A hybrid categorial approach of question composition

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Introduction

- **The core issue: What does a question mean?**

Categorial approaches:	λ-abstract
Hamblin-Karttunen Semantics:	set of propositions
Partition Semantics:	partition of possible worlds

- **Goal**: Revive categorial approach and overcome its problems.
- **Roadmap**
  - Why pursing categorial approach?
  - Problems with traditional categorial approaches
  - Proposal: A hybrid categorial approach
  - Applications/advantages

1. Why pursing a categorial approach?

1.1. The original motivation: short answers in discourse

- Categorial approaches were originally motivated to capture the semantic relation between questions and short answers in discourse.

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

It remains controversial whether a short answer in discourse is bare nominal or covertly clausal.

- If it is **bare nominal**, it should be derivable from a question denotation.
- If it is **covertly clausal**, it denotes a proposition and is derived by ellipsis. (Merchant 2004)

- Compare:
  - **Categorial approaches**:[1] The root denotation of a question is a λ-abstract. Short answers of a question are possible arguments of the λ-abstract denoted by this question.

(2) a. $[\![\text{who came}]\!] = \lambda x[\mathit{hmn}(x).\mathit{came}(x)]$
 b. $[\![\text{who came}]\!]([\![\text{Jenny}]\!]) = \mathit{came}(j)$

  - **Hamblin/Karttunen Semantics**: The root denotation of a question is a set of propositions, each of which is a possible/true answer of this question. Short answers can only be derived by ellipsis.

(3) $[\![\text{who came}]\!] = \{{}^\wedge\mathit{came}(x) : x \in \mathit{hmn}_@\}$

1.2. New evidence for categorial approach

- This talk doesn't take a position on the treatment of short answers in discourse. The following sections present two independent arguments for categorial approach.

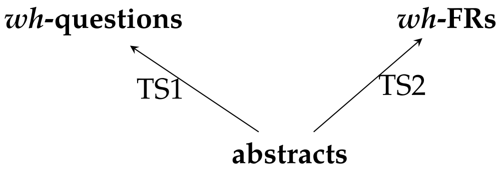
[1] Representatives of categorial approaches include Hausser & Zaefferer (1979), Hausser (1983), Von Stechow & Zimmermann (1984), Jacobson (1995, 2016), Guerzoni & Sharvit (2007), Ginzburg & Sag (2000), and among many others.

1.2.1. Caponigro's generalization on questions and free relatives (FRs)

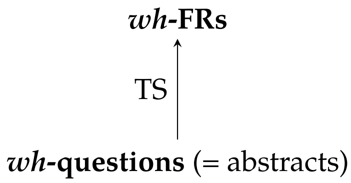
- The meaning of a *wh*-FR systematically equals to the nominal meaning of a/the complete true short answer of the corresponding *wh*-question.

(4) a. John ate what Mary cooked for him. ⇝ *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.*

The similarities between *wh*-FRs and *wh*-questions in form and meaning make it appealing to treat these two constructions uniformly. Options are:



(a) Option I



(b) Option II

- **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.[2]

(5) Spanish *qué* 'what'

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.'

(6) English *who*

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.

Prediction: *Wh*-FRs are formed out of *wh*-questions (Option II). (Chierchia & Caponigro 2013)

☞ The nominal meaning of a short answer must be derivable from the root denotation of a question.

1.2.2. Quantificational variability effects

- Indirect questions with quantity adverbials (e.g., *mostly, for the most part, to a large extent*) are subject to **quantificational variability (QV)** effects. (Berman 1991, Lahiri 2002, Beck & Sharvit 2002)

(7) Jenny mostly knows [$_{\text{Q}}$ who came]. ⇝ MOST x [x came] [J knows that x came]

Typically, the domain restriction of the quantity adverbial can be formed by **atomic short answers** or **atomic propositional answers** of the embedded question. (Lahiri 1991, 2002; Cremers 2016)

(7′) (w: *Among the four considered individuals abcd, abc came but d didn't.*)

a. ✓ MOST x [x is an $\underbrace{\text{atomic true short answer of Q}}_{\{a,b,c\}}$] [J knows that x came]

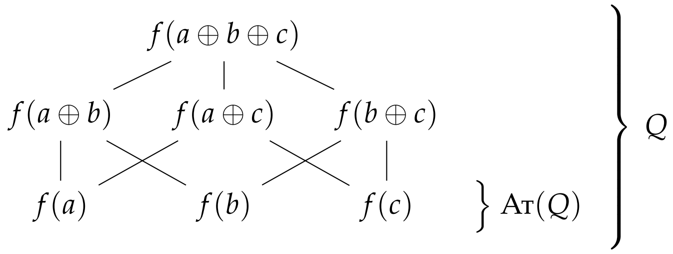
b. ✓ MOST p [p is an $\underbrace{\text{atomic true propositional answer of Q}}_{\{\hat{}came(a), \hat{}came(b), \hat{}came(c)\}}$] [J knows p]

[2]This generalization was firstly made based on 28 languages from Indo-European, Finno-Ugric, and Semitic families. 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).

Atomic propositional answers are those that only entail themselves (Cremers 2016):

(8) $\text{AT}(Q) = \{p : p \in Q \wedge \forall q \in Q[p \subseteq q \rightarrow q = p]\}$

E.g. the answer space (Hamblin set) of *who came*, where $f = \textit{came}$:



- **Challenges to proposition-based accounts**

– **Case 1: questions with a non-divisive predicate**

(9) A predicate P is **divisive** iff $\forall x[P(x) \rightarrow \forall y \leq x[y \in \text{DOM}(P) \rightarrow P(y)]]$.

