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The study of questions

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Abstract

Asking questions is a fundamental aspect of human nature. Languages all around the world encode interrogative constructions. It is therefore incumbent upon semanticists to capture the meaning of questions. However, achieving this goal faces a challenge under a truth conditional approach to meaning, since questions cannot easily be assigned a truth value. Moreover, it is not sufficient to focus only on the questions themselves; one must also determine what counts as a felicitous and informative answer, and how this relates to a speaker's intention in posing a question in a discourse context. How then do semanticists approach an investigation of questions? In this article, we present the core issues inherent to question-answer dynamics, review the main approaches to question-answer meaning, highlight how questions are situated in a discourse context, and explore extensions of questions that highlight the connection between semantics, pragmatics, and human reasoning.

INTRODUCTION

Asking questions is a fundamental aspect of human nature. It is a way of gathering information about the world and our interlocutors. For these reasons, all of the world's languages encode question constructions. However, there are challenges inherent to the study of question-answer dynamics, which go beyond the already complex syntactic variability observed within and across languages. These issues emerge when we try to identify the semantic contribution of questions.

Questions introduce a wrinkle for truth-conditional semantics, since one cannot straight-forwardly evaluate their truth value. If we are to assign questions truth values, how is this done? Once this hurdle is overcome, further questions arise. What problems result from a compositional semantic approach to questions? What happens when questions are embedded in larger structures? Once these questions have been answered, questions regarding the dynamics of question-answer exchanges come into play. Here, we can focus both on asking questions, and on answering them. Our goals influence the way we pose questions; these goals are therefore reflected in the form-meaning mapping. Each question posed by a speaker licenses different types of answers, and a listener must then decide among these possible answers when responding and continuing the conversational exchange.

These issues in turn raise questions about methodologies employed in investigating the meaning of questions. How do we model the question-answer relation formally? How can experimental and computational methods elucidate the border between semantics and pragmatics in questions? What roles do the discourse context and cognitive reasoning play in question-answer dynamics? In short, there are numerous avenues for researchers investigating the semantics of questions.

In this paper, we review these key issues that stand at the heart of the study of questions. A number of researchers have addressed these issues over the years, driving foundational work and exciting work still being done in the field of linguistics today. Our hope is that we can lay out the main issues and challenges in a way that allows advanced students to appreciate what is at stake in the formal study of questions, and become engaged in theoretical, experimental, and computational research on the semantics and pragmatics of questions that shapes the field for years to come.

THE FORCE AND FUNCTION OF QUESTIONS

Questions serve many purposes. For example, they allow us to signal to our interlocutors that we lack basic information that we need or want, and that we think they are in a position to supply it, as in (1). We call these *information-seeking questions*.

(1) a. How do I get to the train station?
b. Who brought which dish to the potluck?
c. What is the value of x in this equation?

We can identify different types of information-seeking questions based on both their syntactic form, and the kind of answer they require. For example, *yes-no* or polar questions, as in (2), have a characteristic fronted auxiliary verb and are answered with a *yes* or a *no*. *Wh*-questions, which involve a moved constituent (a *wh*-word in English), as in (4), and typically are answered with the missing information (e.g., *Commonwealth* or a pair-list answer such as *Dana read Commonwealth, Fox read Bel Canto*, etc.).

(2)	Did Dana read *Commonwealth*?	*YES-NO*
(3)	Did Dana read *Commonwealth* or *Bel Canto*?	ALTERNATIVE
(4)	What/which book did Dana read?	*WH*
(5)	Who read which book for the book club?	MULTIPLE *WH*

Questions allow us to elicit justifications or explanations in cases of disagreement or uncertainty, as in (6). And they can even allow us to move beyond mere information elicitation to create solidarity among interlocutors, as in (7).

(6) a. Why did you say that?
b. Why does he think that?

(7) a. Wasn't that strange?
b. You don't think it will rain on the picnic, do you?

While there are many more question types worth discussing,[1] we restrict our focus here to information-seeking questions (in both their root and embedded form), since there is much to be said about their semantic properties and their connection to the discourse context.

CAPTURING THE MEANING OF QUESTIONS

A long tradition of semantic research stemming from mathematics and logic analyzes the meaning of a proposition expressed by a declarative in terms of its truth-conditions, evaluated with respect to the

[1]Other question types include, for example, rhetorical questions (*Now what I am going to do?*), tag questions (*You like chocolate, don't you?*), or echo questions (*He said what?*).

world. If one asserts (8), we can assess whether the proposition expressed is true or false, given information we can collect in the world regarding the book(s) Dana read.

(8) Dana read *Commonwealth*.

A question, as opposed to a declarative, however, does not *prima facie* have truth conditions. What would it mean to look into the world to determine that any of the questions in (1)-(4) is true? In the sections that follow, we review the major approaches to question meaning set against this backdrop.

Proposition Set Semantics

Hamblin (1973) proposed that the meaning of a question is the set of its answers, and consequently, that knowing a question is equivalent to knowing what counts as an answer to the question.

(9) a. $[\![$What did Dana read?$]\!]$

b. $\lambda p.\exists x \in book.p = \lambda w.read_w(x)(Dana)$

Hamblin treats *wh*-words as existential indefinites (hence, $\exists x$) with implicitly restricted domains depending on the *wh*-word: *what* ranges over (non-animate) things, *who* over people, etc. Here we will assume that *what* is restricted to books; its extension can be written as: $\{x \mid book(x)\}$. Given Hamblin's proposal, the question in (9a) can be thought of as denoting the set described in (9b) By substituting in for *x* each entity in the extension of *what*, we can generate a set of propositional answers to the question concerning propositions about the things that Dana read, and determine the truth or falsity of each one.

