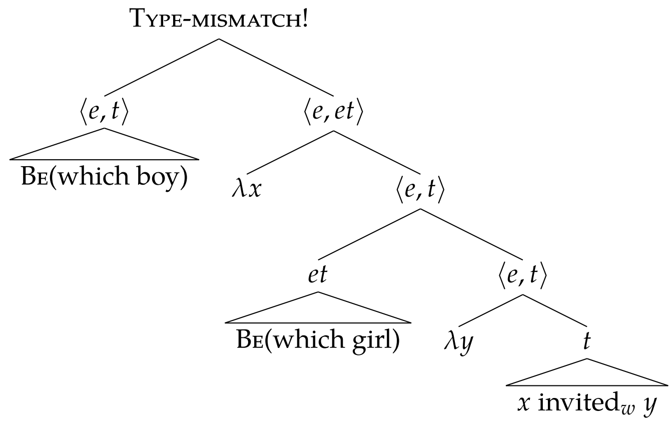
The next step is to combine the property domain $\text{BE}([\![\text{which student}_{@}]\!])$ with the nucleus given by the remnant CP (i.e., $\lambda x.{}^\wedge\textit{came}(x)$). An appealing way of thought would be to compose these two pieces via Predicate Modification (Heim and Kratzer 1998). Nevertheless, employing Predicate Modification suffers type mismatch. First, as shown in (56), 'Be(which student$_{@}$)' is extensional (of type $\langle e, t\rangle$) while its sister node is intensional (of type $\langle e, st\rangle$). Second, a more severe problem arises in deriving the single-pair reading of a multi-*wh* question. For example, even if we neglect the extension-vs.-intension mismatch, the composition in (57) still suffers type mismatch: 'Be(which student$_{@}$)' is of type $\langle e, t\rangle$, but its sister node is of type $\langle e, et\rangle$. The two nodes cannot be combined via Functional Application or Predicate Modification.

[15] The paper considers only *de re* readings, where the extensional value of a *wh*-complement is evaluated under the actual world @. See Sharvit (2002) for a simple treatment of *de dicto* readings.

(56) Which student came?



(57) Which boy invited which girl?



To incorporate the set BE(whP) into the domain of the topical property, I introduce a new type-shifter BEDOM. In semantics, BEDOM shifts a *wh*-item $\mathcal{P}$ (or any $\exists$-quantifier) into a *domain restrictor*. As schematized in (58), BEDOM($\mathcal{P}$) applies to a function θ and returns a similar function P with a more restrictive domain. In particular, the domain of the returned function P is filtered by the quantification domain of the *wh*-item/$\exists$-quantifier $\mathcal{P}$.

(58) **Type-shifter BEDOM**

$$\text{BEDOM}(\mathcal{P}) = \lambda\theta_\tau.\iota P_\tau[[\text{Dom}(P) = \text{Dom}(\theta) \cap \text{BE}(\mathcal{P})] \wedge \forall\alpha \in \text{Dom}(P)[P(\alpha) = \theta(\alpha)]]$$

See (59) for simple illustration. Assume that among the three relevant individuals *abc*, only *ab* are students. A *came*-function θ defined for any atomic or sum individual in the domain of discourse maps each such individual x to the proposition $\hat{}\textsf{came}(x)$. Applying the domain restrictor BEDOM(which student$_@$) to θ excludes the individuals that are not in the set BE(which student$_@$) (i.e., excludes the individuals that are not atomic students) from the domain, and retains the x-to-$\hat{}\textsf{came}(x)$ mapping for the remaining individuals. In consequence, this application returns a partial *came*-function defined only for atomic students.

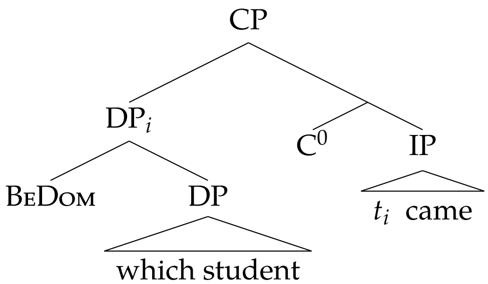
(59) (*Among the three relevant individuals abc, only ab are students in the actual world.*)

a. $$\theta = \begin{bmatrix} a \to \hat{}\textsf{came}(a), & a \oplus b \to \hat{}\textsf{came}(a \oplus b), & a \oplus b \oplus c \to \hat{}\textsf{came}(a \oplus b \oplus c) \\ b \to \hat{}\textsf{came}(b), & b \oplus c \to \hat{}\textsf{came}(b \oplus c), & \\ c \to \hat{}\textsf{came}(c), & a \oplus c \to \hat{}\textsf{came}(a \oplus c), & \end{bmatrix}$$

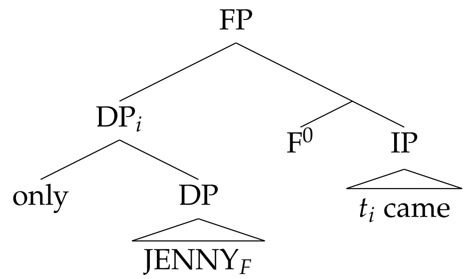
b. $$\text{BEDOM}(\textsf{which student}_@)(\theta) = \begin{bmatrix} a & \to & \hat{}\textsf{came}(a) \\ b & \to & \hat{}\textsf{came}(b) \end{bmatrix}$$

In syntax, BEDOM is a DP-adjunct. In (60), BEDOM adjoins to *which student* and moves together to [Spec, CP]. This movement is syntactically motivated to check off the [+*wh*] feature of *which student*. This movement resembles the DP-movement of '*only*+NP', as shown in (61): *only* is a DP-adjunct of $JENNY_F$; *only*-$JENNY_F$ as a whole moves to [Spec, FP] so as to check off the [+F] feature of $JENNY_F$.

(60) Which student came?

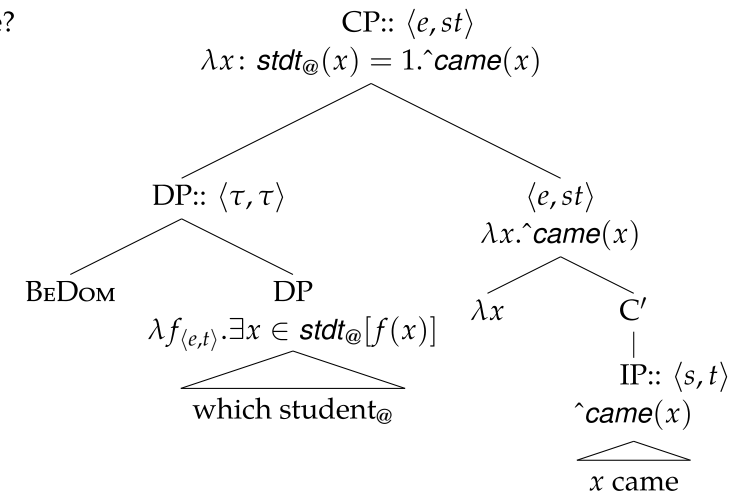


(61) Only JENNY$_F$ came.



To see how the computations of single-*wh* and multiple-*wh* questions work out in practice, consider (62) and (63). It can be nicely observed how the BeDom-shifter turns a *wh*-phrase into a polymorphic domain restrictor (of type $\langle \tau, \tau \rangle$, where τ stands for an arbitrary type): the output partial property P has the identical semantic type as the input property θ. In (62), 'BeDom(which student)' applies to a total *came*-property defined for any entities, and returns a partial *came*-property only defined for atomic students.

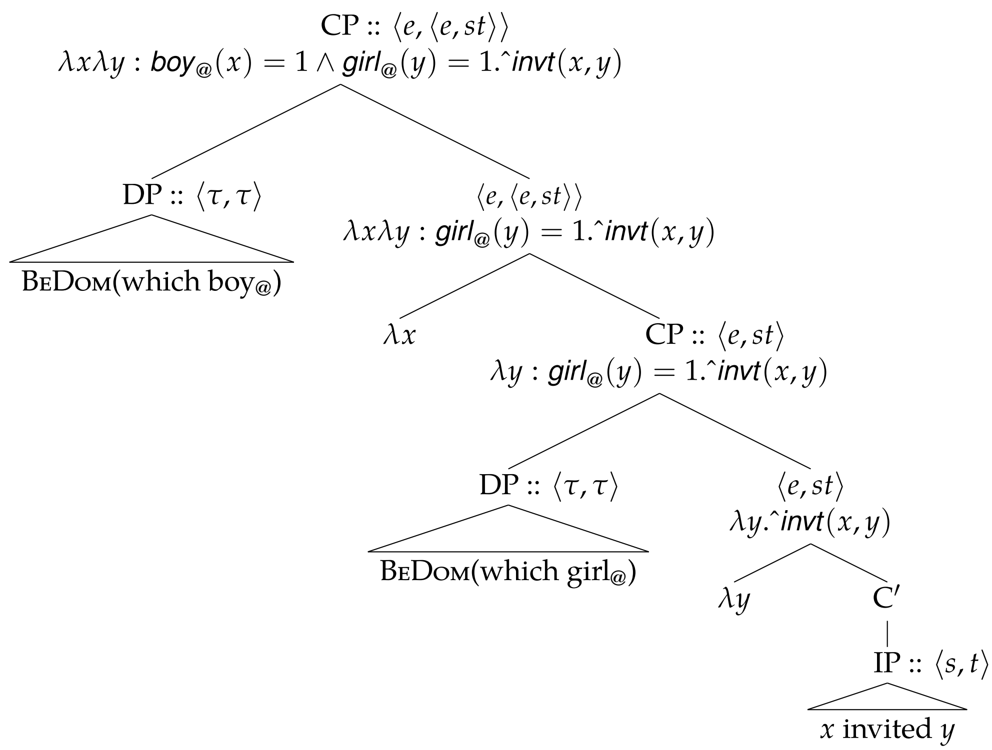
(62) Which student came?



Likewise, in (63), 'BeDom(which boy$_@$)' applies to a total function of type $\langle e, \langle e, st \rangle \rangle$, and returns a partial function of type $\langle e, \langle e, st \rangle \rangle$ defined only for atomic boys. Superior to traditional categorial approaches, since BeDom(*wh*P) can combine with expressions of any type, this way of composition does not suffer type mismatch.

