Semantic approaches to responsive predicates

Wataru Uegaki
Leiden University*

Manuscript submitted to *Language and Linguistics Compass*

Abstract

The complementation pattern of responsive predicates—the clause-embedding predicates that can embed either declarative or interrogative complements—presents a puzzle for the compositional semantics of complementation. The traditional QUESTION-TO-PROPOSITION REDUCTION approach to responsive predicates faces the problem of non-reducibility (George 2011) and a problematic prediction concerning the interpretation of Predicates of Relevance (Elliot et al. 2017). We compare three alternative approaches to responsive predicates, i.e., the PROPOSITION-TO-QUESTION reduction (Uegaki 2015, 2016), the UNIFORMITY approach (Ciardelli et al. 2013) and the ambiguity approach (George 2011), and compare them with respect to how they fare with the two problems for the Question-to-Proposition reduction.

Keywords responsive predicates, complementation, know-wh, semantics of interrogatives, Inquisitive Semantics

*Research leading up to this article has been conducted during the author's PhD study at MIT Department of Linguistics and the postdoctoral study at Keio University and Institut Jean-Nicod (CNRS/ENS). Part of the research was financially supported by Japan Society for the Promotion of Science KAKENHI Grant-in-Aid for JSPS Fellows (15J00143). An earlier version of the current paper has been presented at DIP colloquium at Institute for Logic, Language and Information, University of Amsterdam.

1 Introduction: responsive predicates

This paper surveys approaches to the issue concerning the compositional semantics of pairs of sentences like (1):

(1) a. John {**knows/realized/reported**} that Ann left. (declarative)
  b. John {**knows/realized/reported**} who left. (interrogative)

These examples show that the same predicate (i.e., *know*, *realize* and *report*) can embed either a declarative complement or an interrogative complement. Following Lahiri (2002), I refer to the predicates that show the complementation pattern exemplified in (1) as RESPONSIVE PREDICATES. Responsive predicates pose a non-trivial semantic puzzle because it is plausible to make the following two assumptions:

(2) **Semantic distinction of clause types** Declarative complements and interrogative complements denote semantic objects with distinct types.

  Non-ambiguity Responsive predicates are unambiguous between its declarative-embedding use and its interrogative-embedding use.

Of these two assumptions, the non-ambiguity of responsive predicates is not only intuitively plausible but also empirically motivated by the fact that an interrogative and declarative complement can be coordinated under a single responsive predicate, as in (3):

(3) John **knows/realized/reported** which girl left and that none of the boys left.

If the complement clauses here are really coordinated, *know/realize/report* must have meanings that are compatible with both interrogative and declarative complements. Furthermore, even if (3) is somehow derived from two occurrences of the embedding predicate, as in (4) (e.g., Szabolcsi 2015), it has to be explained why the second occurrence of the predicate can be elided, if the two occurrences have different lexical meanings.

(4) John **knows/realized/reported** which girl left, and ~~he **knows/realized/reported**~~ that none of the boys left.

Similar argument comes from the possibility of gapping as exemplified below:

(5) John **knows/realized/reported** that Ann left and Bill ~~**knows/realized/reported**~~ which other girls left.

In addition, the declarative and interrogative uses of responsive predicates are generally expressed by the same lexical item not just in English, but also in typologically unrelated languages, e.g. Japanese, as demonstrated in (6) with the three responsive predicates *sitteiru* 'know', *kizuku* 'realize' and *hookoku-suru* 'report'.

(6) a. John-wa dono onnanoko-ga kita-ka **sitteiru/kizuita/hookoku-sita**.
  John-TOP which girl-NOM came-Q know/realized/reported
  'John knows/realized/reported which girl came.'
  b. John-wa Mary-ga kita-to **sitteiru/kizuita/hookoku-sita**.
  John-TOP Mary-NOM came-DECL know/realized/reported
  'John knows/realized/reported that Mary girl came.'

The problem then is how to account for the selectional restriction of responsive predicates given these empirical motivations for their non-ambiguity, while considering the plausibility of the semantic distinction of declarative and interrogative clause types.

In this paper, I will survey four approaches to this problem in the literature. Two of the approaches adhere to the assumptions in (2) and reconcile their conflict by positing an operation that turns one kind of semantic object into the other. Depending the *direction* of this extra semantic operation, these two approaches will be called QUESTION-TO-PROPOSITION REDUCTION approach (or Q-TO-P REDUCTION) and PROPOSITION-TO-QUESTION REDUCTION approach (or P-TO-Q REDUCTION). On the other hand, the other two approaches each reject one of the assumptions in (2). The one that rejects the non-ambiguity assumption is the AMBIGUITY approach while the one that rejects the semantic distinction of clause types will be referred to as the UNIFORMITY approach.

The structure of the paper will be the following. I will first present characteristics of the most traditional approach to question-embedding, namely the Question-to-Proposition reduction approach, together with concrete examples of compositional implementations in the literature (§2). After this, I will present two arguments against the Q-to-P reduction (§3). These arguments concern 'non-reducibility' of certain presuppositional responsive predicates discussed by George (2011) and interpretation of Predicates of Relevance, such as *be relevant*, *matter* and *care* (Elliot et al. 2017). I will then introduce three alternative approaches, i.e., Proposition-to-Question reduction approach, the uniformity approach and the AMBIGUITY approach, and compare them in view of whether they can deal with the two problems for the Question-to-Proposition reduction (§5).

2 Question-to-Proposition reduction

The Q-to-P reduction approach is the most traditional approach to the semantics of responsive predicates. This approach dates back at least to Hintikka (1962) and is also adopted by most of subsequent analyses of question-embedding in the formal semantic literature, such as Karttunen (1977); Heim (1994); Dayal (1996); Lahiri (2002), and more recently by Spector and Egré (2015) and Cremers (2016).[1] The characteristics of the Q-to-P reduction approach can be summarized as follows:

(7) **The Question-to-Proposition reduction**

- Responsive predicates semantically select for the denotation of the declarative complement, i.e., propositions.