If the predicate of the embedded question is **non-divisive**, this domain restriction cannot be recovered based propositional answers (Schwarz 1994).[3]

(10) Jenny mostly knows [$_Q$ which professors formed the committee].
$\rightsquigarrow$ 'For most of the professors in the committee, Jenny knows that they were in the committee.'
(w: *The committee was formed by three professors abc*.)

a. ✓ $\text{MOST}\ x\ [\ x \text{ is } \underbrace{\text{an atomic subpart of the true short answer of Q}}_{\text{AT}(a \oplus b \oplus c) = \{a,b,c\}}\ ]$ [J knows that x was in the committee]

b. ✗ $\text{MOST}\ p\ [p \text{ is } \underbrace{\text{an atomic true propositional answer of Q}}_{\{^\wedge \textit{f.t.comm.}(a \oplus b \oplus c)\}}\ ]$ [J knows p]

> **Prediction:** Short answers must be derivable from the denotation of an embedded question.

– **Case 2 (theory-internal): $\forall$/multi-*wh* questions with pair-list readings**

(11) a. Jenny mostly knows which paper every/each student presented. ($\forall$-question)
$\rightsquigarrow$ Most p [p is a true proposition of the form "student x read paper y"] [Jenny knows p]

b. Jenny mostly knows which student read which paper. (multi-*wh* question)
$\rightsquigarrow$ Most p [p is a true proposition of the form "student x read paper y"] [Jenny knows p]

Dayal (1996) defines the embedded $\forall$/multi-*wh* question as a set of conjunctions whose conjuncts are atomic propositions the form $^\wedge \textit{read}(x, y)$ ($x \in \textit{student}, y \in \textit{book}$). But, given a conjunctive proposition, we cannot retrieve its conjuncts semantically. (Lahiri 2002)

> **Interim Summary**
> Caponigro's generalization on distributing *wh*-words and cases of QV effects in quantified question-embeddings show that the root denotation of a question must be able to supply **nominal/predicative** meanings. This requirement leaves **λ-abstract** the only possible question denotation. Thus, we have to pursue a **categorial approach**.

[3] Williams (2000) argues to salvage the proposition-based account by interpreting the embedded question with a **sub-divisive reading**. See Xiang (2018) for arguments against this analysis.

2. Traditional categorial approaches and their problems

2.1. Assumptions of traditional categorial approaches

- Questions denote λ-abstracts.

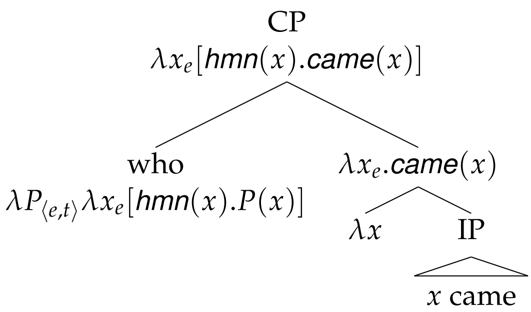
(12) a. $[\![\text{who came}]\!] = \lambda x[\textsf{hmn}(x).\textsf{came}(x)]$
b. $[\![\text{who bought what}]\!] = \lambda x \lambda y[\textsf{hmn}(x) \wedge \textsf{thing}(y).\textsf{bought}(x,y)]$

The *wh*-determiner is a λ-operator.

(13) a. $[\![\text{wh-}]\!] = \lambda A_{\langle e,t\rangle} \lambda P_{\langle e,t\rangle} \lambda x_e[A(x).P(x)]$
b. $[\![\text{who}]\!] = \lambda P_{\langle e,t\rangle} \lambda x_e[\textsf{hmn}(x).P(x)]$

- Composing a single-*wh* question:

(14) Who came?



2.2. Problems of traditional categorial approaches

- **Problem 1. Existential semantics of *wh*-words**

Wh-words are cross-linguistically used to form indefinites. They fall into two types:

Language type	Are *wh*-words morphologically marked in ...	
	... interrogatives?	... existential statements?
I	No	Yes
II	No	No

– For **complex** *wh*-indefinites in **Type I** languages, their existential meaning can be attributed to operations external to the lexicons of the corresponding *wh*-words.

(15) 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.'

Indefinites
↑ Ex-operator
***Wh*-words**

– But, for **bare** *wh*-indefinites in **Type II** languages,[4] their existential meaning shall be part of their lexicons; "it is extremely unlikely that zero-grammaticalization should happen so often, and so systematically." (Haspelmath 1997: pp. 174)

(16) 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.'

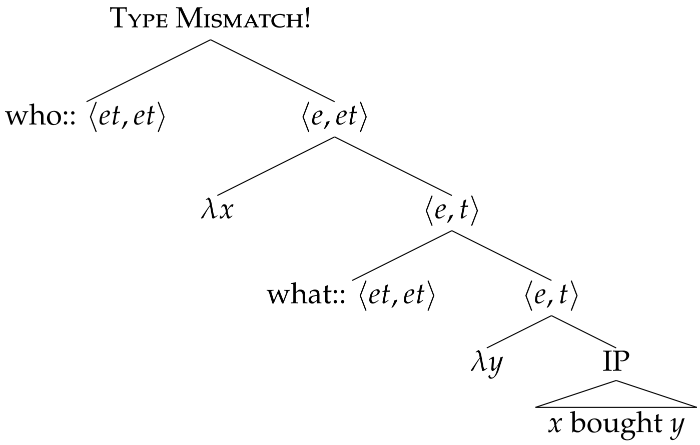
c. Ik heb gegeten [**wat** jij gekookt had].
I have eaten what you cooked had
'I have eaten what you cooked.'