Hamblin provided a formal mechanism to generate this set of answers called *Point-wise Function Application* (subsequently referred to as Hamblin Function Application). Point-wise Function Application is an operation that combines each element of one set with each element of a second set. The output is then collected up into a set. In the case of a question like (9a), the first set is a set of entities that the *wh*-word ranges over $\{x \mid book(x)\}$, and the second is the set containing the function $\lambda x.\lambda w.read_w(x)(Dana)$. The result is a set of propositions—the output of saturating the function denoted by the predicate with each entity in the *wh*-word's domain. These semantic, or congruent, answers are intended to be syntactically and semantically identical to the question (or as close as possible), with the missing information filled in. Figure 1 shows graphically how this works for the question, *"What did Dana read?"* The formal definition follows in (10). Point-wise Function Application takes each element b from the set of things β, and feeds them one-by-one to the (singleton) element in the set α, and returns the set of propositional answers, γ.

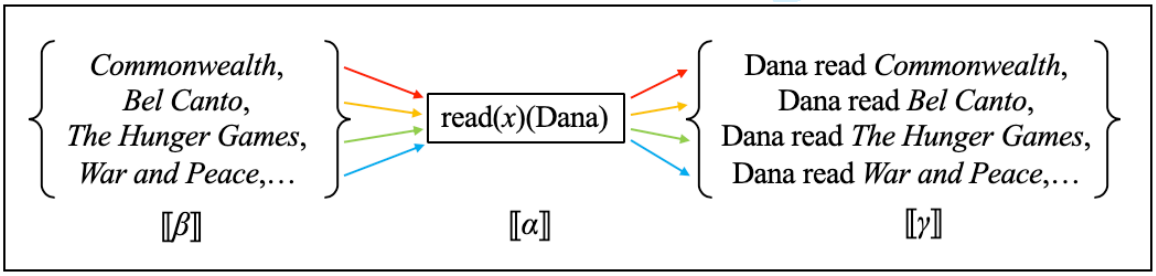

Figure 1: Graphical representation of Hamblin Point-wise Function Application for the question, *What did Dana read?*

(10) If $\{\alpha,\beta\}$ is in the set of γ's daughter nodes, $[\![\alpha]\!]^w \subseteq D_{\langle\sigma,\tau\rangle}$ and $[\![\beta]\!]^w \subseteq D_\sigma$, then $[\![\gamma]\!]^w = \{a(b) \mid a \in [\![\alpha]\!]^w \wedge b \in [\![\beta]\!]^w\}$

Hamblin's proposal in turn gives us a way to assign truth values to sentences in which questions are embedded in a matrix clause, as shown in (11a), where the matrix verb *know* takes an interrogative complement. As a result, we can treat the meaning of the root question and the corresponding embedded question the same. Belnap (1982) later referred to this as the *Equivalency Thesis*. While

Hamblin himself did not give a semantics for embedded questions, an extension of his analysis to (11a) might resemble (11b).

(11) a. ⟦Fox knows what Dana read⟧
b. Fox knows $\lambda p.\exists x \in \text{book}.p = \lambda w.\text{read}_w(x)(\text{Dana})$

In this case, Fox is said to know the set of possible answers to the question. But now, we might ask additional questions. What characterizes what counts as *possible* answers? Do all interrogative-embedding verbs impose the same truth conditions on their set of answers?

In the years following Hamblin's seminal proposal, semanticists have grappled with these very issues. A number of competing theories have developed in response to capture which answers (and which question readings) are licensed. Karttunen (1977) argued that (11) made the wrong predictions, and then refined Hamblin's semantics by imposing a requirement on the set of answers, namely that they must include only *true* answers (and not just *possible* answers). We can describe this as in (12).

(12) $\lambda p.\exists x.[\text{book}(x) \wedge p(w_0) \wedge p = \lambda w.\text{read}_w(x)(\text{Dana})]]$

The formula in (12) denotes the set of propositions *p*, such that for some book *x*, the proposition *p* is true in the actual world, and *p* is equal to the proposition that Dana read *x*. As we mentioned earlier, a question and an answer should share some information: if you ask what Dana read, the answer should correspond to what Dana read. Thus, there is an inherent connection between the question itself and the answers. A *question radical* is the aspect of the formal meaning of the question that is shared between the question and the answer. Here, this would be the function $\lambda x.\lambda w.\text{read}_w(x)(\text{Dana})$.

Karttunen treats *wh*-words as existential quantifiers: *what* denotes $\lambda P.\exists x.[\text{book}(x) \wedge P(x)]$. Interestingly, this move finds empirical support in the fact that in some languages, existential quantifiers and *wh*-words are homophonous, as with *nani* in Japanese. The logical form in (12) can be expressed graphically, as in Figure 2 below. This figure captures the fact that answers may be overlapping, because a question might have more than one true answer in a world.

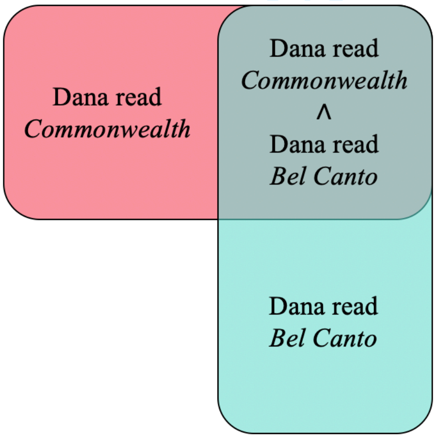

Figure 2: Graphical representation of (Karttunen) proposition sets.