[1]Technically, Karttunen (1977) and Spector and Egré (2015) define two lexical entries for a responsive predicate, one with a proposition-taking denotation and the other with a question-taking denotation. Thus, prima facie, they might seem to fall under the ambiguity approach. However, I categorize them as the Q-to-P reduction approach since their theories include a general mechanism that derives a interrogative-embedding denotation from a declarative-embedding denotation. In other words, their analyses commit to what George (2011) calls the reducibility property discussed below, which I take to be a defining feature of the Q-to-P reduction. Similarly, I categorize Ginzburg's (1995) theory as an instance of the Q-to-P reduction. Although Ginzburg (1995) posits a type-theoretic distinction between the declarative-embedding denotation of a responsive predicate (which selects for either the FACT-type or the PROPOSITION-type) and its interrogative-embedding denotation (which selects for the QUESTION-type), the mechanism of question-to-fact/proposition coercion in his theory effectively plays the role of the Q-to-P reduction.

- The compositional semantics involves a mechanism that reduces the denotation of an interrogative complement into a proposition.

Analyses within this approach differs with respect to the exact nature of the reduction mechanism. For example, in Heim's (1994) reformulation of Karttunen's (1977) analysis of *know*, questions denoted by interrogative complements are mapped to specific propositions by an ANSWERHOOD OPERATOR, such as the following:[2]

(8) $\mathbf{A}_w := \lambda Q_{\langle st,t\rangle}\lambda w'_s.\forall p \in Q[p(w) \to p(w')]$

Using this answer operator, we can analyze the semantics of the interrogative-embedding example as follows:

(9) $[\![\text{know}]\!]^w = \lambda p_{\langle s,t\rangle}\lambda x_e.\mathbf{know}(x, p, w)$

(10) $[\![\text{John knows who danced}]\!] = 1$ iff $\mathbf{know}(\mathbf{j}, \mathbf{A}_w([\![\text{who danced}]\!]^w), w)$

Under this analysis, the denotation of *know* takes a proposition as its first argument. The denotation of an interrogative complement is turned into a proposition by the **A**-operator, which is then fed to the proposition-taking denotation of *know*. Dayal (1996) has further refined this line of analysis by adding a presuppositional component in the answer operator, among other things.

Another implementation of reduction is seen in Spector and Egré (2015), who analyzes interrogative-embedding examples in terms of existential quantification over answers.[3] That is, they analyze an interrogative-embedding sentence as follows, glossing over some irrelevant details for now.

(11) $[\![\text{John knows who danced}]\!]^w = 1$ iff $\exists p[p \in [\![\text{who danced}]\!]^w \wedge \mathbf{know}(\mathbf{j}, p, w)]$

Lahiri (2002) proposes a yet another form of reduction mechanism, where an LF operation called INTERROGATIVE RAISING resolves the type-mismatch between the proposition-taking denotation of responsive predicates and the interrogative complement. These different forms of reduction make distinct predictions with respect to the interpretation of embedded questions, but such differences within the Q-to-P reduction is irrelevant in this paper since the purpose of the current paper is to compare the Q-to-P reduction with other approaches to the problem of responsive predicates.

Note that this approach adheres to the two assumptions in (2). Declarative and interrogative complements have distinct types of objects. In the formulation illustrated above, declarative complements denote *propositions* while interrogative complements denote *sets* of propositions. At the same time, responsive predicates are unambiguous between the declarative-embedding use and the interrogative-embedding use. They have a proposition-taking denotation, and the embedding of interrogative complements involve some form of reduction.

[2]More precisely, Heim (1994) defines two answer operators, one corresponding to (8) and the other deriving the so-called STRONGLY EXHAUSTIVE reading of embedded questions (Groenendijk and Stokhof 1984; Beck and Rullmann 1999). Furthermore, Heim's (1994) formulation assumes that the question denotation is a function from worlds to true answers in the input world.

[3]Incidentally, this analysis is close to one of the first formal semantic analysis of 'knowing-who' by Hintikka (1962: 131), who analyzes the meaning of 'S knows who is P' as $\exists x[K_S(P(x))]$.

The discussion in the rest of the paper will center around the following two predictions of the Q-to-P reduction approach:

(12) **Predictions of the Q-to-P reduction**

a. **Q-to-P reducibility**: Let V be a responsive predicate. Then, for every term α and every interrogative complement φ_{int}, whether $[\![\alpha\ Vs\ \varphi_{int}]\!]^w$ is true depends only on what propositions p are such that $[\![V]\!]^w(p)([\![\alpha]\!]^w)$.

b. **Entailment prediction**: Let V be a responsive predicate. Then, for every term α, every declarative complement φ_{decl} and interrogative complement φ_{int}, if $[\![\alpha\ Vs\ \text{that}\ \varphi_{decl}]\!]^w$ entails—i.e., semantically presupposes or asserts—$R([\![\alpha]\!]^w, [\![\varphi_{decl}]\!]^w)$ for some relation R, then $[\![\alpha\ Vs\ \varphi_{int}]\!]^w$ entails $R([\![\alpha]\!]^w, q)$ for some answer q to $[\![\varphi_{int}]\!]^w$.

Simply put, the first prediction states that the truth conditions of an interrogative-embedding sentence with a responsive predicate can be paraphrased only in terms of declarative-embedding sentence with the same predicate. For example, the prediction states that whether *John knows which students left* is true depends only on what propositions p are such that John knows that p. On the other hand, the second prediction states how the interpretation of a declarative-embedding sentence has to be reflected in the interpretation of an interrogative-embedding sentence. Whatever entailment that follows from *x Vs that p* has to be reflected in *x Vs Q* in a way so that the entailment holds with respect to *some* answer of Q. For example, we can see that the veridicality entailment of *know-that* conforms to this prediction. That is, *x knows that p* entails that p is true, and *x knows Q* entails that some answer to Q is true. In the rest of the paper, we evaluate the viability of Q-to-P reduction as a general theory of responsive predicates by examining these two predictions.

3 Problems with the Question-to-Proposition reduction

The Q-to-P reduction approach introduced in the previous section has been the standard approach to question-embedding at least since Karttunen (1977). Moreover, it fares well with the standard view in epistemic logic after Hintikka (1962) that *know* is a modal operator applying to a proposition. However, in recent years, there have been a number of empirical counterarguments against the approach. In this section, I review two such arguments: one based on non-reducibility of factive predicates, one based on the so-called Predicates of Relevance.[4]

3.1 Non-reducibility of some presuppositional predicates

The first argument concerns the Q-to-P reducibility prediction in (12a). George (2011) points out that there are examples involving the responsive predicate *know* that go against

[4]See Uegaki (2016) for another argument against the Q-to-P reduction based on nominal complements of attitude predicates.