[4]Languages with both bare *wh*-indefinites and (definite) *wh*-FRs include Dutch, German, Russian, Slovene, and Chuj.

Defining the *wh*-determiner as a λ-operator, traditional categorial approaches cannot capture the existential semantics of bare *wh*-indefinites.

- **Problem 2: Composing the single-pair reading of $\mathbf{Q}_{\textbf{multi-}wh}$ suffers type mismatch.**

(17) Who bought what?



- **Problem 3: Coordinations of questions** (Appendix II)

3. Proposal: A hybrid categorial approach

3.1. Question denotation

- Questions denote topical properties (i.e., λ-abstracts ranging over propositions). A topical property maps a short answer to a propositional answer.

(18) Which student came? Jenny.
  a. $\boldsymbol{P} = \lambda x[\textsf{student}_@(x) = 1.{}^\wedge\textsf{came}(x)]$
  b. $\boldsymbol{P}(j) = {}^\wedge\textsf{came}(j)$

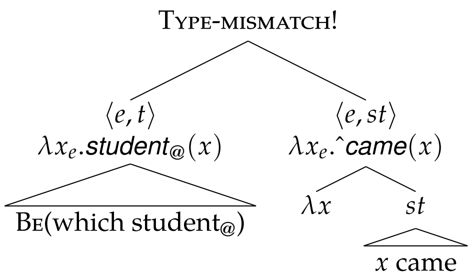
3.2. Question composition

- The domain of a topical property equals to the extension of the *wh*-complement. Defining the *wh*-phrase (*wh*P) as an $\exists$-quantifier, we can extract out this domain by applying a BE-shifter to *wh*P.

(19) BE converts an $\exists$-quantifier to its quantification domain:
  a. $[\![\text{which student}_@]\!] = \lambda f_{\langle e,t\rangle}.\exists x \in \textsf{student}_@[f(x)]$ (To be revised in Appendix II)
  b. $\text{BE} = \lambda \mathcal{P}_{\langle \tau t,t\rangle}\lambda x_\tau[\mathcal{P}(\lambda y.y = x)]$ (Partee 1986)
  c. $\text{BE}([\![\text{which student}_@]\!]) = \textsf{student}_@$

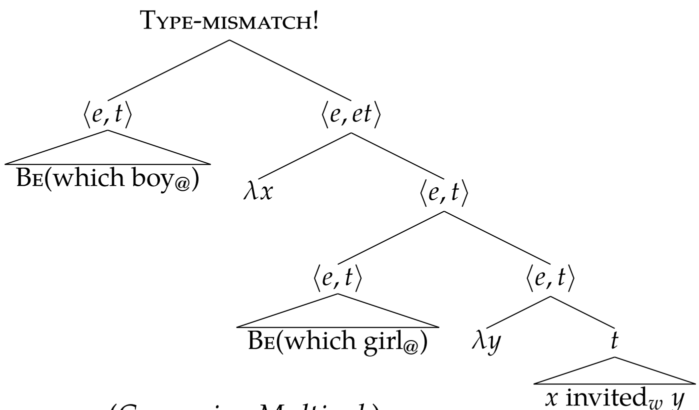
- *A technical difficulty:* How can we incorporate BE(*wh*P) into the topical property?
  Note that Predicate Modification doesn't work:

(20) Which student came?



(*Extension-intension mismatch*)

(21) Which boy invited which girl?



(*Composing Multi-wh*)

Solution: A covert **BeDom-operator** converts the *wh*P into a **domain restrictor**. Moving BeDom(*wh*P) to [Spec, CP] yields a partial property that is only defined for individuals in Be(*wh*P).

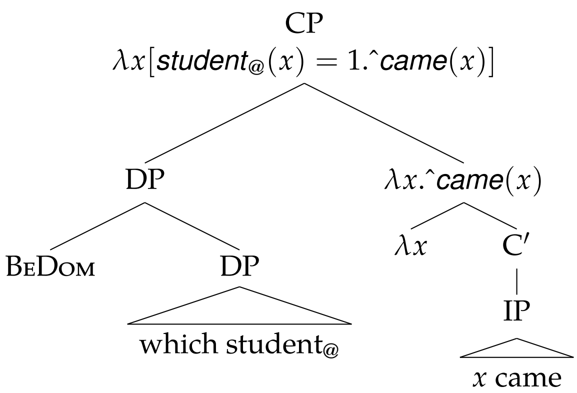
(22) $\textsc{BeDom}(\mathcal{P}) = \lambda\theta_\tau.\iota P_\tau[[\text{Dom}(P) = \text{Dom}(\theta) \cap \textsc{Be}(\mathcal{P})] \wedge \forall\alpha \in \text{Dom}(P)[P(\alpha) = \theta(\alpha)]]$
(For any function θ, restrict the domain of θ with $\textsc{Be}(\mathcal{P})$.)