Karttunen does not employ Hamblin Function Application in question composition. First, the declarative base of the question is shifted to a *proto-question*, $\lambda p.[[p = \lambda w.\text{read}_w(x)(\text{Dana})] \wedge p(w_0)]$, which combines with the existential quantified *what* via a *wh*-quantification rule, and returns the set of true answers. Despite these compositional differences, Hamblin- and Karttunen-style theories are classified together as *propositional set approaches* or often as *alternative semantics*, because the meaning of a question is the set of its propositional answers, or the alternatives. We refer the reader to Chapter 2 of Dayal (2016) for more details about the composition.

Partition Semantics

A different approach to question meaning analyzes questions as *partitions* on worlds (Higginbotham & May 1981, Groenendijk & Stokhof 1982, 1984). We can express it formally for our target sentence as in (13).

(13) a. ⟦What did Dana read?⟧
b. $\lambda w_i.\lambda w_j.[\lambda x.read_{wi}(x)(Dana) = \lambda x.read_{wj}(x)(Dana)]$

Intuitively, a partition can be thought of as a filter that chunks possible worlds into mutually exclusive parts, as represented graphically in Figure 3. When the partition chunks two worlds together, it treats them as indistinguishable. If Dana read only *Bel Canto* in two worlds, a partition semantics will group those worlds in the same partition (here, bottom right). This partition will be different from the one that groups worlds where Dana read *Commonwealth* and *Bel Canto* (here, top right). Thus, a question's meaning in partition semantics is a single proposition that is the complete true answer, rather than a set of propositions.

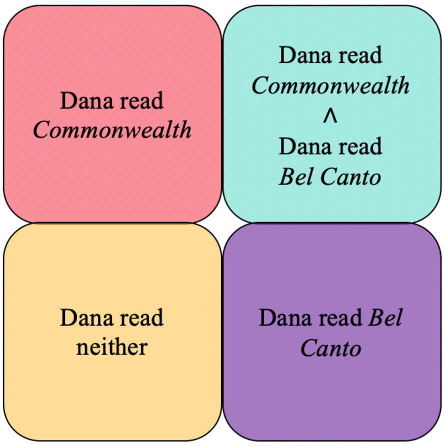

Figure 3: Graphical representation of partitions.

Groenendijk & Stokhof introduced an operator that delivers a particular cell of the partition, identifying the unique true answer to the question (1984, pp. 299). The operator has a meaning equivalent to *only*, essentially rendering the answer set *mutually exclusive and exhaustive*. It forms the basis of the EXH operator which many later theories employ to derive strong exhaustivity.

Functional Semantics

In contrast to these accounts of question semantics are *functional theories* of questions (Krifka 2001, Hagstrom 1998) (sometimes called Structured Meaning or Categorical theories). On these accounts, questions are taken to denote open functions. In Krifka's (2001) semantics, the open function is combined with a speech-act operator QUEST whose meaning is a request for the addressee to provide the missing information.

(14) a. $\lambda x.\lambda w.read_w(x)(Dana)$
b. QUEST $(\lambda x.\lambda w.read_w(x)(Dana))$

Compositional Issues in Questions

As we move beyond simple root questions, capturing question semantics becomes more complicated. Some more challenging questions include multiple *wh*-questions (15), alternative questions (16), and alternative-polar questions (17). (See Dayal (2016).)

(15) Who brought what to the party?
(16) Did Dana read *Bel Canto* or *Commonwealth*?
(17) Did Dana read *Bel Canto* or not?

Coordinated questions, as in (18), highlight some of the differences between the theories discussed above, and the difficulties of giving a unified semantics for all questions and question types. Conjunction is assumed to only coordinate objects of the same type (for example, one cannot grammatically conjoin an NP and a VP). These sentences are acceptable, despite the fact that two different sorts of objects are conjoined.

(18) a. Dana knows who ate cheese and that they acquired it illegally.
b. Dana knows who ate cheese and whether Fox danced the waltz.

Proposition set theories assign different semantic types to propositions and to questions. Thus, to explain the acceptability of the sentences in (18), these theories must abandon a longstanding standard assumption about constraints on conjunction. In contrast, functional theories have no trouble with (18a), but deliver a type mismatch with conjunction of different questions, as in (18b)

Let us explore the problem posed by (18) for a simple Hamblin semantics. Standardly, conjunction is treated as set intersection, while disjunction as set union (one or the other, and perhaps both).

Consider the sentence in (19), which features the conjunction of two propositions in a declarative sentence. Intuitively, this sentence should pick out the set of worlds where Dana both went to the party and she ate pizza last night, which therefore requires an intersection of the propositions (sets of possible worlds) that are associated with the two conjuncts, as captured in Figure 4. In contrast, set union would allow for a disjunctive meaning, where Dana may or may not have come to the party and may or may not have eaten pizza.

(19) Dana went to the party and ate pizza last night.

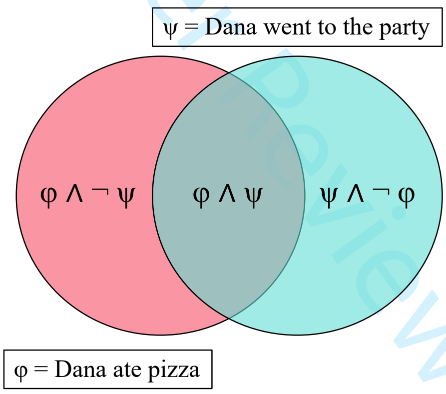

Figure 4: Graphical representation of (19), *Dana went to the party and ate pizza last night.*

Proposition set theories give a uniform semantic type for different questions (sets of propositions). So we should be able to conjoin questions using set intersection. However, because the sets of answers to two different question conjuncts may have no proposition in common, an intersective treatment of conjunction would deliver an empty set for the conjoined question. For example, consider the toy model in (20) for (18b), including two people, Dana and Fox. (20a) corresponds to the first conjunct, and (20b) to the second one. (20c) shows the result of intersecting these two sets.