(12a). The problematic example he describes involves a situation where two individuals have exactly the same set of propositional knowledge, but have different question-knowledge. The concrete example goes as follows.

(13) **Scenario for *know***

- Newstopia sells an Italian newspaper, but PaperWorld doesn't.
- John and Bill know that one can buy an Italian newspaper at Newstopia.
- John is unopinionated about whether one can buy an Italian newspaper at PaperWorld. (i.e., John neither believes nor disbelieves that one can buy an Italian newspaper at PaperWorld)
- Bill wrongly believes that one can buy an Italian newspaper at PaperWorld.
- John and Bill have exactly the same beliefs except for whether one can buy an Italian newspaper at PaperWorld.

(14) a. John knows where one can buy an Italian newspaper.
b. #Bill knows where one can buy an Italian newspaper.

In the scenario described in (13), sentence (14a) is intuitively true, but (14b) isn't.[5]

This is problematic for the Q-to-P reduction analysis of *know*. This is so since John and Bill have exactly the same set of relevant 'propositional' knowledge. That is, all sentences with the declarative-embedding *know* do not differ in truth values, regardless of whether *John* or *Bill* is the subject. Both sentences in (15) are true while both sentences in (16) are presuppositional failures because of the factivity of *know*.

(15) a. John knows that one can buy an Italian newspaper at Newstopia.
b. Bill knows that one can buy an Italian newspaper at Newstopia.

(16) a. John knows that one can buy an Italian newspaper at PaperWorld.
b. Bill knows that one can buy an Italian newspaper at PaperWorld.

Thus, if question-knowledge can be reduced to propositional knowledge, John and Bill should have the same question-knowledge. The fact that (14a) and (14b) differ in the truth values speaks against this prediction.[6]

One way to describe the data above is that the question-embedding meaning of *know* is sensitive to the subject's belief of false-answers (Theiler et al. 2016; Xiang 2016). If the subject believes a false answer of the question, a question-embedding sentence involving factive predicates like *know* does not sound true. However, it turns out that the

[5] Some native speakers express that the judgment depends on the proportion of the false answers believed by Bill with respect to the set of all answers. For example, even if (14b) sounds false in the given situation to these speakers, they feel that the falsity is not clear in a situation where Bill knows a hundred stores that sell Italian newspapers and incorrectly believes for just one store that it does. Note, however, that this judgment is not a problem for the argument here as long as there is a situation in which these speakers too find a contrast in (14).

[6] George's (2011) example above is based on examples that intuitively have a MENTION-SOME interpretation of the complement (Groenendijk and Stokhof 1984; van Rooij 2004; Xiang 2016). Spector (2005), on the other hand, reports a non-reductive judgment of question-embedding *know* embedding a complement with a 'mention-all' interpretation (see also Berman 1991: §4.3.2, Groenendijk and Stokhof 1984: 180 for similar observations).

phenomenon is not restricted to 'false-answer' sensitivity of factive predicates. We can observe a similar phenomenon with the predicate *agree* in the construction *A agrees with B on....* This is shown in the following example:

(17) **Scenario for *agree*.** In addition to the scenario for *know* in (14), we further assume the following: Sue believes that Newstopia sells an Italian newspaper, but PaperWorld doesn't.

(18) a. John agrees with Sue on where one can buy an Italian newspaper.
b. #Bill agrees with Sue on where one can buy an Italian newspaper.

The contrast in the judgment in (18) is problematic for the Q-to-P reduction. This is so since truth values of sentences of the form 'John/Bill agrees with Sue that *p*' doesn't differentiate John and Bill in the scenario. Both sentences in (19) are true while both sentences in (20) are presuppositional failures, given that *X agrees with Sue that p* presupposes that Sue believes that *p*.

(19) a. John agrees with Sue that one can buy an Italian newspaper at Newstopia.
b. Bill agrees with Sue that one can buy an Italian newspaper at Newstopia.

(20) a. John agrees with Sue that one can buy an Italian newspaper at PaperWorld.
b. Bill agrees with Sue that one can buy an Italian newspaper at PaperWorld.

What the above example involving *agree* shows is that the empirical range of predicates that exhibit the non-reductive interpretation of question-embedding is broader than just factive predicates, and includes non-factive presuppositional predicates like *agree (with)*. The general diagnosis of the examples would then be the following: sentences involving certain[7] presuppositional responsive predicates with an embedded question are not true if the subject believes an answer of the embedded question that does *not* satisfy the presupposition. The existence of such systematic counterexamples is a problem for the Q-to-P reduction approach to responsive predicates.

There have been attempts to analyze the kind of 'non-reductive' examples discussed in this section *within* the Q-to-P reduction approach employing the mechanism of exhaustification (Cremers 2016, cf. Uegaki 2015), drawing on the analysis of so-called intermediate exhaustivity by Klinedinst and Rothschild (2011). Due to space limitations, we are unable to detail such analyses here. Interested readers are referred to the cited works.

3.2 Predicates of relevance

The second problem for the Q-to-P reduction concerns the behavior of PREDICATES OF RELEVANCE (PoRs) (Elliot et al. 2017). PoRs are responsive predicates in that they are compatible with both declarative and interrogative complements, as shown in (21).

(21) a. John cares which student left.
b. John cares that Mary left.

[7] I do not generalize this diagnosis to all presuppositional responsive predicates since it is not clear if emotive factives such as *surprise* and *annoy* exhibit non-reducibility.

What is going to be crucial is the presuppositions of these examples. Notice that the declarative embedding use in (21b) presupposes that the complement clause is true, and that John knows it. In contrast, (21a) does *not* presuppose that John believes any answer to the embedded question.

Note that this is a counterexample to the entailment prediction of Q-to-P reduction in (12b), repeated below, assuming that presupposition is a form of entailment.

(12b) **Entailment prediction**: Let V be a responsive predicate. Then, for every term α, declarative complement φ_{decl} and interrogative complement φ_{int}, if $[\![\alpha\ Vs \text{ that } \varphi_{decl}]\!]^w$ entails $R([\![\alpha]\!]^w, [\![\varphi_{decl}]\!]^w)$ for some relation R, then $[\![\alpha\ Vs\ \varphi_{int}]\!]^w$ entails $R([\![\alpha]\!]^w, q)$ for some answer q to $[\![\varphi_{int}]\!]^w$.