(63) Which boy invited which girl? (Single-pair reading)

Option 1: Object-*wh* moves to [Spec, CP]



In the LF of a multi-*wh* question, the movement of the *wh*-object is semantically driven to avoid type-mismatch. It doesn't matter whether the *wh*-object moves to [Spec, CP] or [Spec, IP]. If adopting the view that only one *wh*-phrase can be moved to the spec of an interrogative CP, one can alternatively assume that 'BeDom(which girl)' moves covertly to the left edge of IP simply to avoid type-mismatch, as shown in (64).[16]

[16] Haoze Li (pers. comm.) points out a technical problem of the composition in (64): the shifted *wh*-object can stay in-situ, because it is a flexible domain restrictor which can combine with functions of any type. In the following structure, the domain restrictor [BeDom (which girl)] applies to the two-place predicate *invited* and returns a two-place predicate.

(i) $[_{\mathrm{CP}}\ [_{\mathrm{DP}::\langle\tau,\tau\rangle}$ BeDom (which boy)] $\lambda z\ [_{\mathrm{IP}}\ z\ [_{\mathrm{VP}}$ invited $[_{\mathrm{DP}::\langle\tau,\tau\rangle}$ BeDom (which girl)]]

This structure yields an undesired interpretation: both *wh*-phrases restrict the domain of the object argument.

(ii) a. $[\![\mathrm{VP}]\!] = [\![\textsc{BeDom}(\text{which girl})]\!]([\![\text{invited}]\!]) = \lambda y \lambda x : \textsf{girl}_{@}(y).\textsf{invt}(x, y)$
b. $[\![\mathrm{IP}]\!] = [\![\mathrm{VP}]\!](z) = \lambda x : \textsf{girl}_{@}(z).\textsf{invt}(x, z)$
c. $[\![\mathrm{CP}]\!] = \lambda z \lambda x : \textsf{boy}_{@}(z) \wedge \textsf{girl}_{@}(z).\textsf{invt}(x, z)$

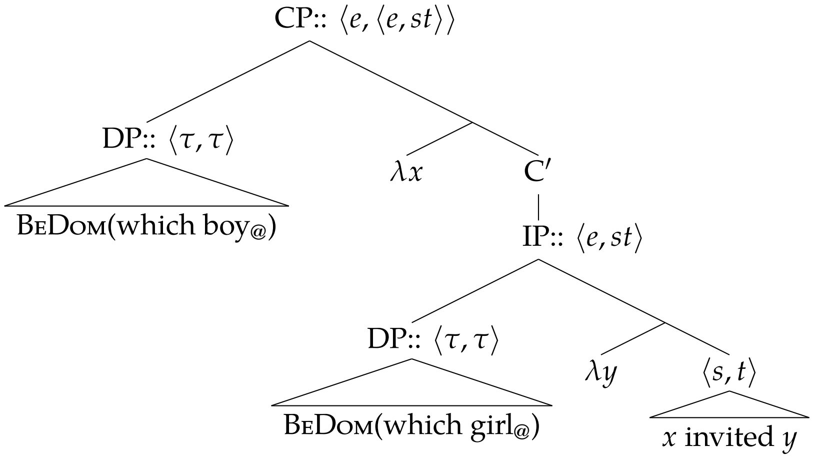
One solution to this problem is to assume that the BeDom-operators are applied after the movement of the *wh*-phrases.

(iii) Step 1: Movement $[_{\mathrm{CP}}$ which-boy$_i$ $[_{\mathrm{IP}}$ which-girl$_j$ [t_i invited t_j]]]
Step 2: Applying BeDom-shifting $[_{\mathrm{CP}}$ BeDom(which-boy$_i$) $[_{\mathrm{IP}}$ BeDom(which-girl$_j$) [t_i invited t_j]]]

The other solution is to apply a type-shifter (written as 'Shift') to the two-place predicate (cf. the type-shifter for argument raising from Hendriks (1993)), as illustrated in the following:

(iv) $[_{\mathrm{CP}}\ [_{\mathrm{DP}}$ BeDom (which boy)] $\lambda x\ [_{\mathrm{IP}}\ x\ [_{\mathrm{VP}}$ [Shift invited] $[_{\mathrm{DP}}$ BeDom (which girl)]]]
a. $[\![\textsc{Shift}]\!] = \lambda V_{\langle e,et\rangle} \lambda f_{\langle\tau,\tau\rangle} \lambda x_e.f(\lambda y_e.V(x, y))$
b. $[\![\textsc{Shift}(\text{invited})]\!] = \lambda f_{\langle\tau,\tau\rangle} \lambda x_e.f(\lambda y_e.\textsf{invt}(x, y))$
c. $[\![\mathrm{VP}]\!] = \lambda x_e \lambda y_e : \textsf{girl}_{@}(y).\textsf{invt}(x, y)$
d. $[\![\mathrm{CP}]\!] = \lambda x_e \lambda y_e : \textsf{boy}_{@}(x) \wedge \textsf{girl}_{@}(y).\textsf{invt}(x, y)$

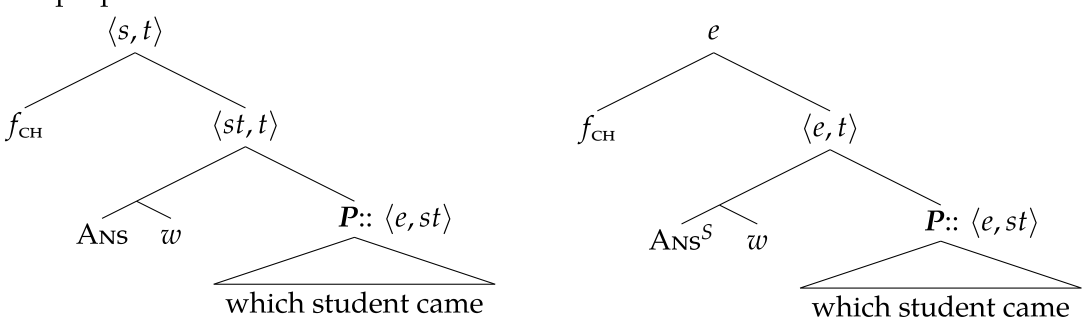
(64) **Option 2:** Object-*wh* moves to [Spec, IP]



4.1.3. Answerhood

The topical property of a question directly enters into an answerhood-operation, returning a set of complete true answers. These answers can be propositional or nominal/short, depending on whether the employed answerhood-operator is Ans or Ans^S (the superscript 'S' stands for 'short'). Finally, a choice function f_{CH} is applied to pick out one of these complete true answers. If a question has only one complete true answer, the output set of employing Ans is a singleton set, and employing f_{CH} returns the unique member of this set. The derivational procedures of the answers are illustrated as follows. Note that here the Ans/Ans^S -operator and f_{CH}-function are not necessarily syntactically presented in the LF. They can be incorporated into an interpretation rule (for matrix questions) or the lexicon of a question-embedding predicate (for embedded questions).

(65) a. For propositional answers b. For short answers



An important feature of the proposed framework is that the procedure of question formation has no stage that creates a Hamblin set or a Karttunen set. Instead, answerhood-operators directly operate on the topical property and hence they can access any information that is retrievable from the topical property, especially the property domain (or equivalently, the possible short answers). This consequence makes the proposed analysis significantly different from George (2011) and a recent analysis by Champollion et al. (2015) using Inquisitive Semantics. The latter two analyses also start with a λ-abstract, but then use a question-formation operator to convert this abstract into a partition or a Hamblin set. In these two proposals, an answerhood-operator or any operation outside a question cannot interact with the domain of the λ-abstract.

In defining complete true answers, I adopt Fox's (2013) view that complete answers can be non-exhaustive, and that a question can have multiple complete true answers. Compared with the more commonly adopted answerhood-operators which require complete answers to be exhaustive (Heim 1994; Dayal 1996), Fox's answerhood-operator leaves space for getting mention-some readings of questions. To see what it means by "mention-some", compare the following two questions:

(66) Who went to the party?
(*w*: *Only John and Mary went to the party.*)
  a. John and Mary.
  b. John did .../ $\rightsquigarrow$ *I don't know who else did.*
     L H* L-H%
  c. # John did.\ $\rightsquigarrow$ *Only John did.*
     H* L-L%

(67) Who can chair the committee?
(*w*: *Only John and Mary can chair; single-chair only.*)
  a. John can.\ $\not\rightsquigarrow$ *Only John can chair.*
  b. John and Mary.\
  c. John or Mary.\

The simple question in (66) requires the addressee to specify all the actual attendants to the party, as in (66a). If the addressee can only provide a non-exhaustive answer, she would have to indicate the incompleteness of her answer in some way, such as marking the answer with a prosodic rise-fall-rise contour (indicated by '.../'), as in (66b). If an incomplete answer is not properly marked, as in (66c) which takes a falling tone (indicated by '\'), it gives rise to an undesired exhaustive inference. In contrast, the $\Diamond$-questions (67) admits non-exhaustive answers (Groenendijk and Stokhof 1984) — it can be naturally answered by specifying one of the chair candidates, as in (67a). Crucially, while being non-exhaustive, the answer (67a) does not need to carry an ignorance mark: it does not yield an exhaustivity inference even if taking a falling tone. To distinguish answers like (67a) from other non-exhaustive answers, we call (67a) a "mention-some answer", questions that admit mention-some answers "mention-some questions", and readings under which a question admits mention-some answers "mention-some readings".

A proper treatment of mention-some is crucial to the issues concerned in this paper, because the mention-some/mention-all contrast is systematically observed in *wh*-constructions with predicative or nominal interpretations. For example, in (68), a *wh*-FR takes an existential reading iff its interrogative counterpart is mention-some. Likewise, as exemplified in (69), a Mandarin *wh*-conditional — a construction consisting of two *wh*-clauses and expressing an inclusion relation between the short answers of the interrogative counterparts of these two clauses — takes an existential reading iff the form of the antecedent *wh*-clause resembles a mention-some question. Using a categorial approach, once we understand the constraints in distributing mention-some reading of matrix questions, we can easily explain the distribution of existential readings in these predicative/nominal constructions. I will return to the derivations of their interpretations in section 5.1.

(68) **Free relatives**
  a. John ate what Mary cooked for him.
     $\rightsquigarrow$ *John ate* ***everything*** *that Mary cooked for him.*

b. John went to where he could get help.
   ⇝ *John went to **some** place where he could get help.*

(69) **Mandarin *wh*-conditionals**

a. Ni qu-guo nar, wo jiu qu nar.
   you go-EXP where, I JIU go where
   'Where you have been to, I will go where.'
   Intended: 'I will go to **every** place where you have been to.'

b. Nar neng mai-dao jiu, wo jiu qu nar.
   where can buy-reach liquor, I JIU go where
   'Where I can buy liquor, I will go where.'
   Intended: 'I will go to **some** place where I can buy liquor.'