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

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

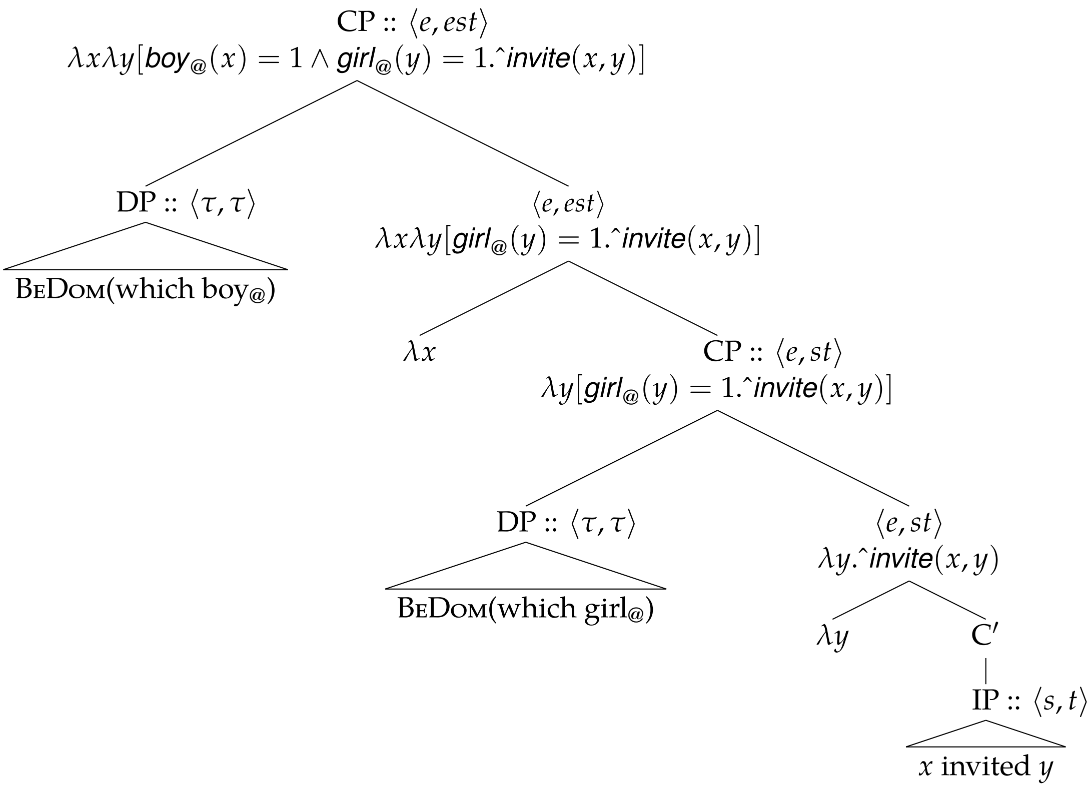
b. $\textsc{BeDom}(\mathsf{which\ student}_@)(\theta) = \begin{bmatrix} a & \to & \hat{}\mathsf{came}(a) \\ b & \to & \hat{}\mathsf{came}(b) \end{bmatrix}$

(24) Which student came?



- $\textsc{BeDom}(\mathcal{P})$ is polymorphic (of type $\langle\tau, \tau\rangle$). Hence, composing multi-*wh* doesn't suffer type-mismatch.

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



3.3. Deriving answers

- Short answers and propositional answers:

$\mathrm{Dom}(\boldsymbol{P})$	$\textit{student}_{@}$
$\{\boldsymbol{P}(\alpha) : \alpha \in \mathrm{Dom}(\boldsymbol{P})\}$	$\{^\wedge\textit{came}(x) : x \in \textit{student}_{@}\}$

- Answerhood: a true answer is complete iff it isn't asymmetrically entailed by any true answers. (Fox 2013; compare Dayal 1996) This answerhood leaves space for mention-some readings of questions; it allows non-exhaustive answers to be complete and allows a question to have multiple good answers.

(26) $\textsc{Ans}_{\mathrm{Fox}}(Q)(w) = \{p \mid w \in p \in Q \wedge \forall q[w \in q \in Q \rightarrow q \not\subset p]\}$

- Adapting to the proposed hybrid categorial approach:

(27) For the complete true **short** answer:
$\textsc{Ans}^{\mathrm{S}}(\boldsymbol{P})(w) = \{\alpha \mid \alpha \in \mathrm{Dom}(\boldsymbol{P}) \wedge w \in \boldsymbol{P}(\alpha) \wedge \forall \beta \in \mathrm{Dom}(\boldsymbol{P})[w \in \boldsymbol{P}(\beta) \rightarrow \boldsymbol{P}(\beta) \not\subset \boldsymbol{P}(\alpha)]\}$

(28) For the complete true **propositional** answer:
$\textsc{Ans}(\boldsymbol{P})(w) = \{\boldsymbol{P}(\alpha) \mid \alpha \in \textsc{Ans}^{\mathrm{S}}(\boldsymbol{P})(w)\}$

Interim Summary

- Traditional categorial approaches cannot capture the ∃-semantics of bare *wh*-indefinites, suffer type-mismatch in composing multi-*wh* questions, and cannot get coordinations of questions.
- A hybrid categorial approach:
  - The root denotation of a question is a topical property. In deriving this topical property, a BeDom-operator converts a *wh*-item into a type-flexible domain restrictor.
  - An answerhood-operator Ans/Ans^S directly operates on the topical property, returning the complete true propositional/short answer.