The above observation about (21) suggests that x *cares that* p presupposes that x believes that p, but x *cares* Q does not presuppose that x believes that q for any answer q of Q. Thus, the observed difference between (21a) and (21b) is difficult to capture under the Q-to-P reduction approach. Under the Q-to-P reduction approach, (21a) is wrongly predicted to presuppose that John believes p, for some answer p of 'which students left'.

4 Alternative approaches to responsive predicates

In the last section, we saw two empirical phenomena that are problematic for the Q-to-P reduction approach to responsive predicates: (i) non-reductive interpretations of certain presuppositional responsive predicates and (ii) presuppositions of Predicates of Relevance.

In this section, I will introduce three alternative approaches to the semantics of responsive predicates, i.e., the Proposition-to-Question reduction (P-to-Q reduction) approach, the uniformity approach and the ambiguity approach. After outlining characteristics of the three approaches together with short reviews of a concrete analysis from the literature, I will compare the three approaches by considering how they would deal with the two phenomena examined in the previous section.

4.1 Proposition-to-Question reduction

As the name suggests, the P-to-Q reduction approach can be conceived of as the mirror image of the Q-to-P reduction approach. Both approaches posit reduction mechanisms to deal with the selectional restriction of responsive predicates, but in different directions. Unlike the Q-to-P reduction outlined in §2, the P-to-Q reduction assumes that the basic denotation of a responsive predicate is *question*-taking and posits an operation that turns a proposition denoted by a declarative complement into a question. This way, the interrogative-embedding use of responsive predicates is straightforwardly analyzed with their denotation while their declarative-embedding use is analyzed as involving the P-to-Q reduction mechanism. Also, note that the approach adheres to the two assumptions discussed in the beginning of the paper: semantic distinction of clause types and the non-ambiguity of responsive predicates.

Uegaki (2015, 2016) proposes an instance of this approach. According to the analysis, responsive predicates like *know* have question-taking denotations, as in the following:

(22) $[\![\text{know}]\!]^w = \lambda Q_{\langle st,t\rangle} : [\exists p' \in Q[p'(w)]]\lambda x.\ \exists p \in Q[\mathbf{JDox}_x^w \subseteq p]$ $\mathbf{JDox}_x^w$:= the set of worlds compatible with x's justified and de-Gettierized beliefs in w[8]

This lexical entry is obviously too simplistic since it only predicts the *mention-some* interpretation of *know-wh*, and we need ways to derive stronger interpretations such as *weakly exhaustive* and *strongly exhaustive* interpretations. For the purpose of the current survey, however, I will stick to the mention-some semantics for expository purposes. The semantics developed here serves as a proof of concept of the P-to-Q reduction approach and the uniformity approach to responsive predicates, which can be substantiated with additional theory of exhaustivity (e.g., Uegaki 2015; Theiler et al. 2016).

With this caveat in place, the following is how the P-to-Q reduction can be fleshed out in a compositional setup. In Uegaki (2015), the reduction from propositions to questions is carried out by the **Ident**-type shifter proposed in the domain of NP-interpretation by Partee (1986):

(23) $[\![\mathbf{Ident}]\!]^w = \lambda p_{\langle s,t\rangle}.\{p\}$ (after Partee 1986)

With this type-shifter, a declarative complement can be turned into a question-type object, which in turn serves as an argument of the predicate *know* in (22). As a result, we can derive the intuitive interpretation of *know-that* sentences. This is illustrated in the derivation of the truth conditions of the following sentence:

(24) $[\![\text{John knows } [\mathbf{Ident} \text{ [that Mary left]}]]\!]^w$

$$= [\![\text{know}]\!]^w([\![\mathbf{Ident}]\!]^w(\lambda w'.\mathbf{left}(\mathbf{m}, w')))(\mathbf{j})$$
$$= [\![\text{know}]\!]^w(\{\lambda w'.\mathbf{left}(\mathbf{m}, w')\})(\mathbf{j})$$
$$= [\lambda Q_{\langle st,t\rangle} : [\exists p \in Q[p(w)]]\lambda x.\exists p' \in Q[p'(w) \wedge \mathbf{JDox}_x^w \subseteq p']](\{\lambda w'.\mathbf{left}(\mathbf{m}, w')\})(\mathbf{j})$$
$$= \begin{cases} 1 & \text{iff } \mathbf{left}(\mathbf{m}, w) \wedge \mathbf{JDox}_x^w \subseteq \{w' \mid \mathbf{left}(\mathbf{m}, w')\} \\ 0 & \text{iff } \mathbf{left}(\mathbf{m}, w) \wedge \mathbf{JDox}_x^w \nsubseteq \{w' \mid \mathbf{left}(\mathbf{m}, w')\} \\ \text{undefined} & \text{otherwise} \end{cases}$$

Here, note that the presupposition of *know* that the question contains a true answer boils down to factivity, capturing the empirically correct factive presupposition of *know-that*.

4.2 Uniformity

In contrast to the two reduction approaches, which assume the semantic distinction of clause types, the uniformity approach argues that declarative and interrogative complements have the *same* semantic type. Under this approach, then, the selectional restriction of responsive predicates does not pose a problem. Rather, it is something that is *expected* from the semantic uniformity between declarative and interrogative complements, without the involvement of any extra reduction mechanism.

Inquisitive Semantics (Ciardelli et al. 2013) offers a concrete analysis of responsive predicates in the uniformity approach (Theiler 2014; Ciardelli and Roelofsen 2015a; Theiler

[8] I assume that some form of solution to Gettier's problem (Gettier 1963) is given, independently of the natural language semantics of the verb *know*, and that this solution is included in the definition of **JDox**.

et al. 2016). According to inquisitive semantics, both declarative and interrogative clauses denote a set of propositions. Here, I will illustrate the treatment in a version of inquisitive semantics without the property of DOWNWARD CLOSURE (referred to as POSSIBILITY SEMANTICS by Ciardelli et al. 2017) in order to make the comparison with other approaches transparent.[9]

In this semantics, the denotations of declarative and interrogative complements would look like the following (see Ciardelli et al. 2017 for compositional derivations):

(25) a. $[\![\text{that Mary left}]\!]^w = \{\, \lambda w'.\mathbf{left}(\mathbf{m}, w')\,\}$
b. $[\![\text{who left}]\!]^w = \{\, p \mid \exists x[p = \lambda w'.\mathbf{left}(x, w')]\,\}$

In prose, the declarative complement *that Mary left* denotes the singleton set containing the proposition that Mary left while the interrogative complement *who left* denotes its usual Hamblin-style denotation.