Fox (2013) proposes that a true answer of a question is complete as long as it is not asymmetrically entailed by any true answers of this question. Following Hamblin-Karttunen Semantics and defining question root as a Hamblin set (written as 'Q'), Fox defines the answerhood-operator as in (70):

(70) $\textsc{Ans}_{Fox}(Q)(w) = \{p \mid w \in p \in Q \wedge \forall q[w \in q \in Q \rightarrow q \not\subset p]\}$ (Fox 2013)
($\{p \mid p$ is a true proposition in Q, and p is not asymmetrically entailed by any true propositions in $Q\}$)

When the concerned question takes a mention-some reading, $\textsc{Ans}(Q)(w)$ consists of multiple true mention-some answers of this question, otherwise it is a singleton set consisting of only the strongest true answer of this question. Due to the scope of this paper and the complexities of deriving mention-some readings, I will not dive into the details. See Xiang (2016: chap. 3) for a review of Fox (2013) and a new explanation to the mention-some/mention-all ambiguity compatible Fox's definition of answerhood. Here the following are the predicted complete true answers for the questions in (66) and (67) following Fox (2013) and Xiang (2016: chap. 3):

(71) a. For the mention-all question (66) :
   $\textsc{Ans}_{Fox}(Q)(w) = \{$John and Mary went to the party$\}$

b. For the ◇-question (67) with a mention-some reading:
   $\textsc{Ans}_{Fox}(Q)(w) = \{$John alone can chair the committee, Mary alone can chair the committee$\}$

Adapting Fox's answerhood-operator to the proposed hybrid categorial approach, I define the answerhood-operators as follows. The major revision is replacing a Hamblin set Q with a topical property $\boldsymbol{P}$, which can supply both propositional answers and short answers.

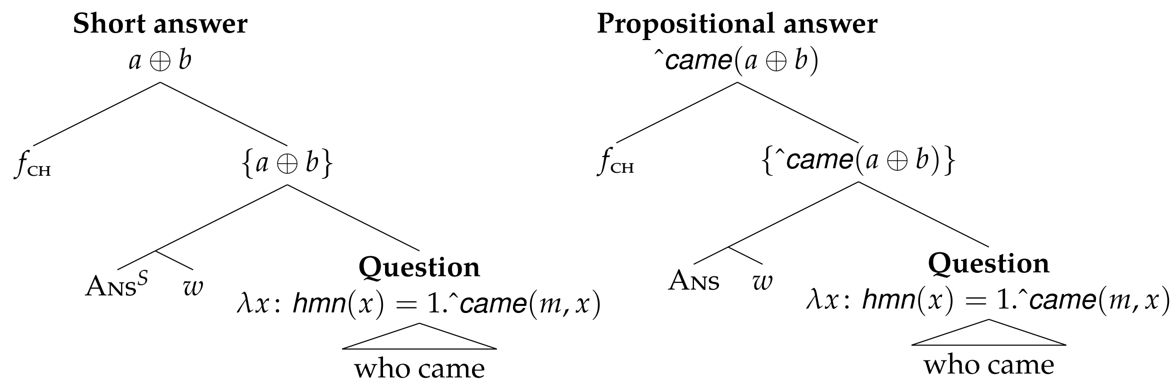
(72) **Answerhood-operators**

a. For short answers
   $\textsc{Ans}^S(\boldsymbol{P})(w) = \{\alpha \mid \alpha \in \mathrm{Dom}(\boldsymbol{P}) \wedge w \in \boldsymbol{P}(\alpha) \wedge \forall \beta \in \mathrm{Dom}(\boldsymbol{P})[w \in \boldsymbol{P}(\beta) \rightarrow \boldsymbol{P}(\beta) \not\subset \boldsymbol{P}(\alpha)]\}$

b. For propositional answers
   $\textsc{Ans}(\boldsymbol{P})(w) = \{\boldsymbol{P}(\alpha) \mid \alpha \in \textsc{Ans}^S(\boldsymbol{P})(w)\}$

Trees in (73) exemplify the applications of $\textsc{Ans}$ and $\textsc{Ans}^S$ to single-*wh* questions. Again, the trees are to illustrate the derivations of answers, not the LFs of matrix questions. The answerhood-operators and choice functions are semantically active but not syntactically present.

(73) (w: *Only Andy and Billy came.*)



Next, let's turn to multi-*wh* questions with single-pair readings. Strictly speaking, the derived root denotation $\boldsymbol{P}$ in (74a) is not a property: it is a function from atomic boys to a property of atomic girls. Moreover, its domain is not a set of short answers, and its range is not a set of propositional answers. Then, how can we derive answers from this $\boldsymbol{P}$? The simplest solution that I have seen so far is to make use of *tuple types*, an idea developed by George (2011: Appendix A). George writes an n-ary sequence as $(x_1; x_2; ...; x_n)$ which takes a tuple type $(\tau_1; \tau_2; ...; \tau_n)$, and then equivocates between the type $\langle \tau_1 \langle \tau_2 \langle ... \langle \tau_n, \sigma \rangle, ... \rangle$ and with the type $\langle (\tau_1; \tau_2; ...; \tau_n), \sigma \rangle$. For instance, $\langle e, \langle e, st \rangle \rangle$ equals to $\langle (e; e), st \rangle$. Following this idea, we can consider the abstract $\boldsymbol{P}$ in (74a) as a property of duple-sequences from an atomic boy to an atomic girl and write its domain as (74b-i). Then answerhood-operations proceed regularly.

(74) Which boy invited which girl?
(w: *John invited only Mary; no other boy invited any girl.*)

a. Topical property
$\boldsymbol{P} = \lambda x \lambda y : \mathit{boy}_{@}(x) = 1 \wedge \mathit{girl}_{@}(y) = 1.\hat{}\mathit{invt}(x, y)$

b. Possible short answers and complete true short answers
   i. $\text{Dom}(\boldsymbol{P}) = \{(x; y) \mid x \in \mathit{boy}_{@}, y \in \mathit{girl}_{@}\}$
   ii. $\text{Ans}^S(\boldsymbol{P})(w) = \{(j; m)\}$

c. Possible propositional answers and complete true propositional answers
   i. $\{\boldsymbol{P}(\alpha) \mid \alpha \in \text{Dom}(\boldsymbol{P})\} = \{\hat{}\mathit{invt}(x, y) \mid x \in \mathit{boy}_{@}, y \in \mathit{girl}_{@}\}$
   ii. $\text{Ans}(\boldsymbol{P})(w) = \{\hat{}\mathit{invt}(j, m)\}$

4.2. Multi-*wh* questions with pair-list readings

Traditional categorial approaches didn't make an attempt to derive pair-list readings of multi-*wh* questions. This section presents a function-based approach to pair-list readings.

Function-based approaches of question semantics were firstly proposed to deal with pair-list readings of questions with a universal quantifier ($\forall$-questions henceforth), and then were extended to multi-*wh* questions. (Engdahl 1980, 1986; Groenendijk and Stokhof 1984; Chierchia 1993; Dayal 1996, 2017) The following examples illustrate individual readings and basic functional readings in single-*wh* questions and $\forall$-questions. Individual readings specify a specific individual, while functional readings specify a function defined for the subject-DP (e.g., *Andy*) or individuals in the domain of the subject-quantifier (e.g., individuals in the domain of *every boy*).

(75) Which girl did Andy/ every boy invite?

   a. Mary. (Individual answer)

   b. His girlfriend. (Functional answer)

Dayal (1996, 2017) argues that pair-list answers to multi-*wh* questions involve a functional dependency between the quantification domains of the *wh*-items. For instance, the pair-list reading of (76) asks about a function **f** from atomic boys to atomic girls such that each boy x invited a girl $\mathbf{f}(x)$, as illustrated in (77).[17] To specify this function, one needs to list all the boy-invite-girl pairs, which is therefore a pair-list answer.

(76) Which boy invited which girl?
$\approx$ 'For which function **f** from $\textsf{\textit{boy}}_@$ to $\textsf{\textit{girl}}_@$ is such that x invited $\mathbf{f}(x)$?'

(77) (*w*: *Andy invited Mary, Billy invited Jenny, Clark invited Sue; no other boy invited any girl.*)

$$\mathbf{f} = \begin{bmatrix} a & \rightarrow & m \\ b & \rightarrow & j \\ c & \rightarrow & s \end{bmatrix}$$

Adopting this idea, I treat pair-list readings of multi-*wh* questions as special functional readings. This section will firstly discuss the derivation of a basic functional reading by assuming a richer *wh*-lexicon, and then show the composition of pair-list readings of multi-*wh* questions.[18]

4.2.1. Functional readings and lexicons of *wh*-items

In section 4.1.2, I defined a *wh*-phrase as an existential indefinite quantifying over the extension of its NP-complement, repeated in the following:

(78) $[\![\text{which student}_@]\!] = \lambda f_{\langle e,t\rangle}.\exists x \in \textsf{\textit{stdt}}_@[f(x)]$

To derive functional readings, I propose that the quantification domain of a *wh*-phrase '*wh*-A' is polymorphic — it consists of not only individuals in the extension of the NP-complement A, but also functions ranging over A.[19]

[17] Dayal (1996, 2002, 2017) claims that multi-*wh* questions with pair-list readings are subject to domain exhaustivity — (76) presupposes that every considered boy invited some girl. I argue that such domain exhaustivity is involved in questions with universal quantifiers, but not in multi-*wh* questions. Compare the following two sentences. Under the given context, where the quantification domain of the subject-*wh*/quantifier is greatly larger than that of the object-*wh*. The contrast between (ia-b) shows that the multi-*wh* question in (ia) is not subject to domain exhaustivity, or at least that its domain exhaustivity effect, if any, is much less robust than that of the ∀-question in (ib).

(i) (Context: *100 candidates are competing for three jobs.*)

   a. $\surd$ "Guess which candidate will get which job."

   b. # "Guess which job will every candidate get."

[18] I will not discuss pair-list readings in questions with quantifiers, since they involve further complications. See Xiang (2016: chap. 6), Dayal (2017: chap. 4), and Ciardelli and Roelofsen (2018) for recent overviews.