(20) a. $[\![\text{who ate cheese}]\!]$ = { Dana ate cheese, Fox ate cheese }
b. $[\![\text{whether Fox danced the waltz}]\!]$ = { Fox danced the waltz, ¬Fox danced the waltz }
c. $[\![\text{who ate cheese}]\!] \cap [\![\text{whether Fox danced the waltz}]\!]$
= { Dana ate cheese, Fox ate cheese } ∩ { Fox danced the waltz, ¬Fox danced the waltz }
= { }

The derived meaning in (20c) is not the intuitive meaning of (18a). Intuitively, the meaning should include the answers to each question conjunct. At first glance, a solution to this problem might be to treat conjunction as set union instead, as in (21). Set union seems to deliver the intuitively correct meaning of (18a). However, upon more consideration, this solution still does not work. A union-based semantics incorrectly predicts that (18b) is true if Dana knows the answer to one of the questions, but not the other: that she and Fox ate cheese but not whether Fox danced the waltz, as in (21). Further, it would seem quite odd to have a procedure where conjunction is treated as set intersection for declaratives and as set union for interrogatives.

(21) ⟦who ate cheese and whether Fox danced the waltz⟧
= ⟦who ate cheese⟧ ∪ ⟦whether Fox danced the waltz⟧
= { Dana ate cheese, Fox ate cheese, Fox danced the waltz, ¬Fox danced the waltz }

Solutions within the proposition-set framework involve type-shifting answerhood operators, like those proposed by Dayal (1994, 1996), Lahiri (1991, 2002), or Heim (1994) (to be introduced in the section "Answers to Questions"). Such an operator shifts the meaning of a question (a set of propositions) into a proposition, which allows us to treat conjunction uniformly as intersection for declaratives and questions. Another solution is proposed by the Inquisitive Semantics framework, which radically alters the meaning of both declaratives and interrogatives. We turn to this approach in the next section.

Inquisitive Semantics

Inquisitive Semantics (Ciardelli, 2009; Groenendijk & Roelofsen, 2009; Ciardelli, Groenendijk & Roelofsen, 2013, 2019) models the relationship between interrogatives and declaratives by defining key properties (*inquisitiveness* and *informativeness*) that track how these two clause types make differing contributions to conversations. The semantic content of a question (or a declarative) is its *resolution conditions*.

Under Stalnaker's (1978, 1999) model of conversations, asserting p updates the context with the content of p, a proposition, which can be thought of as a set of worlds. Inquisitive Semantics builds upon this picture in order to capture the conversational effects of both declaratives and interrogatives. Under this approach, assertions and questions both express propositions, but propositions are modeled as *sets of sets of worlds*.

As a result of this richer type space, Inquisitive Semantics allows for a simplification of embedding verb semantics (see, e.g., Theiler, 2014; Uegaki, 2015; Theiler et al., 2018), and a unified treatment of the logical connectives (Roelofsen, 2013; Ciardelli, et al., 2017). Thus, Inquisitive Semantics offers a solution to the problems discussed in the previous section: conjunction and disjunction are treated as set intersection and union, respectively, and independent of what kinds of clauses are conjoined or disjoined Additionally, it allows questions to be resolved by a variety of answers, accounting for several question types that prove difficult for partition theories (e.g., non-exhaustive, conditional, and disjunctive questions). The difference between clauses lies not in their *type*, but in the *internal properties* of the higher-order propositions that they express.

Let us take a closer look at this approach to question semantics. In Inquisitive Semantics, a proposition p is *downward closed*: for any proposition $q \in p$, if $q' \subset q$, then $q' \in p$. Essentially, if a proposition q resolves the issue raised by a sentence meaning ($q \in p$), then any stronger proposition ($q' \subset q$) will do so too ($q' \in p$). The informative content of a proposition is the union of all the information states in the proposition, info(p) = $\cup p$. A proposition p is *informative* just in case it establishes some non-trivial information (22a). A proposition p is *inquisitive* in case the information it establishes does not settle the issues that have been raised (22b). Essentially, if a proposition p is inquisitive, info(p) will contain multiple maximal elements, or alternatives. In what follows, $\mathcal{W}$ is the set of all possible worlds.

(22) a. INFORMATIVE
A proposition p is *informative* iff info(p) $\neq \mathcal{W}$.

b. **INQUISITIVE**
A proposition p is *inquisitive* iff info(p) $\notin p$.

The distinction between declaratives and interrogatives is thus captured through these properties: the proposition expressed by a declarative is informative but not inquisitive, while the proposition expressed by a question is inquisitive but not informative. Put another way, the proposition expressed by a declarative contains a single alternative, while the one expressed by an interrogative contains multiple alternatives. Using these notions, we can now see how the propositions associated with the sentence types in (23) are distinguished.

(23)	a.	Dana went to the party.	DECLARATIVE
	b.	Did Dana go to the party?	*YES-NO* QUESTION
	c.	Who went to the party?	*WH*-QUESTION (NON-EXHAUSTIVE)
	d.	Who went to the party?	*WH*-QUESTION (STRONG EXHAUSTIVE)

Assume a model with only four logically possible worlds: one where Dana and Fox both come to the party (w_1), one where Dana comes to the party and Fox does not (w_2), one where Fox comes to the party but Dana does not (w_3), and a final where neither one comes to the party (w_4). The set of all worlds, $\mathcal{W}$, is thus $\{w_1, w_2, w_3, w_4\}$. Each box in Figure 5 (a)-(d) represents the proposition expressed by the respective sentences in (23). The groups of text correspond to a world (w_1 top left, w_2 top right, w_3 bottom left, w_4 bottom right), and the colored bubbles around the worlds represent the maximal element(s) or each proposition (the alternatives). Given downward closure, a full elaboration of each proposition would include all the subsets of the included alternatives.