Given this uniform semantics for complements, the selectional restriction of responsive predicates can be analyzed with the denotation for *know* we introduced in the discussion of P-to-Q reduction analysis above. I repeat the denotation for *know* below:

(26) $[\![\text{know}]\!]^w = \lambda Q_{\langle st,t\rangle} : [\exists p' \in Q[p'(w)]]\lambda x.\, \exists p \in Q[\mathbf{JDox}_x^w \subseteq p]$

Again, this denotation only derives a mention-some reading of *know-wh*, and something further has to be said to account for empirically attested readings with other kinds of exhaustivity. The truth conditions of *know-that* and *know-wh* sentences according to this analysis are exemplified below (the underlined conditions are those contributed by the presuppositions):

(27) a. $[\![\text{John knows that Mary left}]\!]^w = 1$ iff $\underline{\mathbf{left}(\mathbf{m}, w)} \wedge \mathbf{JDox}_x^w \subseteq \{\, w' \mid \mathbf{left}(\mathbf{m}, w')\,\}$
b. $[\![\text{John knows who left}]\!]^w = 1$ iff
$\underline{\exists x[\mathbf{left}(x, w)]} \wedge \exists p' \in \{\, p \mid \exists x[p = \lambda w'.\mathbf{left}(x, w')]\,\}[p'(w) \wedge \mathbf{JDox}_x^w \subseteq p']$

It is worth mentioning that the uniformity analysis I just sketched and the P-to-Q reduction approach sketched in the previous section are similar in the sense that both analyze the denotation of responsive predicates as selecting for a *set of propositions*. The only difference lies in whether the analysis assumes the set of propositions to be the basic semantic type of a declarative complement. In the P-to-Q reduction, a declarative complement denotes a proposition *simpliciter*. Thus, an extra reduction mechanism is needed to convert the proposition into a set of propositions. On the other hand, in the uniformity analysis, declarative complements denote a set of propositions, just like interrogative complements do. Therefore, there is no need for an extra reduction operation.

4.3 Ambiguity

Instead of rejecting the semantic distinction of declarative and interrogative clause types, the ambiguity approach rejects the assumption that responsive predicates are non-ambiguous.

[9] See Ciardelli et al. (2017) for a comparison of semantics with and without the downward closure, and theoretical and empirical motivations for preferring the former.

Thus, the ambiguity approach posits distinct denotations for the proposition-taking and question-taking denotations of responsive predicates.

A potential problem with the ambiguity approach in general is the intuitive connection between the declarative-embedding use and the interrogative-embedding use of responsive predicates. As pointed out in the beginning of this survey, this intuition is also empirically motivated by data involving coordinations (see (3-5)).

George (2011) addresses this problem by proposing the TWIN RELATIONS THEORY of responsive predicates. According to this theory, every responsive predicate V is associated in the lexicon with two meaning components $V_\forall$ and $V_\exists$. Given these two meaning components, there are general schemata that specify the question-taking denotation V_Q and the proposition-taking denotation V_P. Thus, the analysis captures the intuitive semantic connection between the question-taking denotation and the proposition-taking denotation in terms of their relations to the same semantic core, the two relations $V_\forall$ and $V_\exists$.[10]

For example, the responsive predicates *know* is associated with the two meaning components as shown below.[11]

(28) a. $\mathbf{know}_\exists := \lambda p_{\langle s,t\rangle}\lambda x\lambda w : [p(w)].\mathbf{JDox}_x^w \subseteq p$

b. $\mathbf{know}_\forall := \lambda p_{\langle s,t\rangle}\lambda x\lambda w.\mathbf{Dox}_x^w \subseteq p \rightarrow p(w)$

These meaning components are used to derive the predicates' question-taking and proposition-taking denotations according to the following general schemata.

(29) **General schemata for responsive denotations in George (2011)**

a. $V_Q := \lambda Q_{\langle st,t\rangle}\lambda x_e\lambda w.\begin{pmatrix} \exists p'' \in Q[V_\exists(p'')(x)(w)]\wedge \\ \forall p' \in Q[V_\forall(p')(x)(w)] \end{pmatrix}$

b. $V_P := \lambda p_{\langle s,t\rangle}\lambda x\lambda w.V_\exists(p)(x)(w) \wedge V_\forall(p)(x)(w)$

Instantiating the schemata with $\mathbf{know}_\exists$ and $\mathbf{know}_\forall$, we get the following denotations of *know*, one question-taking and the other proposition-taking.[12]

(30) a. $\mathbf{know}_Q = \lambda Q_{\langle st,t\rangle}\lambda x\lambda w : [\exists p \in Q[p(w)]].\begin{pmatrix} \exists p'' \in Q[\mathbf{JDox}_x^w \subseteq p'']\wedge \\ \forall p' \in Q[\mathbf{Dox}_x^w \subseteq p' \rightarrow p'(w)] \end{pmatrix}$

b. $\mathbf{know}_P = \lambda p_{\langle s,t\rangle}\lambda x\lambda w : [p(w)].\begin{pmatrix} \mathbf{JDox}_x^w \subseteq p \\ \mathbf{Dox}_x^w \subseteq p \rightarrow p(w) \end{pmatrix}$

$\equiv \lambda p_{\langle s,t\rangle}\lambda x\lambda w : [p(w)].\mathbf{JDox}_x^w \subseteq p$

(The equivalence in (30b) is due to the fact that $\mathbf{JDox}_x^w \subseteq p$ entails both $\mathbf{Dox}_x^w \subseteq p$ and $p(w)$)

A substantial feature of the analysis is that the denotation already incorporates a solution to the problem of non-reducibility of *know* discussed in §3.1. To see this, let us revisit the 'non-reductive' example involving *know*.

[10] Of course, the theory has to be supplemented with a concrete theory of gapping to account for the fact that the gapping in (5) is licensed given the semantic relationship between V_Q and V_P. George (2011) himself does not address issues concerning sentences like (5).

[11] $\mathbf{know}_\forall$ is defined in terms of **Dox** instead of **JDox** since we would like the additional condition contributed by $\mathbf{know}_\forall$ in the case of the question-taking $\mathbf{know}_Q$ to be *false* if the subject *unjustifiably* believes a false answer. Empirically, a *know-wh* sentence is judged untrue if the subject believes a false answer whether or not the belief is justified.