4. Applications

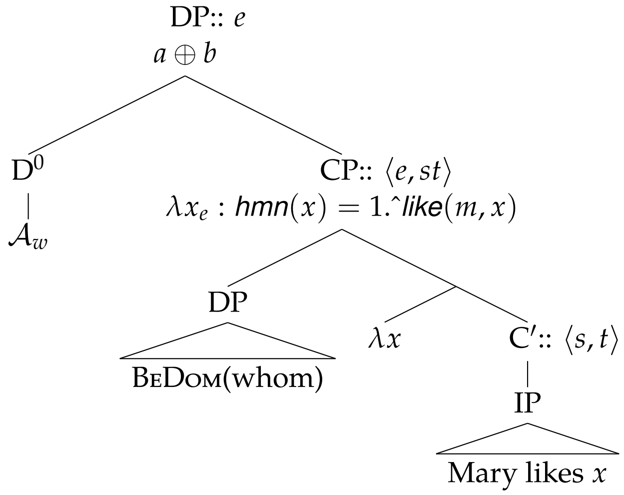
4.1. Kin of *wh*-questions

4.1.1. Free relatives

- **Proposal**: *Wh*-FRs are derived from *wh*-questions with the application of an $\mathcal{A}$-determiner.
  ☞ Caponigro's generalization is captured as long as the application of $\mathcal{A}$ can sometimes be blocked.

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

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



4.1.2. Mandarin *wh*-conditionals

- Mandarin *wh*-conditionals usually express a universal condition wrt the short answers of the two involves *wh*-questions: every true short answer of the antecedent *wh*-clause is also a true short answer of the consequent *wh*-clause.

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

b. Ni xuan **shei**, **shei** daomei.
you pick who, who unlucky
'Whomever you pick is unlucky.'

But, a *wh*-conditional takes an existential reading if the antecedent *wh*-clause resembles a mention-some question (Liu 2016).

(31) **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.'

- **Proposal:** (i) The two *wh*-clauses in a *wh*-conditional are questions, denoting topical properties. (ii) A *wh*-conditional denotes a condition on the short answers of the two questions.

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

4.2. Getting quantificational variability effects

- The quantification domain of the quantity adverbial can be recovered based on the complete true short answer of the embedded question:

(33) Let $\boldsymbol{P} = [\![\mathrm{Q}]\!]$, the QV inference of "Jenny mostly knows Q":
a. Option I: $\lambda w.\textsc{Most}\ x[x \in \textsc{At}(f_{\textsc{ch}}[\textsc{Ans}^S(\boldsymbol{P})(w)])][\mathit{know}_w(j, \boldsymbol{P}(x))]$
(For most x s.t. x is an atomic part of some particular complete true short answer of Q, Jenny knows the proposition $\boldsymbol{P}(x)$.)
b. Option II: $\lambda w.\textsc{Most}\ x[x \in \textsc{At}(f_{\textsc{ch}}[\textsc{Ans}^S(\boldsymbol{P})(w)])][\mathit{know}_w(j, \lambda w'.x \leq f'_{\textsc{ch}}[\textsc{Ans}^S(\boldsymbol{P})(w')])]$
(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.)

- **Challenging case I**: questions with a non-divisive predicate

(34) Jenny mostly knows [$_{\mathrm{Q}}$ which professors formed the committee].
(w: *The committee is formed by three professors abc*.)
a. $\textsc{Ans}^S(\boldsymbol{P})(w) = \{a \oplus b \oplus c\}$ complete true short answer
b. $\textsc{At}(a \oplus b \oplus c) = \{a, b, c\}$ Quantification domain of *mostly*
c. $\lambda w.\textsc{Most}\ x[x \in \{a, b, c\}][\mathit{know}_w(j, \lambda w'.x \leq f'_{\textsc{ch}}[\textsc{Ans}^S(\boldsymbol{P})(w')])]$ QV inference

- **Challenging case II**: $\forall$/multi-*wh* questions with pair-list readings

I define these pair-list readings as **special functional readings**; they denote topical properties over functions. (See appendix II.) The domain of *mostly* is defined based on the **atomic parts of functions**.

(35) Atomic functions and atomic parts of functions
a. A function $\mathbf{f}$ is atomic iff $\bigoplus \mathrm{Dom}(\mathrm{f}')$ is atomic.
b. $\textsc{At}(\mathbf{f}) = \{\mathrm{f}' : \mathrm{f}' \subseteq \mathbf{f} \text{ and } \bigoplus \mathrm{Dom}(\mathrm{f}') \text{ is atomic}\}$

For multi-*wh* questions:

(36) 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

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

c. Quantification domain of *mostly*

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

d. The QV inference (use Option 1)

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

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

e. The QV inference (use Option II)

$$\lambda w.\text{M}\textsc{ost}\ \text{f}' \left[\text{f}' \in \left\{ \begin{matrix} [a \to m] \\ [b \to j] \\ [c \to s] \end{matrix} \right\} \right] \left[\textsf{know}(j, \lambda w'.\text{f}' \leq f_{\text{CH}}[\text{A}\textsc{ns}^s(\boldsymbol{P})(w')]) \right]$$

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

In (36e), the sub-divisive inference is true iff in every world w' that is compatible with J's belief, the complete true short answer of the embedded Q in w' is one of the seven functions below:

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

Conclusions

- **Reasons for pursing a categorial approach:**
  - Caponigro's generalization
  - Quantificational variability effects
- **Problems with traditional categorial approaches**
  - Existential semantics of *wh*-words
  - Type-mismatch in composing multi-*wh* questions
  - Coordinations of questions
- **A hybrid categorial approach**
  - *Wh*-phrases are existential quantifiers.
  - The root denotation of a question is a topical property.
  - In composition, BeDom shifts the *wh*-phrase into a type-flexible domain restrictor.
- **Applications**: Free relatives, *wh*-conditionals, QV effects

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Appendix I: Deriving answers from single-pair reading multi-*wh* questions