[19] The quantification domain of a number-neutral or plural-marked *wh*-phrase also contains generalized boolean disjunctions (Spector 2007, 2008; Fox 2013) and conjunctions (Xiang 2016: section 1.6). As such, we expect that the

(79) **Lexical entries of *wh*-items** (Revised definition)

a. $[\![\text{which}]\!] = \lambda A \lambda P. \exists x \in A \cup \{\mathbf{f} \mid \text{Range}(\mathbf{f}) \subseteq A\}[P(x)]$

b. $\textsc{Be}([\![\text{which } A]\!]) = A \cup \{\mathbf{f} \mid \text{Range}(\mathbf{f}) \subseteq A\}$

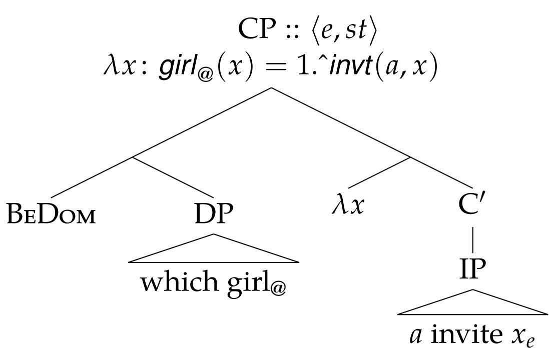
c. $\textsc{Be}([\![\text{which girl}_@]\!]) = \textsf{\textit{girl}}_@ \cup \{\mathbf{f} \mid \text{Range}(\mathbf{f}) \subseteq \textsf{\textit{girl}}_@\}$

In a *wh*-question, the semantic type of the topical property is determined by the highest *wh*-trace, as shown in (80). If the *wh*-item moves directly from the insitu position and leaves only an individual trace, the obtained topical property is a property of individuals, yielding an individual reading. Likewise, if the movement of a *wh*-item leaves a functional trace, the obtained topical property is a property over functions.[20]

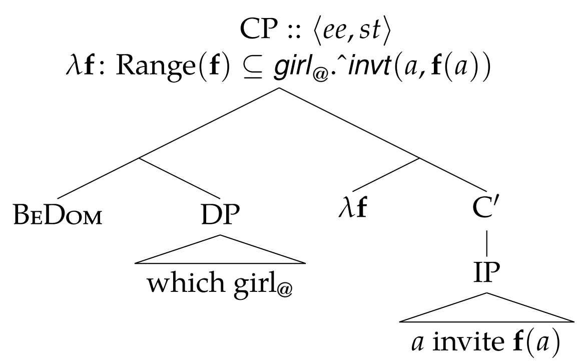
(80) Which girl did Andy invite?

a. Individual reading: 'Which girl x is such that Andy invited x?'

b. Functional reading: 'Which function to $\textsf{\textit{girl}}_@$ is such that Andy invited $\textsf{\textit{f}}(\textsf{\textit{Andy}})$?'



(Individual reading)



(Functional reading)

4.2.2. Deriving pair-list readings

Let's return to the composition of multi-*wh* questions with pair-list readings. The following tree illustrates the derivation of a root denotation:

(81) Which boy invited which girl?

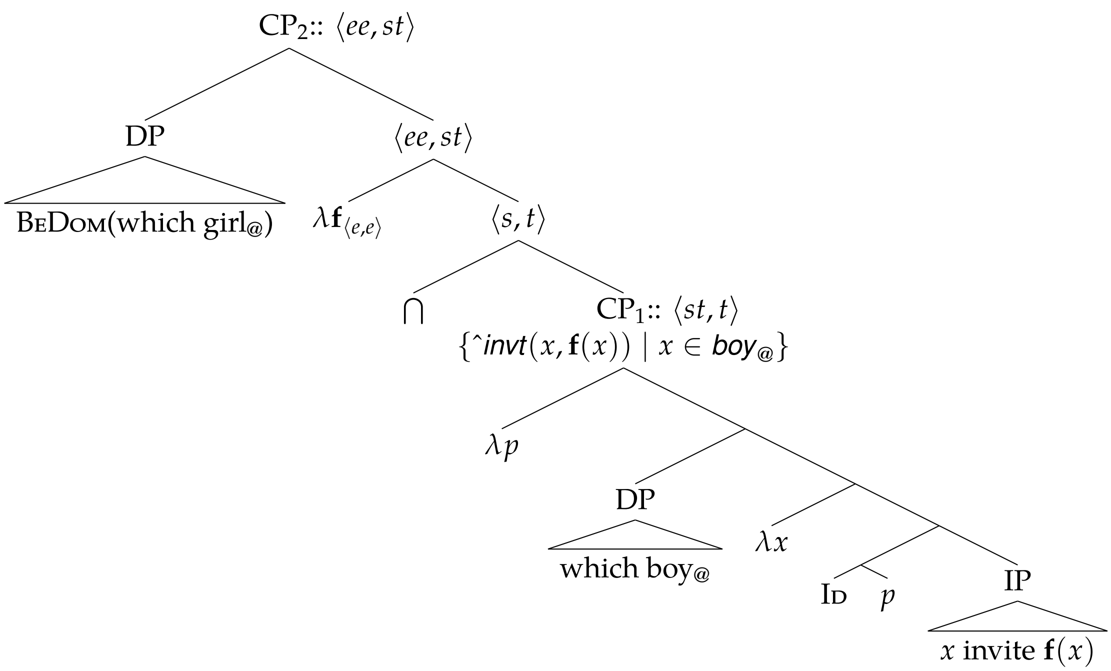
---

domain of such a *wh*-item contains also functions to generalized boolean disjunctions/conjunctions, or boolean disjunctions/conjunctions of functions. For example in (i), the disjunction in the short answer is interpreted under the necessity modal *have to*. This reading requires the (highest) *wh*-trace to be a generalized quantifier over functions (or functions to generalized quantifiers).

(i) Speaker A: 'Who does Andy have to invite?'
Speaker B: 'His mother or sister. [The choice is up to him.]'

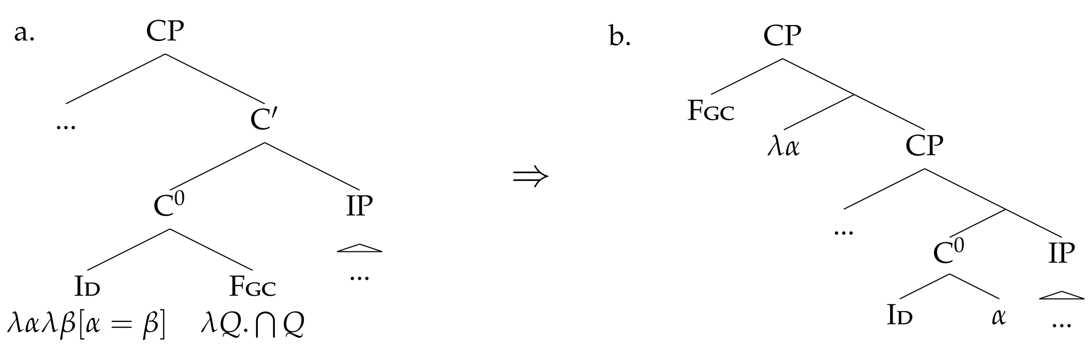
[20] More accurately, a functional answer has an intensional meaning (of type $\langle e, se \rangle$. It denotes a function from individuals to individual concepts. A more precise schematization for the topical property of a functional reading is as follows:

(i) $\boldsymbol{P} = \lambda \mathbf{f}_{\langle e,se \rangle} : \forall x \forall w[\mathbf{f}(x)(w) \in \textsf{\textit{girl}}_@].\lambda w[\textsf{\textit{invt}}_w(a, \mathbf{f}_w(a))]$



This LF involves two layers of interrogative CPs. The embedded CP_1 denotes a set of propositions (roughly, the Hamblin set of the single-*wh* question "which boy x invited $\mathbf{f}(x)$?"), compositionally derived based on the regular GB-transformed LF for Karttunen Semantics (see (45) in §3.2.2). This proposition set is immediately closed by a $\bigcap$-closure, returning a conjunctive proposition. This $\bigcap$-closure can be considered as a *function graph creator* (Fgc) in the sense of Dayal (2017). Accordingly, the abstraction of the first argument of Id is due to a type-driven movement of the Fgc-operator:

(82) **The movement of the Fgc-operator**
The Id function requires its two arguments to be of the same semantic type. Since IP denoting a proposition, interpreting Fgc insitu yields type-mismatch. Hence, Fgc moves to the left edge of CP and leaves a trace of type $\langle s, t \rangle$.



Next, moving the object-*wh* 'BeDom(which girl)' to [Spec, CP_2] leaves a functional trace within IP and forms a property of functions, just like what we saw with the basic functional reading in (80a). This topical property, as schematized in (83b), is defined for functions ranging over atomic girls, and it maps each such function to a conjunctive proposition that spells out the graph of this function. Note that here $\boldsymbol{P}$ restricts the range of $\mathbf{f}$, but not the domain of $\mathbf{f}$; in other words, any function mapping to $girl_@$ counts a possible "short" answer of this question. Applying $\boldsymbol{P}$ to each of those functions point-wise returns the set of possible propositional answers, as list in (83b).[21] Finally, as in (83c), applying an Ans-operator and Ans^S-operator to the topical property returns a singleton set containing the pair-list answer and the singleton set containing the corresponding boy-to-girl function, respectively.

(83) Which boy invited which girl? (Pair-list reading)

a. Root denotation of the multi-*wh* question

$$\begin{aligned}\boldsymbol{P} &= \iota P[\text{Dom}(P) = \{\mathbf{f} \mid \text{Range}(\mathbf{f}) \subseteq \textit{girl}_@\} \wedge \forall\alpha \in \text{Dom}(P)[P(\alpha) = \bigcap[\![\text{CP}_1]\!]]] \\ &= \iota P[\text{Dom}(P) = \{\mathbf{f} \mid \text{Range}(\mathbf{f}) \subseteq \textit{girl}_@\} \wedge \\ &\qquad\qquad \forall\alpha \in \text{Dom}(P)[P(\alpha) = \bigcap\{{}^\wedge\textit{invt}(x, \alpha(x)) \mid x \in \textit{boy}_@\}]] \\ &= \lambda\mathbf{f}\colon \text{Range}(\mathbf{f}) \subseteq \textit{girl}_@ . \bigcap\{{}^\wedge\textit{invt}(x, \mathbf{f}(x)) \mid x \in \textit{boy}_@\}\end{aligned}$$

b. Possible propositional answers

$$\begin{aligned}\{\boldsymbol{P}(\mathbf{f}) \mid \mathbf{f} \in \text{Dom}(\boldsymbol{P})\} &= \left\{ \bigcap\{{}^\wedge\textit{invt}(x, \mathbf{f}(x)) \mid x \in \textit{boy}_@\} \mid \text{Range}(\mathbf{f}) \subseteq \textit{girl}_@ \right\} \\ &= \left\{ \begin{array}{ll} {}^\wedge\textit{invt}(a, m) & {}^\wedge\textit{invt}(a, m) \cap {}^\wedge\textit{invt}(b, m) \\ {}^\wedge\textit{invt}(a, j) & {}^\wedge\textit{invt}(a, m) \cap {}^\wedge\textit{invt}(b, j) \\ {}^\wedge\textit{invt}(b, m) & {}^\wedge\textit{invt}(a, j) \cap {}^\wedge\textit{invt}(b, m) \\ {}^\wedge\textit{invt}(b, j) & {}^\wedge\textit{invt}(a, j) \cap {}^\wedge\textit{invt}(b, j) \end{array} \right\}\end{aligned}$$

c. Complete true answers

(w: *Andy invited Mary, Billy invited Jenny; no other boy invited any girl.*)

i. $\text{Ans}(\boldsymbol{P})(w) = \{{}^\wedge\textit{invt}(a, m) \cap {}^\wedge\textit{invt}(b, j)\}$

ii. $\text{Ans}^S(\boldsymbol{P})(w) = \left[\begin{array}{c} a \to m \\ b \to j \end{array} \right]$

4.3. Interim summary

The following summarizes the major ingredients of the proposed hybrid categorial approach.