[12] I assume that the factive presupposition of $\mathbf{know}_\exists$ is existentially projected in $\mathbf{know}_Q$.

(13) • Newstopia sells an Italian newspaper, but PaperWorld doesn't.
• John and Bill know that one can buy an Italian newspaper at Newstopia.
• John is unopinionated about whether one can buy an Italian newspaper at PaperWorld. (i.e., John neither believed nor disbelieved that one can buy an Italian newspaper at PaperWorld)
• Bill wrongly believes that one can buy an Italian newspaper at PaperWorld.
• John and Bill have exactly the same beliefs except for whether one can buy an Italian newspaper at PaperWorld.

(14) a. John knows where one can buy an Italian newspaper.
b. #Bill knows where one can buy an Italian newspaper.

The judgment that (14b) is false in the scenario in (14) is correctly captured by the denotation in (30a). This is so since (30a) predicts that (14b) would be true only if all answers to the embedded question that Bill believes are true. This is obviously not the case in the given scenario due to Bill's belief that one can buy an Italian newspaper at PaperWorld. Thus, the analysis correctly captures the fact that *know* is sensitive to the subject's belief in false answers. In fact, George's (2011) ambiguity theory is devised as a direct reaction to the non-reducibility of the question-embedding denotation of some responsive predicates.

5 Comparing the non-traditional approaches

How do the three non-traditional approaches reviewed in the previous section fare with the two problems for the Q-to-P reduction approach? In this section, I go through the two problematic phenomena and examine if the three approaches have resources to account for them.

5.1 Non-reducibility of presuppositional predicates

5.1.1 P-to-Q reduction and uniformity

Both the P-to-Q reduction approach and the uniformity approach have a straightforward way to capture the Q-to-P non-reducibility of presuppositional responsive predicates: the denotation of the predicates can simply include the condition that the subject cannot believe any answer that fails the presupposition of the predicate. For example, *know* and *agree with* in such accounts would look like the following:

(31) a. $[\![\text{know}]\!]^w = \lambda Q_{\langle st,t\rangle} : [\exists p \in Q[p(w)]].\lambda x. \begin{pmatrix} \exists p \in Q[p(w) \wedge \mathbf{JDox}_x^w \subseteq p] \wedge \\ \forall p' \in Q[\mathbf{Dox}_x^w \subseteq p' \rightarrow p'(w)] \end{pmatrix}$

b. $[\![\text{agree with}]\!]^w = \lambda y \lambda Q_{\langle st,t\rangle} : [\exists p \in Q[\mathbf{Dox}_y^w \subseteq p]].\lambda x. \begin{pmatrix} \exists p' \in Q[\mathbf{Dox}_y^w \subseteq p' \wedge \mathbf{Dox}_x^w \subseteq p'] \wedge \\ \forall p'' \in Q[\mathbf{Dox}_x^w \subseteq p'' \rightarrow \mathbf{Dox}_y^w \subseteq p'] \end{pmatrix}$

The second line of the truth conditions that the denotation of *know* in (31) returns states that all answers that the subject believes are true. In (31b), the condition is modified so that all answers that the subject believes are also believed by the comitative ('with') argument.[13] These conditions adequately capture the relevant conditions that are Q-to-P non-reducible.

Also, note that there is no distinction between the P-to-Q reduction approach and the uniformity approach with regard to the solution to this problem. This is so since the only difference between the two approaches concerns the treatment of declarative complements, and what the solution above hinges on is the question-taking semantics for responsive predicates, which the P-to-Q reduction and the uniformity approach share.

5.1.2 Ambiguity approach

George's (2011) ambiguity approach was proposed as a response to the observation of the Q-to-P non-reducibility of factive predicates, and we have already seen in §4.3 how his analysis would account for the Q-to-P non-reducibility of *know*. Here, I will simply show that the analysis can be extended to *agree* by defining appropriate meaning components $\mathbf{agree}_\exists$ and $\mathbf{agree}_\forall$ as follows:

(32) a. $\mathbf{agree\text{-}with}_\exists := \lambda y \lambda p_{\langle s,t\rangle} \lambda x \lambda w : [\mathbf{Dox}^w_y \subseteq p].\mathbf{Dox}^w_y \subseteq p \wedge \mathbf{Dox}^w_x \subseteq p$

b. $\mathbf{agree\text{-}with}_\forall := \lambda y \lambda p_{\langle s,t\rangle} \lambda x \lambda w.\mathbf{Dox}^w_x \subseteq p \rightarrow \mathbf{Dox}^w_y \subseteq p$

(33) a. $\mathbf{agree\text{-}with}_Q = \lambda y \lambda Q_{\langle st,t\rangle} \lambda x \lambda w : [\exists p \in Q[\mathbf{Dox}^w_y \subseteq p]]. \begin{pmatrix} \exists p'' \in Q[\mathbf{Dox}^w_y \subseteq p'' \wedge \mathbf{Dox}^w_x \subseteq p''] \wedge \\ \forall p' \in Q[\mathbf{Dox}^w_x \subseteq p' \rightarrow \mathbf{Dox}^w_y \subseteq p'] \end{pmatrix}$

b. $\mathbf{agree\text{-}with}_P = \lambda y \lambda p_{\langle s,t\rangle} \lambda x \lambda w : [\mathbf{Dox}^w_y \subseteq p] \begin{pmatrix} [\mathbf{Dox}^w_y \subseteq p \wedge \mathbf{Dox}^w_x \subseteq p] \wedge \\ [\mathbf{Dox}^w_x \subseteq p \rightarrow \mathbf{Dox}^w_x \subseteq p] \end{pmatrix}$
$\equiv \lambda y \lambda p_{\langle s,t\rangle} \lambda x \lambda w : [\mathbf{Dox}^w_y \subseteq p].\mathbf{Dox}^w_y \subseteq p \wedge \mathbf{Dox}^w_x \subseteq p$

The condition requiring that the subject believes no answer that fails the presupposition of (the declarative-embedding version of) the predicate is contributed by $\mathbf{agree}_\forall$. In sum, just like the the P-to-Q reduction approach and the uniformity approach, George's (2011) ambiguity approach has resources to capture the Q-to-P non-reducibility of *know* and *agree*.

5.2 Predicates of Relevance

Next, we turn to how the three approaches deal with Predicates of Relevance (PoRs) like *care*, *be relevant* and *matter*. The relevant examples with *care* are repeated below from §3.2.