- The denotation of a single-pair reading multi-*wh*-question is not a function from short answers to propositional answers. Deriving answers can make use of **tuple types** (George 2011: Appendix A):

  (i) An n-ary sequence $(x_1; x_2; ...; x_n)$ takes a tuple type $(\tau_1; \tau_2; ...; \tau_n)$,

  (ii) $\langle \tau_1 \langle \tau_2 \langle ... \langle \tau_n, \sigma \rangle, ... \rangle$ equals to $\langle (\tau_1; \tau_2; ...; \tau_n), \sigma \rangle$

  (37) Which boy invited which girl? (Single-pair reading)
  a. $\boldsymbol{P} = \lambda x \lambda y[\mathsf{boy}_@(x) = 1 \wedge \mathsf{girl}_@(y) = 1.{}^\wedge\mathsf{invite}(x, y)]$
  b. $\mathrm{Dom}(\boldsymbol{P}) = \{(x; y) : x \in \mathsf{boy}_@, y \in \mathsf{girl}_@\}$
  c. $\{\boldsymbol{P}(\alpha) : \alpha \in \mathrm{Dom}(\boldsymbol{P})\} = \{{}^\wedge\mathsf{invite}(x, y) : x \in \mathsf{boy}_@, y \in \mathsf{girl}_@\}$

Appendix II: Coordinations of questions

- **Problem:** Conjunction and disjunction are standardly defined as **meet** $\sqcap$ and **join** $\sqcup$, which operate on meanings of the same **conjoinable type**. (Partee & Rooth 1983, Groenendijk & Stokhof 1989)[5]

  Questions can be coordinated. But categorial approaches assign them different semantic types.

  (38) Jenny knows [[who came]$_{\langle e,t \rangle}$ **and/or** [who bought what]$_{\langle e,et \rangle}$]

  Even if the coordinated questions are of the same conjoinable type, traditional categorial approaches do not predict the correct reading.[6]

  (39) Jenny knows [$_{\langle e,t \rangle}$ who voted for Andy] and [$_{\langle e,t \rangle}$ who voted for Billy].
  (Predicted reading: # 'Jenny knows who voted for both Andy and Billy.')

- **Solution**: Coordinations can be interpreted either as meet/join or generalized quantifiers (GQs) (cf. Krifka 2011: pp. 1757). The restriction of a GQ can contain elements of different types.[7]

  (40) a. **Generalized conjunction**
  $A' \barwedge B' = \lambda \alpha[\alpha(A') \wedge \alpha(B')]$
  $= \lambda \alpha.\{A', B'\} \subseteq \alpha$

  b. **Generalized disjunction**
  $A' \veebar B' = \lambda \alpha[\alpha(A') \vee \alpha(B')]$
  $= \lambda \alpha[\{A', B'\} \cap \alpha \neq \varnothing]$

  Question coordinations are GQs. When embedded, a question coordination undertakes QR and moves to the left edge of the matrix clause.[8]

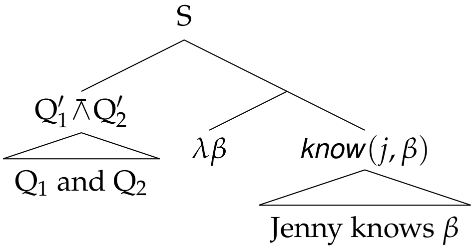
[5] Conjoinable types: (i) t is a conjoinable type; (ii) if τ is a conjoinable type, then for any type σ: $\langle \sigma, \tau \rangle$ is a conjoinable type.

[6] Hamblin-Karttunen Semantics also has this problem: if conjunction is treated standardly as meet, conjunctions of questions would be analyzed as the intersection of two proposition sets. Inquisitive Semantics solves this problem. (Ciardelli & Roelofsen 2015, Ciardelli et al. 2017)

[7] This definition of generalized conjunction/disjunction is different from the one given by Partee & Rooth (1983). P&R treat conjunction as meet over Montague-lifted conjuncts: $[\![A \text{ and } B]\!] = \textsc{Lift}(A') \sqcap \textsc{Lift}(B') = (\lambda P.P(A')) \sqcap (\lambda P.P(B'))$. Unlike the proposed definition, P&R's requires $\textsc{Lift}(A')$ and $\textsc{Lift}(B')$ to be of the same conjoinable type.

[8] A technical problem: the sister node of the question coordination cannot have a fixed semantic type; the function denoted by this node 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 conflicting 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 (41), 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 $\langle \langle e, st \rangle | \langle e, est \rangle, et \rangle$. Thank Danny Fox, Floris Roelofsen, Simon Charlow, and Manuel Križ for discussions.

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



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

(Jenny knows who came, and she knows who bought what.)

Prediction: A question coordination has to scope over an embedding predicate.

This prediction cannot be evaluated based on (41) because *know* is divisive:

$$\textit{know}(j, p \sqcap q) \Leftrightarrow \textit{know}(j,p) \sqcap \textit{know}(j,q)$$

– *Evidence 1*: [Q_1 and Q_2] > *surprise*
  Conjunctions of questions under **non-divisive** predicates admit only wide scope readings.

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

– *Evidence 2*: [Q_1 or Q_2] > *know*
  In (43b), John needs to know the complete true answer of one of the questions, not just the disjunction of the complete true answers of the two questions.