First, the root denotation of a question is cross-linguistically a topical property. In languages with bare *wh*-indefinites, this root denotation is derived as follows: (i) *wh*-phrases are existential quantifiers, but can be shifted into polymorphic domain restrictors via the application of a BeDom-operator; (ii) moving BeDom(*wh*P) to [Spec, CP] yields a partial property that is defined for only elements in the quantification domain of the *wh*-phrase.

Second, an answerhood-operator, which might be encoded within an interpretation rule or a question-embedding predicate, directly operates on the topical property and returns a set of complete true answers. The returned answers can be nominal or propositional, depending on the employed answerhood-operator. In particular, answerhood is defined following Fox (2013), which allows mention-some answers to be complete answers.

Last, pair-list readings of multi-*wh* questions are special functional readings. In the derivation, the movement of the object-*wh* leaves a functional trace, whose argument is bound by the subject-*wh*. The obtained question denotation is a property for functions from a subset of the subject-*wh* domain to the object-*wh* domain.

[21] As a function, **f** maps every item in its domain to one and only one girl. Hence, there is no possible answer of the form ${}^\wedge\textit{invt}(a, m) \cap {}^\wedge\textit{invt}(a, j)$.

5. Advantages

Defining a question as a topical property, the proposed hybrid categorial approach can easily retrieve the short answers of the embedded question. This section responses to the two new arguments for pursing categorial approaches introduced in section 2.2. I will show a simple derivation of *wh*-FRs (§5.1.1) and extend the discussion to Mandarin *wh*-conditionals (§5.1.2). Next, I will explain how to account for QV effects using the hybrid categorial approach (§5.2).

5.1. *Wh*-constructions with predicative or nominal meanings

5.1.1. *Wh*- free relatives

The meaning of a *wh*-FR is systematically equivalent to the nominal meaning of the/a complete true short answer of the corresponding *wh*-question. In particular, a *wh*-FR is interpreted existentially if the corresponding *wh*-question admits a "mention-some" reading, and is interpreted exhaustively otherwise. The following examples are repeated from (68).

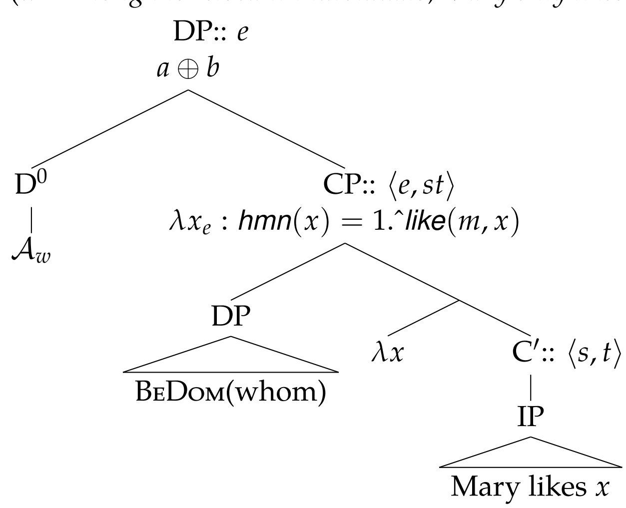
(84) a. John ate what Mary cooked for him.
$\rightsquigarrow$ *John ate **everything** that Mary cooked for him.*

b. John went to where he could get help.
$\rightsquigarrow$ *John went to **some** place where he could get help.*

Caponigro's Generalization on the cross-linguistic distribution gap of *wh*-words teaches us that *wh*-FRs are derivatives of *wh*-questions. In the proposed hybrid categorial approach, defining questions as topical properties make it simple to derive the nominal meaning of a *wh*-FR out of a *wh*-question. I assume the following LF for *wh*-FRs:

(85) a. $[\![\mathcal{A}]\!] = \lambda w \lambda \boldsymbol{P}. f_{\text{CH}}[\text{Ans}^S(\boldsymbol{P})(w)]$

b. John invited [$_{\text{FR}}$ whom Mary likes].
(w: *Among the relevant individuals, Mary only likes Andy and Billy.*)



At this LF, an $\mathcal{A}$-determiner selects for an interrogative CP-complement and returns a nominal DP. The CP-complement denotes a topical property, derived in the same way as it is in the corresponding matrix question. The $\mathcal{A}$-determiner can be decomposed into a choice function and an Ans^S-operator; it picks out a complete true short answer of the question denoted by the CP-complement, which is therefore the denotation of the *wh*-FR. Caponigro's Generalization is predicted as long as the use of the $\mathcal{A}$-determiner is partial and can be blocked for whatever reasons.

Compared with earlier accounts which define questions as λ-abstracts but *wh*-FRs as definite descriptions (e.g., Jacobson 1995; Caponigro 2003, 2004),[22] the proposed analysis easily captures the existential readings: if the CP-complement takes a mention-some reading, the application of the $\mathcal{A}$-operator would return one of the short mention-some answer, yielding an existential reading.

5.1.2. Mandarin *wh*-conditionals

In Mandarin, a *wh*-conditional is a conditional made up of two *wh*-clauses. In syntax, the two *wh*-clauses use the very same *wh*-words or *wh*-phrases, as shown in (86).

(86) a. Shei xian dao, shei xian chi.
who first arrive, who first eat.
'whoever arrives first, he eats first.'

b. Ni qu nar, wo qu nar.
you go where, I go where.
'Wherever you go, I will go there.'

a′. * Shei xian dao, shei xian chi sha.
who first arrive, who first eat what

b′. * Shei qu nar, wo qu nar.
who go where, I go where

The *wh*-items in these two clauses can serve distinct syntactic roles. For example, in (87a), the *wh*-word *shei* 'who' serves as the object in the antecedent but the subject in the consequent.

(87) a. Ni xuan shei, shei daomei.
you pick who, who unlucky
'Whomever you pick is unlucky.'

b. Shei xuan wo, wo yaoqing shei.
you pick I, I invite who
'I will invite whomever picks me.'

In semantics, as seen in the aforementioned examples, a *wh*-conditional usually expresses a universal or exhaustive condition: every true short answer of the antecedent *wh*-clause is also a true short answer of the consequent *wh*-clause. Note that the exhaustivity requirement doesn't apply to the other direction. As shown in (88), it is possible that some true short answer of the consequent *wh*-clause is not a true short answer of the antecedent clause, or equivalently, the complete true short answer of the antecedent *wh*-clause can be a partial true short answer of the consequent clause.[23]

[22] Jacobson (1995) and Caponigro (2003, 2004) follow traditional categorial approaches and interpret *wh*-words as functions from predicates to predicates (e.g., $[\![\text{whom}]\!] = \lambda X \lambda x[\mathit{hmn}(x) \wedge X(x)]$) and the CP-complement extensionally as a predicate (e.g., $[\![\text{whom Mary likes}]\!]^w = \lambda x[\mathit{hmn}(x) \wedge \mathit{like}_w(m, x)]$). Moreover, the D head is interpreted as a σ-closure (Link 1983). It selects out the unique maximal element in the extension of the CP-complement.

(i) **The σ-closure** (Link 1983)
$\sigma = \lambda A : \exists x[x \in A \wedge \forall y[y \in A \rightarrow y \leq x]].\iota x[x \in A \wedge \forall y[y \in A \rightarrow y \leq x]]$
(For any set A, returning the maximal element in A, defined only if this maximal element exists.)

[23] Surprisingly, *wh*-conditionals made up of degree questions seem to be bi-directionally exhaustive. The following sentence conveys a command that one should take exactly the amount of the food that he will eat.

(i) Chi duoshao, na duoshao.
eat how.much, take how.much
'How much [food] you will eat, how much [food] you take.' (Modified from Liu 2016)

One way to account for this seeming bi-directional exhaustivity is to assume that answers of degree questions are all

(88) Ni xiang jian shui, wo jiu yaoqing shui. Dan wo ye hui yaoqing qita-ren.
You want meet who, I JIU invite who. But I also will invite other-person
'Whomever you want to see, I will invite him. But I will also invite some other people.'

Interestingly, in analogous to an existential *wh*-FR, a *wh*-conditional takes an existential reading if the antecedent *wh*-clause resembles a mention-some question (Liu 2016), as seen in (89).

(89) Nar neng mai-dao jiu, wo jiu qu nar.
where can buy-reach liquor, I JIU go where
'Where I can buy liquor, I will go where.'
Intended: 'I will go to **one** of the places where I can buy liquor.'

Using the proposed hybrid categorial approach, I propose to treat the two *wh*-clauses as questions and define the semantics of a *wh*-conditional as a condition on the short answers of the two questions. The syntactic requirement that the two *wh*-clauses must use the same *wh*-items is ascribed to a presupposition that the topical properties denoted by the two *wh*-clauses have the same domain. The truth conditions of *wh*-conditionals are thus schematized as follows uniformly, where $\boldsymbol{P}_1$ and $\boldsymbol{P}_2$ are topical properties denoted by Q_1 and Q_2, respectively:

(90) $[\![Q_1, Q_2]\!] = \lambda w : \mathrm{Dom}(\boldsymbol{P}_1) = \mathrm{Dom}(\boldsymbol{P}_2).\forall w'[\mathrm{Acc}(w', w) \rightarrow w' \in \boldsymbol{P}_2(f_{\textsc{ch}}[\textsc{Ans}^S(\boldsymbol{P}_1)(w')])]$
(Some complete true short answer of Q_1 is a true short answer of Q_2 in every accessible world; defined only if the topical properties denoted by Q_1 and Q_2 have the same domain.)

This definition predicts the following: a *wh*-conditional takes an existential reading iff its antecedent *wh*-clause Q_1 takes a mention-some reading. For instance, the universal *wh*-conditional (86a) has a mention-all antecedent: $\textsc{Ans}^S(\boldsymbol{P}_1)(w)$ is a singleton consists of only the sum of the individuals arriving first in w, and thus (86a) means that whoever arrives first will eat first. In contrast, the existential *wh*-conditional (89) has a mention-some antecedent: $\textsc{Ans}^S(\boldsymbol{P}_1)(w)$ denotes a set of places where I can buy liquor, at least one of which is a true short answer of the consequent.