(21) a. John cares which students left.

b. John cares that Mary left.

[13] In footnote 5, I discussed native speaker judgments that are sensitive to the *proportion* of false answers (or answers that are not believed by the 'with'-argument) in the set of answers believed by the subject. Whatever the exact condition of such a proportion is, it should be noted that it can be encoded in the question-taking meaning of the relevant predicates, by minimally modifying the denotations in (31). (e.g., in the case of *know*, by the condition that *most* of the answers that the subject believes have to be true.)

The problem posed by these predicates is that (21a) presupposes that John believes that some student left (and not that he believes a specific answer to the embedded question), cannot be accurately described in a Q-to-P reduction approach, given that the declarative-embedding version (21b) presupposes that John believes that Mary left.

5.2.1 P-to-Q reduction and uniformity

The P-to-Q reduction approach and the uniformity approach can accurately account for the presupposition of (21a) by making the denotation of *care* refer to its question argument itself. For example, the denotation of *care* can be analyzed as follows:

(34) $[\![\text{care}]\!]^w = \lambda Q_{\langle st,t\rangle} : [\exists p \in Q[p(w')]]\lambda x : [\mathbf{Dox}_x^w \subseteq \{\, w' \mid \exists p \in Q[p(w')]\,\}].\mathbf{care}(x, Q, w)$

The presupposition specified after the argument x above states that x believes that some answer of the embedded question is true. This captures the presuppositions of (21a), as shown in the underlined part of the following truth conditions derived from (34) (where Q is the denotation of the embedded question *which students left*).

(35) a. $[\![(21a)]\!]^w$ is defined iff $\exists p \in Q[p(w)] \wedge \mathbf{Dox}_{\mathbf{j}}^w \subseteq \{\, w' \mid \exists p \in Q[p(w')]\,\}$.
b. If defined, $[\![(21a)]\!]^w = 1$ iff $\mathbf{care}(\mathbf{j}, Q, w)$.

The denotation for *care* in (34) correctly captures the presuppositions of the declarative-embedding sentence in (21b) as well, given that the P-to-Q reduction approach and the uniformity approach assign a singleton-set meaning to declarative complements, either through a reduction operation or as the basic meaning of the complement itself, as in (36).

(36) a. $[\![\mathbf{Ident}\ [\text{that Mary left}]]\!]^w = \{\lambda w'.\mathbf{left}(\mathbf{m}, w')\}$ (P-to-Q reduction)
b. $[\![\text{that Mary left}]\!]^w = \{\lambda w'.\mathbf{left}(\mathbf{m}, w')\}$ (uniformity)

(37) a. $[\![(21b)]\!]^w$ is defined
iff $\exists p \in \{\lambda w''.\mathbf{left}(\mathbf{m}, w'')\}[p(w)] \wedge \mathbf{Dox}_{\mathbf{j}}^w \subseteq \{\, w' \mid \exists p \in \{\lambda w''.\mathbf{left}(\mathbf{m}, w'')\}[p(w')]\,\}$
iff $\mathbf{left}(\mathbf{m}, w) \wedge \mathbf{Dox}_{\mathbf{j}}^w \subseteq \{\, w' \mid \mathbf{left}(\mathbf{m}, w')\}$.
b. If defined $[\![(21b)]\!]^w = 1$ iff $\mathbf{care}(\mathbf{j}, \{\lambda w'.\mathbf{left}(\mathbf{m}, w')\}, w)$

Since a belief that some answer is true in a singleton-set question denotation is equivalent to the belief that its unique answer is true, the second presupposition of *care* in (34) boils down to the presupposition that the subject believes the complement. Furthermore, note that the analysis correctly captures the factivity of *care* in the case of declarative-embedding. This is so because the first presupposition of (34) (that some answer of the question is true) boils down to factivity in the case of declarative-embedding, as can be seen in (37).

5.2.2 Ambiguity approach

How would the ambiguity approach deal with PoRs? Interestingly, there is no obvious way in which the approach can capture the problematic presuppositions of PoRs. I will show this by first examining George's (2011) predictions with respect to PoRs, and then generalizing the argument to any George-style ambiguity theory.

To see how George (2011) would deal with PoRs, let us start with the predicted denotations of the question-taking $\textbf{care}_Q$ and the proposition-taking $\textbf{care}_P$ according to his schema:

(38) a. $\textbf{care}_Q = \lambda Q_{\langle st,t\rangle}\lambda x_e \lambda w. \left(\begin{array}{c} \exists p'' \in Q[\textbf{care}_\exists(p'')(x)(w)] \wedge \\ \forall p' \in Q[\textbf{care}_\forall(p')(x)(w)] \end{array} \right)$

b. $\textbf{care}_P = \lambda p_{\langle s,t\rangle}\lambda x \lambda w.\textbf{care}_\exists(p)(x)(w) \wedge \textbf{care}_\forall(p)(x)(w)$

Of course, the content of these meanings are still unclear unless $\textbf{care}_\forall$ and $\textbf{care}_\exists$ are substantiated. However, we already know at this point that the belief presupposition of *care-that*—that the subject believes the complement—has to be encoded in $\textbf{care}_\forall$ or $\textbf{care}_\exists$ in (38b). But then, either case, $\textbf{care}_Q(Q)(x)(w)$ is predicted to entail that, for some answer p of Q, x believes p. Here is why: if $\textbf{care}_\exists$ triggers the belief presupposition, given the form of (38a), $\textbf{care}_Q(Q)(x)(w)$ would be true only if there is some answer that satisfies the belief presupposition, i.e., is believed by x in w; On the other hand, if $\textbf{care}_\forall$ triggers the belief presupposition, $\textbf{care}_Q(Q)(x)(w)$ would be true only if all answers satisfy the belief presupposition, i.e., is believed by x in w. Thus, $\textbf{care}_Q(Q)(x)(w)$ would entail that x believes a specific answer of Q in w whether the belief presupposition is encoded in $\textbf{care}_\forall$ or in $\textbf{care}_\exists$. What we see here is that the predicted belief presupposition of the question-embedding *care* in George's (2011) theory is too strong, just as in the case of Q-to-P reduction approaches.