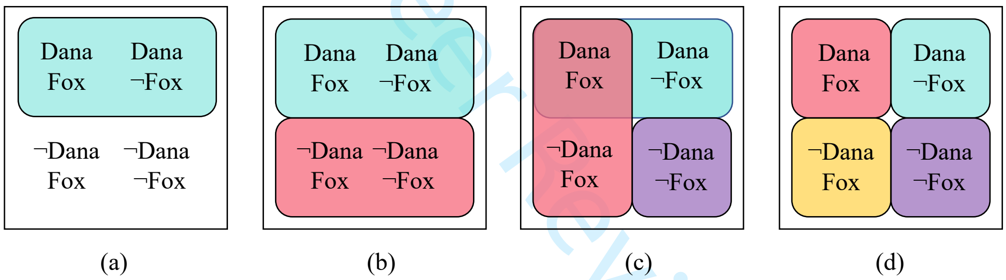

Figure 5: Graphical representation of the meanings of (23) in Inquisitive Semantics.

The proposition expressed by the declarative in (23a) can be fully elaborated as the (downward closed) set in (24).

(24) $A = \{\{w_1, w_2\}, \{w_1\}, \{w_2\}, \varnothing\}$

Recall that the informative content of A, info(A) is $\bigcup A$, the set, $\{w_1, w_2\}$. (23a) is not inquisitive because info(A) is an element of the set in (24), However, A is informative because info(A) $\neq \mathcal{W}$. For another example, the *yes-no* question in (23b) is inquisitive, because info(B) = $\{w_1, w_2, w_3, w_4\}$ and $\{w_1, w_2, w_3, w_4\} \notin B$. However, it is not informative because info(B) = $\mathcal{W}$.

(25) $B = \{\{w_1, w_2\}, \{w_3, w_4\}, \{w_1\}, \{w_2\}, \{w_3\}, \{w_4\}, \varnothing\}$

Finally, (23c) and (23d) are both inquisitive, but not informative. Note the similarity between the picture in Figure 5d, which represents a strong exhaustive set and the graph of a partition in Figure 3. We will introduce and discuss strengths of exhaustivity in the next section.

Because both declarative and interrogative sentence meanings are modeled as non-empty, downward-closed sets, entailment orderings may be defined for both inquisitive and informative content (i.e., between questions as well as declaratives). In virtue of these orderings, the logical notions for coordination may be preserved: *and* can be treated as a join operator (intersection), while *or* can be treated as a meet operator (union). Thus, coordination is treated consistently regardless of clause type or question type. See Roelofsen (2013) for algebraic details.

ANSWERS TO QUESTIONS

Earlier we emphasized the relation between a question's meaning and the answers it permits. Hintikka (1976) proposed that questions permit both an existential and a universal reading, and corresponding answers. Take the embedded question captured in the italicized part of (26). (26) actually has multiple truth conditions, captured in (27). (27a) is the existential reading: it requires that Fox knows of *at least one book that Dana read it*. (27b) is the universal reading: it requires that he know of *all of the books that Dana read*, *that she read them*. The existential reading is called the *non-exhaustive* reading, while the universal reading is called the *exhaustive* one. In this section, we focus on exhaustive readings, and come back to the non-exhaustive reading in a later section.

(26) Fox knows *what Dana read*.

(27) a. $\exists x$ [Dana read x ∧ Fox knows that Dana read x]

b. $\forall x$ [Dana read x → Fox knows that Dana read x]

Karttunen (1977) took issue with the non-exhaustive reading, pointing out that if (27a) were a possible reading of (26), then in a situation in which Dana read multiple books, one of which was *Bel Canto*, (28) would be acceptable. However, (28) is a contradiction, according to Karttunen: if Fox knows what Dana read, this entails that he knows that she read *Bel Canto*, in addition to any other book that she read.

(28) # Fox knows what Dana read, but he doesn't know that she read *Bel Canto*.

Karttunen argued that question meaning should encode *true* answers, which captures *weak exhaustivity*. In contrast, a Groenendijk & Stokhof style approach encodes question meanings as partitions on logical space. As we indicated earlier, partitions deliver mutually exclusive answers: once the true partition is determined, all other partitions are ruled out, thereby yielding *strong exhaustivity*. Thus, to know *what Dana read* entails knowing all of the books she read, and also knowing what she did not read.

Consider a world in which Dana read only *Commonwealth* and *Bel Canto*. Figure 2 presented us with a graphical representation of proposition set semantics, while Figure 3 presented us with partitions. Figure 2 does not encode any information about negative answers; all it provides is two overlapping answers: that Dana read *Commonwealth* and that Dana read *Bel Canto*. One of the key differences between proposition set semantics (weak exhaustivity) and partition semantics (strong exhaustivity) is what is encoded in the explicit answers delivered. In proposition set semantics, the statement *Dana read Bel Canto* is neutral as to whether Dana read *Commonwealth*, while partition semantics delivers answers that make determinations about every object in the domain. Thus, is it not possible to know what Dana read without knowing whether *Commonwealth* was read. Strong exhaustive semantics then tracks Groenendijk & Stokhof's intuitions about what is required of subjects in embedded-*wh* reports.