5.2. Getting quantificational variability effects

Recall the two accounts of QV inferences that are compatible with Hamblin-Karttunen Semantics:

(91) The QV inference of *Jenny mostly knows Q*.
  a. By the propositional answer-based account
  $\textsc{Most}\ p\ [w \in p \in \mathrm{AT}([\![Q]\!])][\mathit{know}(j, q)]$
  (For most p such that p is a true atomic proposition in $[\![Q]\!]$, Jenny knows p.)
  b. By the sub-question-based account
  $\textsc{Most}\ Q'\ [\exists p[w \in p \in \mathrm{AT}([\![Q]\!]) \wedge Q' = \mathit{whether}\text{-}p]][\mathit{know}(j, Q')]$

exclusive. This assumption is supported by the infelicity of using a partiality-marker *for example* in a degree questions, as exemplified in (ii). As seen in section 2.2.2, *for example* presupposes the existence of a partial true answer. The infelicity in (ii) is predicted if the answers are all exclusive — for example, answers to (iib) are of the form "John ran exactly *n*-fast".

(ii) a. How much food will you eat, # for example?
  b. How fast did John run, # for example?

But, to assess this assumption, we should also consider its predictions on phenomena such as negative island effects and modal obviation effects (Fox and Hackl 2007; Abrusán 2007; Abrusán and Spector 2011). I will leave this issue open.

(For most Q' of the form *whether*-p such that p is a true atomic proposition in $[\![\mathrm{Q}]\!]$, Jenny knows Q'.)

A more precise schematization that extends to mention-some questions is as follows. In both formulas, the choice function variable is bound globally. $\textsc{Ans}([\![\mathrm{Q}]\!])(w)$ denotes the set of complete true answers of Q in w, defined following Fox (2013): when Q takes a mention-some reading, $\textsc{Ans}([\![\mathrm{Q}]\!])(w)$ consists of multiple true mention-some answers of Q, and otherwise it is a singleton set consisting of the unique strongest true answer of Q.

(92) The QV inference of *Jenny mostly knows Q*.

a. By the propositional answer-based account
$\textsc{Most}\ p\ [p \in \mathrm{AT}([\![\mathrm{Q}]\!]) \wedge f_{\textsc{ch}}[\textsc{Ans}([\![\mathrm{Q}]\!])(w)] \subseteq p][\textsf{know}(j,q)]]$
(For most proposition p such that p is an atomic propositional answer of Q entailed by some particular complete true answer of Q, Jenny knows p.)

b. By the sub-question-based account
$\textsc{Most}\ Q'\ [\exists p[p \in \mathrm{AT}([\![\mathrm{Q}]\!]) \wedge f_{\textsc{ch}}[\textsc{Ans}([\![\mathrm{Q}]\!])(w)] \subseteq p \wedge Q' = \textsf{whether-}p]][\textsf{know}(j,\mathrm{Q}')]$
(For most Q' of the form *whether*-p such that p is an atomic propositional answer of Q entailed by some particular complete true answer of Q, Jenny knows Q'.)

The revised definitions in (92) can nicely explain the infelicity of using a quantity adverbial in (93), where the embedded question takes a mention-some reading:

(93) Speaker A: "I'm so sleepy. I need to get some coffee."
Speaker B: "Jenny (#mostly/#partly) knows where you can get coffee."

The quantity adverbial *mostly/partly* requires a non-singleton quantification domain, while a mention-some answer of the embedded question in (93) names only one atomic place and supplies only a singleton quantification domain.

As seen in section 2.2.2, the propositional answer-based account and the sub-question-based account both require to form a proper set of atomic propositional answers, which however is challenging in the following two cases. First, in (94) and (95) (repeated from (26a) and (26c)) where the predicates of the embedded questions are non-divisive, the quantification domains of *for the most part* and *mostly* cannot be formed by atomic propositional answers (in the sense of Lahiri (2002) and Cremers (2016)) or by sub-questions (in the sense of Beck and Sharvit (2002)).

(94) Jenny knows for the most part which students formed the bassoon quintet.
$\rightsquigarrow$ *For most x such that x is part of the group of students who formed the bassoon quintet, Jenny knows that x is part of the group of the students who formed the bassoon quintet.*

(95) Jenny mostly knows which professor formed the committee.
$\rightsquigarrow$ *For most x such that x is part of the group of professors who formed the committee, Jenny knows that x is part of the group of professors who formed the committee.*

Second, in (96) (repeated from (34)) where the embedded multi-*wh* question takes a pair-list reading, atomic propositions of the form "boy x invited girl y" cannot be recovered out of the conjunctions of these propositions. This technical difficulty challenges the analysis by Dayal (1996, 2017), which follows Hamblin-Karttunen Semantics and analyzes the embedded multi-*wh* question as denoting a set of conjunctive propositions.

(96) Jenny mostly knows which boy invited which girl.

a. $\rightsquigarrow$ *For most p such that p is a true proposition of the form 'boy x invited girl y', Jenny knows p.*

b. $\rightsquigarrow$ *For most boy-girl pairs $\langle x, y \rangle$ such that x invited y, Jenny knows that x invited y.*

Defining a question as a topical property whose domain can supply short answers, the proposed hybrid categorial approach can easily retrieve the short answers of the embedded question and define the quantification domain of *mostly* based on short answers:

(97) Deriving the quantification domain of *mostly* in the QV inference of *Jenny mostly know Q*: Given a complete short answer α of the embedded question (viz., $\alpha = f_{\textsc{ch}}[\textsc{Ans}^S(\boldsymbol{P})(w)]$ where $\boldsymbol{P}$ is the topical property denoted by embedded question Q and w is the evaluation world), the domain of *mostly* is simply $\textsc{At}(\alpha)$.

With this quantification domain, there are two ways to define the QV inference, as schematized in the following. Again, choice function variables are all globally bound.

(98) Let $\boldsymbol{P} = [\![\mathrm{Q}]\!]$, the **QV inference** of *Jenny mostly knows Q* is:

a. Definition I
$\lambda w.\textsc{Most}\ x[x \in \textsc{At}(f_{\textsc{ch}}[\textsc{Ans}^S(\boldsymbol{P})(w)])][\textit{know}_w(j, \boldsymbol{P}(x))]$
(For most x s.t. x is an atomic subpart of some particular complete true answer of Q, Jenny knows $\boldsymbol{P}(x)$.)

b. Definition II
$\lambda w.\textsc{Most}\ x[x \in \textsc{At}(f_{\textsc{ch}}[\textsc{Ans}^S(\boldsymbol{P})(w)])][\textit{know}_w(j, \lambda w'.x \leq f'_{\textsc{ch}}[\textsc{Ans}^S(\boldsymbol{P})(w')])]$
(For most x s.t. x is an atomic part of some particular complete true short answer of Q, Jenny knows that x is a part of some particular complete true short answer of Q.)

In Definition I, the scope of Most is simply 'Jenny knows the propositional answer based on the atomic short answer x'. This way of deriving QV inferences only works in cases where the topical property $\boldsymbol{P}$ of the embedded question is divisive, as exemplified in (99).

(99) Jenny mostly knows [$_{\mathrm{Q}}$ which students came].
(w: *Among the relevant students, only abc came.*)

a. $\boldsymbol{P} = \lambda x\colon {}^{*}\textit{stdt}_{@}(x) = 1.{}^{\wedge}\textit{came}(x)$	Topical property of Q
b. $\textsc{Ans}^S(\boldsymbol{P})(w) = \{a \oplus b \oplus c\}$	Complete true short answer of Q
c. $\textsc{At}(a \oplus b \oplus c) = \{a, b, c\}$	Quantification domain of *mostly*
d. $\lambda w.\textsc{Most}\ x[x \in \{a, b, c\}][\textit{know}_w(j, {}^{\wedge}\textit{came}(x))]$	The QV inference

In Definition II, what Jenny knows is a sub-divisive inference, namely, the proposition that x is a part of certain complete true short answer of Q, as exemplified in (100).[24] This definition extends to cases where the property of the embedded question is non-divisive.

[24] The sub-divisive QV inferences derived in (100) is pretty much the same as the the sub-divisive QV inferences derived by Williams (2000) (see (27) in section 2.2.2). However, while Williams (2000) ascribes the sub-divisiveness to the lexicon of the *wh*-determiner and inevitably over generates sub-divisive readings in matrix questions, my analysis has room to attribute the sub-divisiveness to operators or shifting rules external to the root denotation of the embedded questions.

(100) Jenny mostly knows [$_{\text{Q}}$which professors formed the committee].
(*w*: *The committee was formed by three professors abc.*)

a. $\boldsymbol{P} = \lambda x\colon \textsf{*prof}_{@}(x) = 1.\,{}^\wedge\textsf{f.t.c}(x)$ — Topical property of Q

b. $\textsc{Ans}^S(\boldsymbol{P})(w) = \{a \oplus b \oplus c\}$ — Complete true short answer of Q

c. $\textsc{At}(a \oplus b \oplus c) = \{a, b, c\}$ — Quantification domain of *mostly*

d. $\lambda w.\textsc{Most}\ x[x \in \{a, b, c\}][\textsf{know}_w(j, \lambda w'.x \leq f'_{\text{CH}}[\textsc{Ans}^S(\boldsymbol{P})(w')])]$ — The QV inference

A similar sub-divisive reading is observed with the indirect mention-some question (101). Contrary to the case of (93), *mostly* can be felicitously used in (101). The reason is that each mention-some answer of the embedded question in (101) names a group of individuals, which therefore can supply a non-singleton quantification domain for *mostly*.

(101) John mostly knows [who can serve on the committee]$_{\text{MS}}$.

Now turn to the case of pair-list readings. While Dayal follows Hamblin-Karttunen Semantics and treats the root dentation of a multi-*wh* question as a set of propositions, the proposed hybrid categorial approach treats the root denotation as a property of functions, which can supply short answers. Hence, in the proposed account, the quantification domain of *mostly* can be formed based on the short answers: given a function **f** such that **f** is complete true short answer of the embedded question, the quantification domain of matrix quantificational adverb *mostly* is the set of functions that are atomic subsets of **f**. I define atomic functions as follows: a function is atomic iff its domain is a singleton set containing only an atomic item, or equivalently, the supremum of its domain is an atomic element. Notice that $\mathbf{f}_2$ is atomic, even though *a* is paired with a non-atomic element.