Mary invite ...	*a*	*b*	*a or b* (*or both*)
Fact	Yes	Yes	Yes
John's belief	?	?	Yes

(43) a. John knows that Mary invited *a* or *b* (or both). True
 b. John knows [whether Mary invited *a*] **or** [whether Mary invited *b*]. False

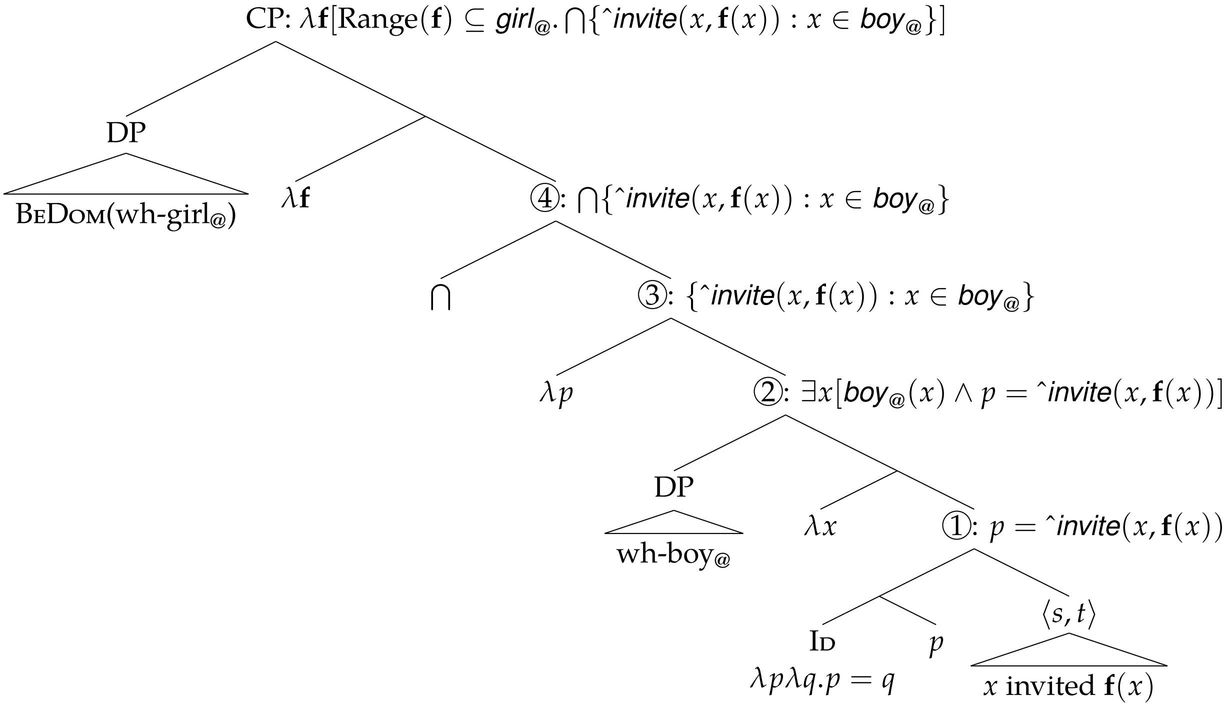
Appendix III: Composing complex questions (Xiang 2016: ch. 5-6, 2017a)

- Proposal: (i) pair-list/choice readings are **special functional readings**: the object-*wh* trace is functional, and its argument variable is bound by the *wh*-/∀-/∃-subject; (ii) 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.

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

- **Composing pair-list readings of multi-*wh* questions**

(45) Which boy invited which girl?