Many have proposed type-shifting operators to reconcile the descriptive insights of Hamblin, Karttunen and Groenendijk & Stokhof, and to account for various empirical facts. For example, Dayal (1994, 1996) proposed one to account for cross-linguistic facts about scope marking, and presuppositions associated with number marking in questions. Lahiri (1991, 2002) covered quantificational variability effects. These authors have argued that in these phenomenon, the correct interpretation depends on the availability of a Hamblin set---thus, their operators take as input a Hamblin set ($\lambda p.\exists x.[p = \lambda w'.read_{w'}(x)(Dana)]$), and derive from that more restricted answer sets.

Heim's operators are presented in (29). ANS_1 delivers weak exhaustivity, while ANS_2 delivers strong exhaustivity. In contrast to Dayal and Lahiri's operators, Q denotes an intensionalized Karttunen set, $\lambda w.\lambda p.\exists x.[book(x) \wedge p(w) \wedge p = \lambda w'.read_{w'}(x)(Dana)]$.

(29) a. $[\![\mathrm{ANS}_{\mathrm{HEIM1}}\ Q]\!] = \lambda w.\bigcap Q(w)$ WEAK EXHAUSTIVE
b. $[\![\mathrm{ANS}_{\mathrm{HEIM2}}\ Q]\!] = \lambda w_i.\lambda w_j.[\mathrm{ANS}_1(Q)(w_i) = \mathrm{ANS}_1(Q)(w_j)]$ STRONG EXHAUSTIVE

ANS_1 yields the intersection of the true answers, and ANS_2 yields a partition. Note that ANS_2 is defined in terms of ANS_1; the weak exhaustive meaning is more primitive than the strong exhaustive one. An embedding predicate may select for one operator or the other. Heim suggested that *know* selects for ANS_2 (and therefore gives rise to strong exhaustivity). We return to this point below. Beck & Rullmann (1999) modified Heim's two operators, and include a third one that delivers a non-exhaustive meaning to account for their observations about degree questions.[2]

George's (2011) derives the two readings not from two different operators, but via the presence or absence of an exhaustivity operator, X, as shown by the two LFs in (30). The Q operator existentially quantifies over the question abstract to derive a Hamblin set (and non-exhaustive readings), while the X operator (only present in (b)) returns an exhaustified set of propositions.

(30) a. $[\![\mathrm{Q}\ [\text{ what Dana read }]\ ]\!] =$ NON-EXHAUSTIVE
$\lambda p_{\langle s,t\rangle}.\exists\beta_e.[p = \lambda w.\mathrm{read}_w(\beta)(\mathrm{Dana})]$
b. $[\![\mathrm{Q}\ [\ \mathrm{X}\ [\text{ what Dana read }]\ ]\ ]\!] =$ STRONG EXHAUSTIVE
$\lambda p_{\langle s,t\rangle}.\exists\beta_{\langle e,t\rangle}.[p = \lambda w.[\beta = \lambda x.\mathrm{read}_w(x)(\mathrm{Dana})]]$

Similar to Heim, George posits that different embedding verbs may select for the X operator or not. Unlike Hamblin/Karttunen and other proposition set theories, George treats *wh*-words as lambda abstractors rather than as existentials.

Strong and weak exhaustivity are not the only possibilities. Another is *intermediate exhaustivity* (Spector 2005, Klinedinst & Rothschild 2011). A weak exhaustive semantics would predict that (26) is true in a situation where Fox knows the true answers, but is either ignorant about the books Dana didn't read, or falsely believes that Dana read a book that she actually did not read. This reading is sometimes described as being *false-answer sensitive*, referring to a more general effect whereby judgements of *know*-*wh* reports are rejected when the attitude holder has false beliefs about the false answers.

Klinedinst & Rothschild (2011) propose that an exhaustivity operator may be applied in two different places in the LF of a declarative with an embedded question, as shown by the LFs in (31), where α stands for a question-embedding verb, and *s* stands for a subject. Q denotes a weak exhaustive set.

(31) a. $[_{\mathrm{TP}}\ s\ [_{\mathrm{VP}}\ \alpha\ [_{\mathrm{CP}}\ \mathbf{EXH}\ \mathbf{Q}\ ]\ ]\ ]$ STRONG EXHAUSTIVE
b. $[_{\mathrm{CP}}\ \mathbf{EXH}\ [_{\mathrm{TP}}\ s\ [_{\mathrm{VP}}\ \alpha\ [_{\mathrm{CP}}\ \mathbf{Q}\ ]\ ]\ ]\ ]$ INTERMEDIATE EXHAUSTIVE
c. $[_{\mathrm{CP}}\ \ [_{\mathrm{TP}}\ s\ [_{\mathrm{VP}}\ \alpha\ [_{\mathrm{CP}}\ \mathbf{Q}\ ]\ ]\ ]\ ]$ WEAK EXHAUSTIVE

The intermediate exhaustive reading is derived via matrix exhaustification, (31b), and the strong exhaustive reading via embedded exhaustification, (31a). Finally, the weak exhaustive reading is derived when there is no exhaustivity operator present in the LF, (31c). This proposal thus has the benefit of capturing Heim's insight that weak exhaustivity is primitive, and strong exhaustivity is derived.

Exhaustivity and embedding predicates

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[2]We might say that these theories appeal to a *covert ambiguity*, because the phonological string associated with a question alone does not distinguish between the multiple abstract semantic representations which correspond to different meanings. Further, it is a *lexical ambiguity* because the representations differ only in *which* ANS operator is present, rather than its position at LF. In contrast, accounts like George (2011), Nicolae (2014), or Xiang (2016) would count as *structural ambiguity*, because they attribute different readings to the structural differences in the underlying LF.

Given a question-declarative pair such as the one in (32), a key question is, to what extent the answers permitted in the embedded question are linked to or constrained by the matrix verb?