(102) **Atomic functions**

a. A function **f** is atomic iff $\bigoplus \text{Dom}(\text{f}')$ is atomic.

i. Examples of atomic functions:
$\mathbf{f}_1 = [\ a \to m\ ]$
$\mathbf{f}_2 = [\ a \to m \oplus j\ ]$

ii. Examples of non-atomic functions:
$\mathbf{f}_3 = [\ a \to m, \quad b \to j\ ]$
$\mathbf{f}_4 = [\ a \oplus b \to j\ ]$

b. $\textsc{At}(\mathbf{f}) = \{\text{f}' \mid \text{f}' \subseteq \mathbf{f} \text{ and } \bigoplus \text{Dom}(\text{f}') \text{ is atomic}\}$

The QV inference of (96) is derived as follows following Definition I. The complete true short answer of the embedded question is a function, and its atomic subparts are atomic functions.

(103) Jenny mostly knows [$_{\text{Q}}$ which boy invited which girl].
(*w*: *Andy, Billy, and Clark invited Jenny, Mary, and Sue, respectively*.)

a. Topical property of Q
$\boldsymbol{P} = \lambda \mathbf{f}\colon \text{Range}(\mathbf{f}) \subseteq \textsf{girl}_{@}.\bigcap\{{}^\wedge\textsf{invt}(x, \mathbf{f}(x)) \mid x \in \textsf{boy}_{@}\}$

b. Complete true short answers of Q

$$\textsc{Ans}^S(\boldsymbol{P})(w) = \left\{ \begin{bmatrix} a \to m \\ b \to j \\ c \to s \end{bmatrix} \right\}$$

c. Quantification domain of *mostly*

$$\textsc{At}\left(\begin{bmatrix} a \to m \\ b \to j \\ c \to s \end{bmatrix} \right) = \left\{ \begin{matrix} [a \to m] \\ [b \to j] \\ [c \to s] \end{matrix} \right\}$$

d. The QV inference

$$\lambda w.\textsc{Most}\ \mathrm{f}'\left[\mathrm{f}' \in \left\{\begin{array}{l}[a \to m]\\ [b \to j]\\ [c \to s]\end{array}\right\}\right]\left[\textsf{know}_w(j, \boldsymbol{P}(\mathrm{f}))\right]$$

$$= \lambda w.\textsc{Most}\ \mathrm{f}'\left[\mathrm{f}' \in \left\{\begin{array}{l}[a \to m]\\ [b \to j]\\ [c \to s]\end{array}\right\}\right]\left[\textsf{know}_w(j, \bigcap\{{}^\wedge\textsf{invt}(x, \mathrm{f}'(x)) \mid x \in \textsf{boy}_@\})\right]$$

$$= \lambda w.\textsc{Most}\ \mathrm{f}'\left[\mathrm{f}' \in \left\{\begin{array}{l}[a \to m]\\ [b \to j]\\ [c \to s]\end{array}\right\}\right]\left[\textsf{know}_w(j, {}^\wedge\textsf{invt}(x, \mathrm{f}'(x)))\right]$$

(Jenny knows most of the following boy-invite-girl pairs: a invited m, b invited j, and c invited s.)

Defining the QV inference following Definition II yields the same consequence. As in (104), the scope of Most can be defined as involving a sub-divisive inference:[25]

(104) $$\lambda w.\textsc{Most}\ \mathrm{f}'\left[\mathrm{f}' \in \left\{\begin{array}{l}[a \to m]\\ [b \to j]\\ [c \to s]\end{array}\right\}\right]\left[\textsf{know}(j, \lambda w'.\mathrm{f}' \leq f_{\text{CH}}[\textsc{Ans}^s(\boldsymbol{P})(w')])\right]$$

(For most functions f' in $\{[a \to m], [b \to j], [c \to m]\}$, Jenny knows that f' is a subpart of some particular complete true short answer of Q.)

With three relevant girls *mjs*, this sub-divisive inference is true iff in every world w' such that w' is compatible with Jenny's belief, the complete true short answer of the embedded multi-*wh* question Q in w' is one of the seven functions list in Table 5.

	$\begin{bmatrix} a \to j \\ b \to j \\ c \to s \end{bmatrix}$	$\begin{bmatrix} a \to s \\ b \to j \\ c \to s \end{bmatrix}$
$\begin{bmatrix} a \to m \\ b \to m \\ c \to s \end{bmatrix}$	$\begin{bmatrix} a \to m \\ b \to j \\ c \to s \end{bmatrix}$	$\begin{bmatrix} a \to m \\ b \to s \\ c \to s \end{bmatrix}$
$\begin{bmatrix} a \to m \\ b \to j \\ c \to m \end{bmatrix}$	$\begin{bmatrix} a \to m \\ b \to j \\ c \to j \end{bmatrix}$	

Table 5: Illustration of (104)

[25]This way of formalizing QV inferences for questions with pair-list readings is more advantageous if the embedded question is a ∀-question. Intuitively, the QV inference in (i) is similar to that of the case of multi-*wh* question in (103).

(i) Jenny mostly knows $[_{\text{Q}}$ which girl every boy invited$]_{\text{PL}}$.

a. ⇝ *For most p such that p is a true proposition of the form 'boy x invited girl y', Jenny knows p.*

b. ⇝ *For most boy-girl pairs* $\langle x, y\rangle$ *such that x invited y, Jenny knows that x invited y.*

However, different from pair-list readings in questions with multiple *wh*-phrases, pair-list readings in questions with a universal quantifier are subject to domain exhaustivity (see footnote 17). Therefore, the topical property of the embedded ∀-question in (i) is only defined for functions that are defined for every atomic boy, and is undefined for the atomic functions in (103c). As such, the QV inference in (i) cannot be formulated following Definition I.

Table 5 illustrates a partition of possible worlds. Each cell in this table represents the set of worlds where the contained set of functions is the complete true answer of Q. The union of these cells represents the sub-divisive inference $\lambda w'.\mathrm{f}' \leq f_{\text{CH}}[\text{Ans}^s(\boldsymbol{P})(w')]$, or equivalently, the set of worlds w' such that that most of the functions in $\{[a \to m], [b \to j], [c \to m]\}$ (viz., the complete true short answer of Q in the actual world) are parts of the complete true short answer of Q in w'. From this table, it can be easily observe that the sub-divisive QV inference in (104) is equivalent to the QV inference in (103d).

6. Coordinations of questions

Recall the major criticism to categorial approaches: questions of different kinds are assigned different semantic types, which makes it difficult to account for question coordinations. The proposed hybrid categorial approach inherits this problem: questions denote topical properties, which can take different semantic types. For example, the two coordinated questions in (105) are treated as of type $\langle e, st\rangle$ and $\langle e, \langle e, st\rangle\rangle$, respectively.

(105) Jenny knows [who came] and [who bought what]

One appealing way of thought would be to type-shift the coordinated questions into expressions of the same conjoinable type, such as shifting them into proposition sets or partitions of possible worlds. However, as seen in section 2.2.2 and 5.2, to get QV inferences in question-embeddings, a matrix quantification adverbial should have access to the complete true short answers of the embedded question. Therefore, the interrogative complement of the question-embedding predicate should denote something out of which we can retrieve the short answers. Options include the root question denotation $\boldsymbol{P}$, the set of complete true short answers $\text{Ans}^S(\boldsymbol{P})(w)$, and the intension of this answer set $\lambda w.\text{Ans}^S(\boldsymbol{P})(w)$. Regardless of the choice we take, the coordinated questions cannot be of the same conjoinable type.

I argue that question coordinations are not meet and join, but rather generalized quantifiers, in line with an idea briefly mentioned by Krifka (2011) in a review of categorial approaches. To be more specific, when used to coordinate two questions, *and*/*or* does not directly coordinate the denotations of the two questions, but rather two predication operations (of type *t*).

Recall that conjunction and disjunction are traditionally treated as *meet* and *join*, respectively, which are only defined for conjoinable expressions, namely, expressions of a semantic type of the form $\langle, ...t\rangle$ (Partee and Rooth 1983, Groenendijk and Stokhof 1989). If A' and B' are of a non-conjoinable type or of different types, meet and join cannot proceed. For such cases, I propose that *A and/or B* can be interpreted as a generalized quantifier, defined as in (106b)/(107b).[26] (In the formalizations, '$\wedge$' and '$\vee$' are reserved for coordinating truth values, while '$\sqcap$' and '$\sqcup$' are reserved for meet and join. See definitions of meet and join in (49).)

(106) A conjunction "A and B" is ambiguous between (a) and (b):

a. **Meet**

[26]Note that the following expressions are different:

(i) a. $a \triangledown b \triangledown a \oplus b = \lambda P[P(a) \vee P(b) \vee P(a \oplus b)]$
b. $(a \triangledown b) \triangledown a \oplus b = \lambda \theta[\theta(a \triangledown b) \vee \theta(a \oplus b)]$

$[\![A \text{ and } B]\!] = A' \sqcap B'$; defined only if A' and B' are of the same conjoinable type.

b. **Generalized boolean conjunction**
$[\![A \text{ and } B]\!] = A' \barwedge B' = \lambda\alpha[\alpha(A') \wedge \alpha(B')]$

(107) A disjunction "A or B" is ambiguous between (a) and (b):

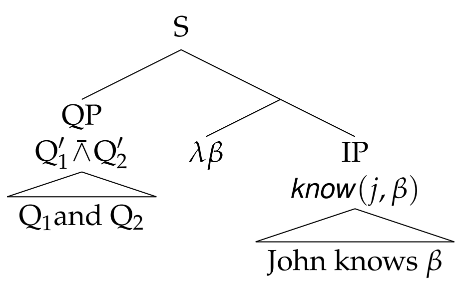
a. **Join**
$[\![A \text{ or } B]\!] = A' \sqcup B'$; defined only if A' and B' are of the same conjoinable type.

b. **Generalized boolean disjunction**
$[\![A \text{ or } B]\!] = A' \veebar B' = \lambda\alpha[\alpha(A') \vee \alpha(B')]$

The generalized boolean conjunction $A' \barwedge B'$ universally quantifies over a possibly polymorphic set $\{A', B'\}$ and selects for an item with an ambiguous type as its scope. Equivalently, in set-theoretic notations, $A' \barwedge B'$ denotes the family of sets such that each set contains both A' and B' (formally: $\{\alpha \mid A' \in \alpha, B' \in \alpha\}$). The generalized boolean disjunction $A' \veebar B'$ is analogous.