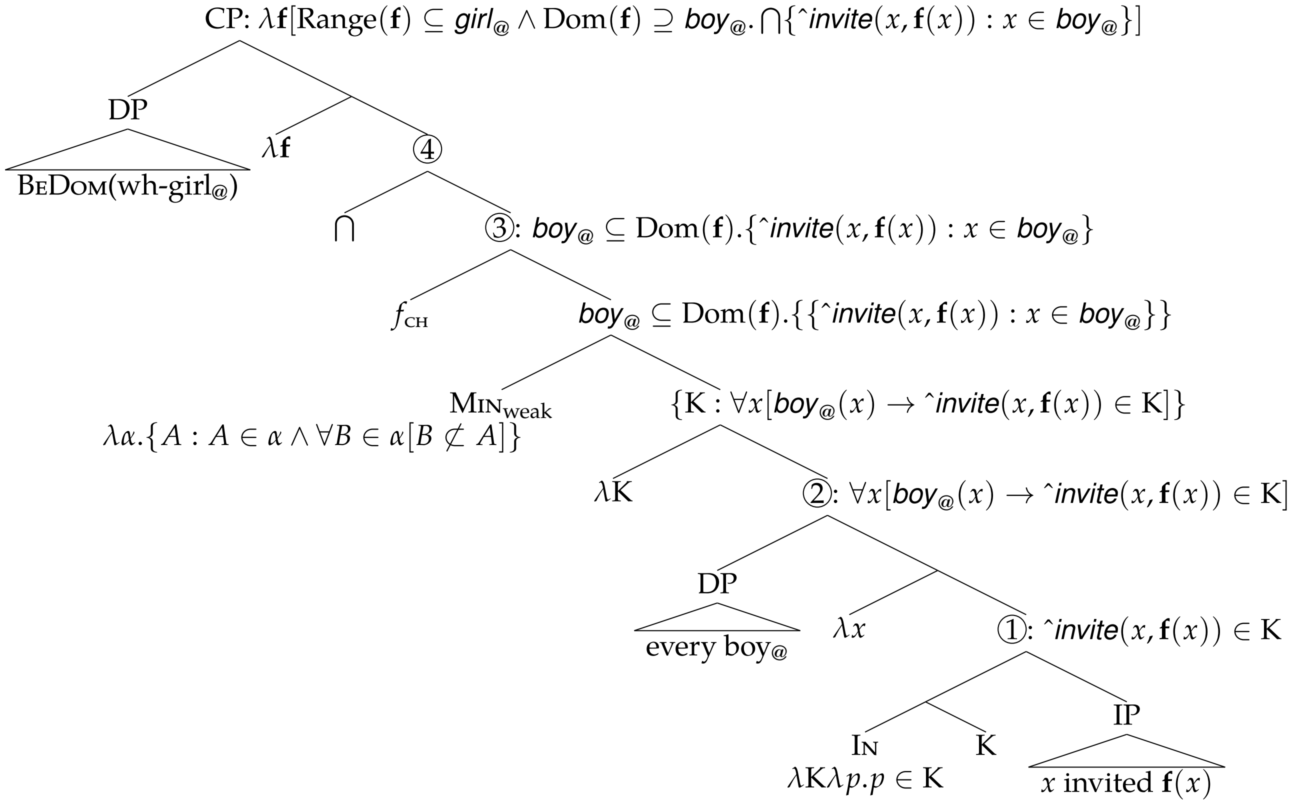


Functions that are possible short answers of this question do not have to be defined for all the boys. Hence no domain exhaustivity.

- **Composing pair-list readings of ∀-questions**

  Two tricks: (i) letting the quantifier quantifies into a membership relation, (ii) extracting out a minimal K set that satisfies the quantified membership relation.[9] Crucially, the meaning of Node ② presupposes that **f** is defined for every boy. This presupposition projects and yields domain exhaustivity.

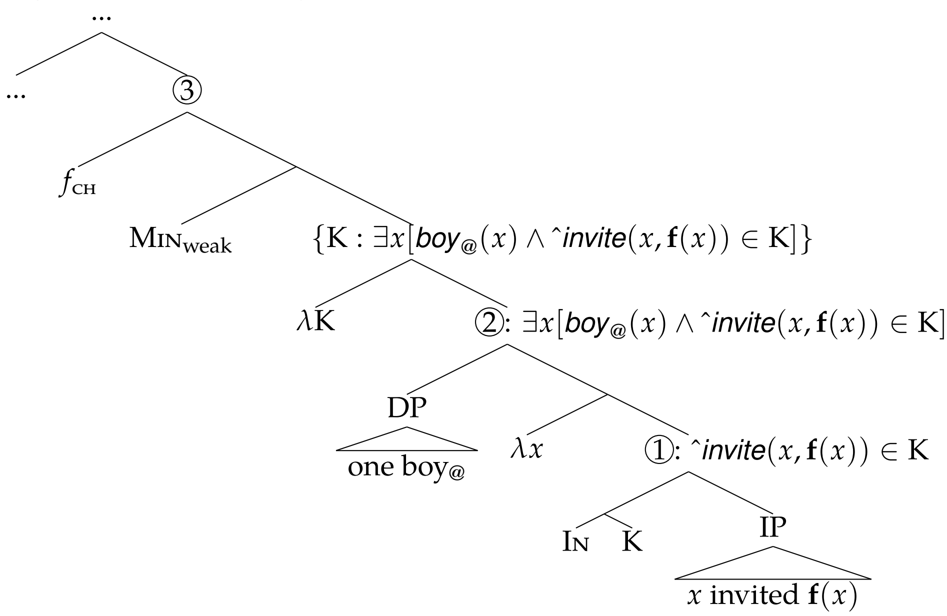
(46) Which girl did every boy invite?



[9] These tricks have been reached by Fox (2012b). My analysis overcomes the following problems: (i) Fox pursues a family-of-question approach for both $Q_{\text{multi-}wh}$ and $Q_\forall$, which cannot explain the semantic differences between their pair-list readings; (ii) Fox uses Pafel's (1999) Mɪɴ-operator ($[\![\text{Min}]\!]_{\text{Pafel-Fox}} = \lambda\alpha.\iota A[A \in \alpha \wedge \forall B \in \alpha[A \subseteq B]]$), which cannot extend to $Q_\exists$.

- **Composing choice readings of $\mathbf{Q}_\exists$** (the same as composing the pair-list reading of $Q_\forall$)

(47) Which girl did one of the boys invite?



Compare the derivations of the two pair-list readings:

- In $Q_{\text{multi-wh}}$, *which boy* existentially quantifies into an **identity** relation;
  In $Q_\forall$, *every boy* universally quantifies into a **membership** relation.
- At node ③, both derivations return the proposition set $\{\hat{}\textit{invite}(x, \mathbf{f}(x)) : x \in \textit{boy}_@\}$. But the one in $Q_\forall$ also presupposes that $\mathbf{f}$ is defined for every boy, yielding domain exhaustivity.

Compare $\mathbf{Q}_\forall$ and $\mathbf{Q}_\exists$:

- $Q_\forall$ doesn't take a choice reading: there is **only one** minimal eligible K set that contains all propositions of the form 'boy x invited $\mathbf{f}(x)$'.

  $Q_\exists$ takes a choice reading: there are **multiple** minimal sets that contain one proposition of the form 'boy x invited $\mathbf{f}(x)$'. Each minimal set yields a possible Q.
- $Q_\forall$ takes a pair-list reading: the unique eligible minimal set is **non-singleton**.

  $Q_\exists$ doesn't take a pair-list reading: all the eligible minimal sets are **singletons**.

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