(32) a. What did Dana read?
b. Fox knows what Dana read.

It is well known that verbs have both syntactic subcategorization restrictions and semantic selectional restrictions on their arguments (Grimshaw, 1979). For example, a verb like *know* can embed either an interrogative or a declarative proposition, as in (33), a verb like *wonder* can only embed a question, as shown in (34), and a verb like *think* can only embed a declarative, as shown in (35). For a typological distinction within interrogative-taking verbs, see Figure 6.

(33) a. Fox knows where Dana bought coffee.
b. Fox knows that Dana bought coffee.
(34) a. Fox wondered where Dana bought coffee.
b. *Fox wondered that Dana bought coffee (at Stumptown).
(35) a. *Fox thinks where Dana bought coffee.
b. Fox thinks that Dana bought coffee (at Stumptown).

Many researchers have attempted to provide a unified explanation of embedding predicates (Karttunen, 1977; Groenendijk & Stokhof, 1982; Ginzburg, 1995; Lahiri, 2002; Egré, 2008; Theiler, 2014; Romero, 2015; Spector & Egré, 2015; Uegaki, 2015; Theiler, Roelofsen, & Aloni, 2019; Mayr, 2019; Uegaki & Sudo, 2019, a.o.). Some researchers connect selectional restrictions to semantic properties of the embedding verb (e.g., factivity or veridicality). Responsive predicates in particular are troublesome because they allow both declarative and interrogative complements, yet their semantic properties do not always appear consistent across complements. For example, *tell* is non-veridical when it embeds a proposition, but appears to be veridical when it embeds an interrogative. While this point originated with Karttunen (1977), many recent scholars have questioned it (see Spector & Egré (2015)).

One question that arises is how to articulate the lexical entry for these verbs, and whether to proliferate entries for each syntactic frame a verb takes. Many treat the declarative-embedding use as basic, and attempt to reduce the interrogative-embedding uses to this basic one. This can be achieved in a number of ways: by separate lexical entries for each complement (cf. Spector & Egré, 2015; Karttunen, 1977), or by positing operator(s) that type-shift interrogatives to declaratives (Heim, 1994; Dayal, 1996; Beck & Rullmann, 1999; Lahiri, 2002). Still others take a different approach. Uegaki (2015) argues for a *reduction* in the other direction. George (2011) derives both uses from a common lexical entry. Inquisitive Semantic accounts like Theiler et al. (2018, 2019) avoid the problem all together because declaratives and interrogatives have the same semantic type. See Theiler et al. (2018), and Uegaki (2019) for thorough reviews of this issue.

Many theoreticians have suggested that the distributional differences in exhaustivity of embedded questions arise from either semantic selection restrictions or the verb's lexical semantics (see George, 2011; Guerzoni & Sharvit, 2007; Heim, 1994; Klinedinst & Rothschild, 2011; Lahiri, 2002; Spector and Egré, 2015; Uegaki, 2015; Theiler, 2014; Mayr, 2019, Uegaki, 2019). For example, it has frequently been claimed that *know* selects for strong exhaustivity (Groenendijk & Stokhof, 1982, 1984; Berman, 1991; Heim, 1994; George, 2011; Schulz & Roeper, 2011). However, there are clearly cases where strong exhaustivity is not required for *know*, as in (36).

(36) a. Dana knows where Fox can get a cup of coffee.
b. Dana knows how to get to Quantico.

Indeed, Hintikka (1976) and Asher & Lascarides (1998) have argued for a non-exhaustive semantics for questions on the basis of *know-how*-questions, Beck & Rullmann (1999) on the basis of degree questions (*know how much/many*), and Lahiri (2002) on the basis of quantificational variability effects (sentences like, *Fox mostly knows what Dana read*).

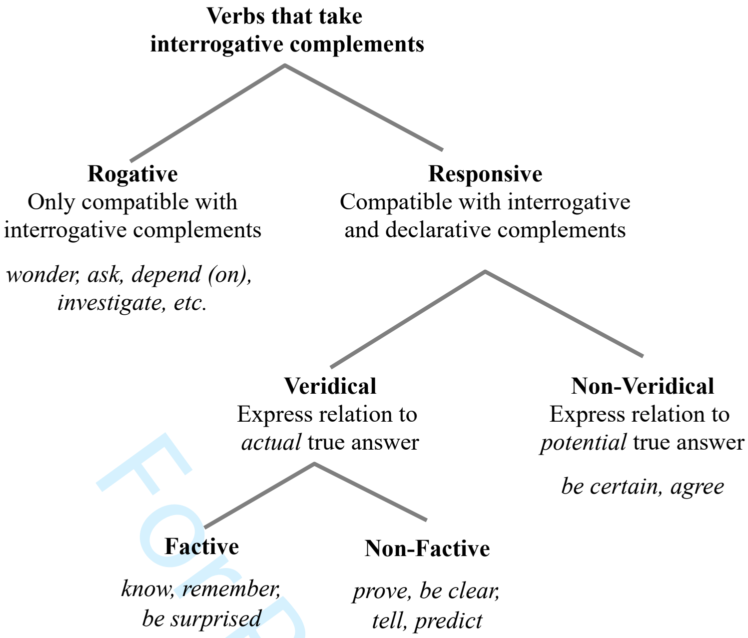

Figure 6: Typology of verbs, after Lahiri (2002)

Emotive factives such as *be surprised* or *be happy*, are often presented in support of a Karttunen-style semantics. These verbs seem to robustly allow weak exhaustivity, and perhaps even disallow strong exhaustivity (in contrast to *know*) (Berman, 1991; Beck and Rullmann, 1999; Heim, 1994; Sharvit, 2002). Lahiri (2002), Uegaki (2015), and others have argued that emotive factives do not allow for strong exhaustivity, because of their monotonicity properties. Monotonicity is defined for a relation between two sets that either preserves or reverses an ordering. Here, the relevant ordering is entailment. Consider the simple entailments between the sentences in (37). The truth of (37a) entails the truth of (37b). However, the truth of (37a) does not entail the truth of (37c).