The argument above targets George's (2011) theory specifically, but one could have a version of the ambiguity theory where denotations of responsive predicates are derived from core meanings in ways that are different from George's (2011) schemata. It turns out, however, that PoRs pose problems for such accounts in general as long as the core meanings are proposition-taking. To see this, consider the following generic formulation of the George-style ambiguity theory:

(39) **Core meanings for an arbitrary responsive predicate** V

- $\mathbf{V_1} = \lambda p_{\langle s,t\rangle}\lambda x \lambda w.(...)$
- $\mathbf{V_2} = \lambda p_{\langle s,t\rangle}\lambda x \lambda w.(...)$

  ...
- $\mathbf{V_n} = \lambda p_{\langle s,t\rangle}\lambda x \lambda w.(...)$

(40) **General schemata for the denotations of responsive predicates**

a. $\mathbf{V_Q} = \lambda Q_{\langle st,t\rangle}\lambda x \lambda w : [\textit{presupposition}].(...\mathbf{V_1}...\mathbf{V_2}...\mathbf{V_n}...)$

b. $\mathbf{V_P} = \lambda p_{\langle st,t\rangle}\lambda x \lambda w : [\textit{presupposition}].(...\mathbf{V_1}...\mathbf{V_2}...\mathbf{V_n}...)$

The problem with George's (2011) original account is rooted in the fact that the belief presupposition of *care* has to be encoded in one of its core meaning components, i.e., $\textbf{care}_\forall$ or $\textbf{care}_\exists$. Yet, we can think of a version of the theory where the presupposition is encoded in the general schemata rather than the core meanings. Specifically, the schemata could look like the following:

(41) a. $\mathbf{V_Q} = \lambda Q_{\langle st,t\rangle}\lambda x \lambda w : [\textbf{believe}(x, \lambda w'.\exists p \in Q[p(w')], w)].(...\mathbf{V_1}...\mathbf{V_2}...\mathbf{V_n}...)$

b. $\mathbf{V_P} = \lambda p_{\langle st,t\rangle}\lambda x \lambda w : [\textit{presupposition}].(...\mathbf{V_1}...\mathbf{V_2}...\mathbf{V_n}...)$

What is crucial in (41) is that the question-taking denotation of any responsive predicate is specified to presuppose that the subject believes that some of the answers is true. Given this kind of mechanism, the belief presupposition of *care-wh* can be accounted for without encoding the presupposition in one of its core meaning components. (The presupposition of *care-that*, on the other hand, could be encoded in a core meaning of *care*.)

However, a problem with (41) is that it seems to make wrong predictions for many responsive predicates other than *care*. For example, communication predicates like *tell* and *lie* do not seem to carry the presupposition that the subject believes that the embedded question contains a true answer. This can be seen in the fact that the following examples sound consistent (Tsohatzidis 1993; Spector and Egré 2015).

(42) a. John **told** me which great universities he was accepted to. However, it turned out that he was lying, and that he was accepted to no university at all (and he knew it).

b. John **lied** to me about which great universities he was accepted to. In fact, he was accepted to no university at all (and he knew it).

Another example of a responsive predicate that does not have the relevant belief presupposition is the verb *ignorer* 'be ignorant' in French and corresponding verbs in other Romance languages. The consistency of the following example suggests that the French *ignorer* does not presuppose that the subject believes that the question contains a true answer.

(43) Anne **ignore** quelles écoles ont accepté Jean. En fait, elle ne sait
Ann IGNORER which schools have accepted John. In fact, she NEG know
même pas si Jean a été accepté par la moindre école.
even NEG if John has been accepted by the least school
'Ann doesn't know which schools have accepted John. In fact, she doesn't even know if John was accepted to any school.'

6 Conclusions

In this survey, we reviewed the traditional Q-to-P reduction approach to the semantics of responsive predicates, as well as three non-traditional approaches. The latter three approaches, i.e., the P-to-Q reduction approach, the uniformity approach and the ambiguity approach, were compared in view of how they would treat the two phenomena that pose problems for the more standard Q-to-P reduction approach. The non-reducibility of presuppositional predicates can be accounted for in all three approaches by encoding the appropriate conditions in the lexical denotations (or meaning cores) of relevant predicates. On the other hand, when it comes to the other problem with the traditional approach, i.e., predicates of relevance, it turns out that only the P-to-Q reduction and the uniformity approach, but not the ambiguity approach, have necessary resources to account for their behavior. In the following table, the comparison is summarized in terms of whether a theory shares the two problematic predictions, i.e., Q-to-P reducibility and the Entailment Prediction, with the Q-to-P reduction approach.

	Q-to-P reducibility	Entailment Prediction
Q-to-P reduction	Yes	Yes
P-to-Q reduction	No	No
Uniformity	No	No
Ambiguity (esp. George 2011)	No	Yes

Table 1: Comparison of the four approaches w.r.t. whether they make the two problematic predictions: Q-to-P reducibility and Entailment Prediction

Although the current survey was mostly concerned with the behavior of English responsive predicates, it is evident that in-depth cross-linguistic investigation of the lexical semantics of responsive predicates sheds additional light on the debate. For example, Roberts (2017) claims that the Estonian verb *mõtlema*—whose meaning is close to 'wonder' when it embeds an interrogative complement while it is close to 'think' when it embeds a declarative complement—can be adequately analyzed only under the P-to-Q reduction/Uniformity approaches to responsive predicates. At the same time, whichever approaches that turn out to be cross-linguistically empirically adequate should be evaluated in view of their predictive powers, in particular, how they can explain cross-linguistically stable generalizations about the interpretations of responsive predicates (cf. George 2011: §4.5.2).

Finally, theories of responsive predicates can also be assessed in view of their predictions concerning the selectional restrictions of other clause-embedding predicates, such as those that only embed interrogative complements (e.g., *wonder*, *inquire*) and those that only embed declarative complements (e.g., *believe*, *hope*). The selectional restrictions of these predicates is also an active domain of research in the current semantic literature. Uegaki (2015, 2016) and Ciardelli and Roelofsen (2015b) explain why *wonder* cannot embed declarative complements on the basis of the systematic contradiction of *wonder-that* predicted under the P-to-Q reduction/Uniformity approaches. Theiler et al. (2017) and Mayr (2017) explain the selectional restrictions of neg-raising attitude predicates such as *believe* and *think*, drawing on an earlier observation by Zuber (1982). Among non-neg-raising predicates, Uegaki and Sudo (2017) propose an explanation for the selectional restrictions of non-veridical preferential predicates, such as *hope* and *fear*, under the uniformity approach.

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