To see how this approach works in practice, consider the composition of (108). The question coordination denotes a generalized boolean conjunction, labeled as QP. It undergoes QR and moves to the left edge of the matrix clause, yielding a wide scope reading of *and* relative to the embedding-predicate *know*. (Domain conditions of the topical properties are neglected.)[27]

(108) John knows [$_{Q_1}$ who came] and [$_{Q_2}$ who bought what].



$$
\begin{aligned}
[\![\mathrm{S}]\!] &= (\mathrm{Q}'_1 \barwedge \mathrm{Q}'_2)(\lambda\beta.\textit{know}(j,\beta)) \\
&= (\lambda\alpha[\alpha(\mathrm{Q}'_1) \wedge \alpha(\mathrm{Q}'_2)])(\lambda\beta.\textit{know}(j,\beta)) \\
&= (\lambda\beta.\textit{know}(j,\beta))(\mathrm{Q}'_1) \wedge (\lambda\beta.\textit{know}(j,\beta))(\mathrm{Q}'_2) \\
&= \textit{know}(j,\mathrm{Q}'_1) \wedge \textit{know}(j,\mathrm{Q}'_2) \\
&= \textit{know}(j,\lambda x.{}^\wedge\textit{came}(x)) \wedge \textit{know}(j,\lambda x\lambda y.{}^\wedge\textit{bought}(x,y))
\end{aligned}
$$

(J knows who came and J knows who bought what.)

[27] There are two non-trivial technical issues worthy of noticing. First, the proposed definition of generalized boolean conjunction/disjunction differs from the one given by Partee and Rooth (1983) in getting NP-coordination and extended to question coordination by Groenendijk and Stokhof (1984) and Szabolcsi (1997, 2016). This analysis treats conjunction/disjunction as meet/join over Montague-lifted conjuncts/disjuncts. The case of conjunction is as schematized in (i): Montague lift shifts an expression of type τ to a generalized quantifier of type $\langle\langle\tau,t\rangle,t\rangle$, and then meet conjoins two generalized quantifiers.

(i) NP/question-coordinations as coordinations of two quantifiers
$[\![A \text{ and } B]\!] = \textsc{Lift}(A') \sqcap \textsc{Lift}(B') = (\lambda P.P(A')) \sqcap (\lambda P.P(B'))$

In this analysis, the meet operation requires $\textsc{Lift}(A')$ and $\textsc{Lift}(B')$ to be of the same conjoinable type and hence A' and B' to be of the same conjoinable type. Hence, it is not helpful for solving the type-mismatch problem in question coordinations.

Second, I also must admit that the proposed composition in (108) is not flawless — the sister node of the question coordination doesn't have a fixed semantic type, which is not permitted by the *simple type theory* (Church 1940) employed in Montagovian compositional semantics (Montague 1973). Specifically, the function denoted by this node (viz., $\lambda\beta.\textit{know}(j,\beta)$) should be able to take both Q'_1 (of type $\langle e, st\rangle$) and Q'_2 (of type $\langle e, est\rangle$) as arguments, yielding conflict requirements on the type of the abstracted variable β. One solution is to assume that the abstracted variable β has a *sum type*, a type that can be one of multiple possible options. For example, if D_a is conceived as the set of items of type a and D_b as the set of items of type b, then $D_{a|b}$ is the set of items of type $a|b$, or equivalently, $D_a \cup D_b$. Accordingly, in (108), the β variable is of the sum type $\langle e, st\rangle|\langle e, est\rangle$, and then the embedding-predicate *know* is a polymorphic function of the type $\langle\langle e, st\rangle|\langle e, est\rangle, et\rangle$.

The proposed analysis of question coordinations yields the following prediction: in an indirect question where the question-embedding predicate embeds a coordination of questions, this coordination can and can only take scope above the question-embedding predicate. This prediction cannot be validated or falsified based on sentences like (108). The predicate *know* is divisive — knowing the conjunction of two questions is semantically equivalent to knowing the questions individually (formally: $\textsf{\textit{know}}(j, Q_1 \textsf{\textit{ and }} Q_2) \Leftrightarrow \textsf{\textit{know}}(j, Q_1) \wedge \textsf{\textit{know}}(j, Q_2)$), and therefore the wide scope reading and the narrow scope reading of the disjunction yield the same truth conditions. To evaluate this prediction, we can replace the conjunction with a disjunction, or *know* with a non-divisive predicate. The observations in what follows support the prediction.

First, in (109) and (110), the disjunctions clearly take scope above the question-embedding verb *know*. For the these sentences to be true, John needs to know the complete true answer of at least one of the involved questions, as described in (109a) and (110a). Conversely, if what John believes is just a disjunctive inference as in (109b) and (110b), we cannot conclude (109) and (110) to be true.

(109) John knows who invited Andy or who invited Billy.
(*w*: *Mary invited both Andy and Billy, and no one else invited Andy or Billy.*)
  a. $\surd$ John knows that Mary invited Andy, or John knows that Mary invited Billy.
  b. $\times$ John knows that Mary invited Andy or Billy (or both).

(110) John knows whether Mary invited Andy or whether Mary invited Bill.
(*w*: *Mary invited both Andy and Billy.*)
  a. $\surd$ John knows that Mary invited Andy, or John knows that Mary invited Billy.
  b. $\times$ John knows that Mary invited Andy or Billy.

In comparison, observe that the question-embedding sentence (111) is ambiguous. The embedded disjunction of two declaratives admits both a narrow scope reading and a wide scope reading. The narrow scope reading is derived when the disjunction is interpreted as a join/union of two propositions, as in (111a). The wide scope reading arises if the disjunction is read as a generalized conjunction that quantifies over a set of two propositions, as in (111b).[28]

(111) John knows [$_{S_1}$ Mary invited Andy] or [$_{S_2}$ Mary invited Billy].
  a. *know* $\gg$ *or*
    i. $[\![\mathrm{S}_1 \text{ or } \mathrm{S}_2]\!] = \mathrm{S}_1' \sqcup \mathrm{S}_2'$
    ii. $[\![\text{John knows } \mathrm{S}_1 \text{ or } \mathrm{S}_2]\!] = \textsf{\textit{know}}(j, \mathrm{S}_1' \sqcup \mathrm{S}_2')$
  b. *or* $\gg$ *know*
    i. $[\![\mathrm{S}_1 \text{ or } \mathrm{S}_2]\!] = \mathrm{S}_1' \bar{\vee} \mathrm{S}_2' = \lambda\alpha[\alpha(\mathrm{S}_1') \vee \alpha(\mathrm{S}_2')]$
    ii. $[\![\text{John knows } \mathrm{S}_1 \text{ or } \mathrm{S}_2]\!] = \textsf{\textit{know}}(j, \mathrm{S}_1') \vee \textsf{\textit{know}}(j, \mathrm{S}_2')$

Second, conjunctions of questions embedded under non-divisive predicates admit only wide scope readings. The predicate *be surprised (at)* is non-divisive. In (112), the agent being surprised at the conjunction of two propositions does not necessarily implies that the agent is surprised at each atomic proposition: $\textsf{\textit{surprise}}\ (j,\, p \wedge q) \not\Rightarrow \textsf{\textit{surprise}}\ (j,\, p) \wedge \textsf{\textit{surprise}}(j,\, q)$.

[28]To observe this ambiguity, we have to drop the complementizer *that*, otherwise prosody easily disambiguates the sentence. This ambiguity is more clear in languages that do not have overt complementizers (e.g., Chinese).

(112) John is surprised that [Mary went to Boston] and [Sue went to Chicago]. (He expected that them would go to the same city.)
$\not\rightsquigarrow$ *John is surprised that Mary went to Boston.*

Nevertheless, when embedding a conjunction of questions, *be surprised (at)* seemingly takes only a divisive reading. For example, (113) expresses that John is surprised at the complete true answer of each involved question.

(113) (*w*: *Only Mary went to Boston, and only Sue went to Chicago.*)
John is surprised at [$_{Q_1}$ who went to Boston] and [$_{Q_2}$ who went to Chicago].
  a. $\rightsquigarrow$ *John is surprised at who went to Boston.*
  b. $\rightsquigarrow$ *John is surprised that Mary went to Boston.*

The seeming divisive reading in (113) is predicted by the proposed analysis: the conjunction of questions is a generalized boolean conjunction, which can and can only scope above *be surprised (at)*. A schematized derivation is as follows:

(114) a. $[\![\text{Q}_1 \text{ and } \text{Q}_2]\!] = \text{Q}'_1 \bar{\wedge} \text{Q}'_2 = \lambda\alpha[\alpha(\text{Q}'_1) \wedge \alpha(\text{Q}'_2)]$
  b. $[\![\text{John is surprised at Q}_1 \text{ and Q}_2]\!] = \textsf{surprise}(j, \text{Q}'_1) \wedge \textsf{surprise}(j, \text{Q}'_2)$

There some seeming counterexamples. As Groenendijk and Stokhof (1989) observe, in (115), the disjunction of questions can freely take scope above or below the embedding predicate *wonder*. The wide scope reading says that the speaker knows that Peter wants to know the answer to one of the two questions, but she is unsure which one this is. The narrow scope reading says that Peter will be satisfied as long as he gets an answer to one of the questions involved, no matter which one.

(115) Peter wonders [whom John loves] or [whom Mary loves].

So, how can we get such narrow scope readings? Based on a long-standing intuition, we can decompose the intensional predicate *wonder* into 'want to know' (Karttunen 1977, Guerzoni and Sharvit 2007, Uegaki 2015: chap. 2). Thus, the seeming narrow scope reading is actually an "intermediate" scope reading: Peter wants it to be the case that he knows whom John loves or that he knows whom Mary loves. Such a reading arises when the disjunction takes QR and gets interpreted between *want* and *know*, as illustrated in (116b).

(116) Peter **wants to know** [$_{Q_1}$whom John loves] or [$_{Q_2}$whom Mary loves].
  a. [[Q_1 or Q_2] $\lambda\beta$ [Peter wants to know β]] [*or* $\gg$ *want to know*]
  b. [Peter wants [[Q_1 or Q_2] $\lambda\beta$ [to know β]]] [*want* $\gg$ *or* $\gg$ *know*]

To sum up, coordinations of questions are generalized quantifiers quantifying over possibly polymorphic sets. In a question coordination, the conjunctive/disjunctive coordinates two predications (of type t), not directly the root denotations of the conjoined/disjoined questions.

7. Conclusions

The primary goal of this paper has been to revive categorial approaches of question semantics. Two new pieces of evidence, namely, Caponigro's generalization on the distribution of *wh*-words in questions and FRs, and cases of QV inferences in question-embeddings, suggest that question denotations must be able to supply nominal meanings of short answers. This requirement leaves abstracts (or more precisely, functions from short answers) the only possible denotations of questions.

I argued to define questions as topical properties and proposed a hybrid categorial approach to compose those topical properties. This approach overcomes the problems and insufficiencies with traditional categorial approaches in defining *wh*-words (especially *wh*-words in languages that use bare *wh*-words as indefinites) and composing multi-*wh* questions (with single-pair readings or pair-list readings).

I also proposed that question coordinations are generalized quantifiers quantifying over possibly polymorphic sets. This assumption is supported by the lack of narrow scope reading of question-coordinations.

Acknowledgement [To be added ...]

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