(37) a. Cezi is a grey cat.
b. Cezi is a cat.
c. Cezi is a grey tabby cat.

An upward monotone function preserves truth from a subset to a superset (e.g., from *cute cat* to *cat*). A downward monotone function preserves truth from superset to subset (e.g., from *cute cat* to *cute tabby cat*).[3] Consider what happens when sentences like those in (37) are embedded, as in (38) and (39).

(38) a. It surprised Dana that Cezi is a grey cat.
b. It surprised Dana that Cezi is an cat.
c. It surprised Dana that Cezi is a grey tabby cat.[4]

(39) a. Dana knows that Cezi is a grey cat.
b. Dana knows that Cezi is a cat.

[3] The relevant notion for NPI licensing is actually Strawson entailment (von Fintel 1999) not classical entailment as presented in (38)-(40). *p entails q* if and only if every context where *p* is true, *q* is also true. But *p Strawson entails q* iff *p* classically entails *q* and all the presuppositions of *p* and *q* are met.
[4] One might argue that (38a) Strawson entails (38c), to the extent that the presupposition that Dana finds out that Cezi is a tabby when she finds out that Cezi is a cat is satisfied.

c. Dana knows that Cezi a grey tabby cat.

Despite the fact that (37a) entails (37b), this entailment is not preserved when these sentences are embedded under *surprise*, as in (38), but it *is* when they are when embedded under *know*. This is because *know* is upward monotonic on its complement, while *surprise* is non-monotonic. However, recent literature has suggested that strong exhaustivity may indeed be available with emotive predicates. (Klinedinst & Rothschild 2011, Theiler 2014, Cremers & Chemla 2017; Uegaki & Sudo 2019).

Negative Polarity Items (NPIs) have been argued to be licensed in downward-monotone/entailing environments (Ladusaw, 1979). Thus, their acceptability might present a diagnostic for exhaustivity. Observe the contrast in (40): *surprise* licenses NPIs with a declarative complement but not with an interrogative complement ((40a) v. (40b)). This suggests that the problem is tied to the *wh*-clause. However, the contrast between (40a) and (40c) suggests that (40a) is not ungrammatical because of the embedded question *per se*, but rather because of the interaction of *(be) surprise(d by)* with the embedded question.

(40) a. * Dana is surprised by <u>who has **ever** been to Paris</u>.
b. Dana is surprised <u>that Fox has **ever** been to Paris</u>.
c. Dana knows who has **ever** been to Paris.

Given this pattern, Guerzoni & Sharvit (2007) argue that emotive factives with embedded questions do not license NPIs, because they are weakly exhaustive. Only a strongly exhaustive operator can create a downward monotonic environment that licenses NPIs. Other explanations are given by Nicolae (2013) and Mayr (2013). For Nicolae, the exhaustivity operator that creates a downward entailing environment is optional, therefore explaining why (41a) is ungrammatical with NPIs. See also Schwarz (2017) for arguments against accounts which posit a covert exhaustivity operator.

Klinedinst & Rothschild (2011) argue that non-factive verbs (in particular, *tell* and *predict*) provide evidence for the intermediate exhaustive reading. Consider (41) in a situation where Frank and Emilio are the only people who sang.

(41) John predicted/told me who sang.

Klinedinst & Rothschild report (following Spector 2005, 2006) that if John predicts/tells me that Frank and Emilio sang, but has no opinions about anyone else, then (41) seems intuitively true. Thus, *predict* and *tell* do not appear to require strong exhaustivity. However, if John predicts/tells me that Frank, Emilio, *and Ted* sang, (41) is reported to be false.

Some verbs do not distinguish between true and false answers. For example, the non-factive verbs *agree* and *be certain* are argued to permit false answers (Berman 1991; Lahiri 1991, 2002; Beck & Rullmann, 1999; Spector, 2005; George, 2011; Spector & Egre, 2015; Theiler et al., 2018), as shown in (42). In (42a), Dana and Fox could have the same beliefs about who was elected, but they need not be accurate. The same can be said for (43b): Dana could be certain about who attended the party without being correct. Some have provided analyses of *be certain* to account for these non-veridicality facts, while maintaining a strongly exhaustive semantics (see Uegaki, 2015; Theiler et al., 2018).

(42) a. Dana and Fox agree on who was elected.
b. Dana is certain (about) who was at the party.

Experimental evidence for multiple readings of embedded questions

Given the various claims about the readings licensed by different embedding verbs, and disagreements about exhaustivity, researchers in recent years have turned to experimental methods in an attempt to understand which readings are available. By recruiting these methods to achieve more robust data, these researchers hope to clarify the theoretical landscape to determine a proper treatment of question semantics.

White & Rawlins (2016, 2018) have elucidated our understanding of attitude verb selectional restrictions by conducting large-scale acceptability judgements on over 1000 English clausal embedding verbs in dozens of different syntactic frames (the "MegaAttitude dataset"). Their computational model of selection encodes systematic mappings from semantic type to syntactic distribution. They trained this model on the acceptability data, and found that it derived selectional patterns consistent with many of the theoretical claims in the literature discussed above. White & Rawlins (2018) tested hypotheses about the relationship between the ability of a verb to embed a question (responsivity) and veridicality/factivity, and found that neither veridicality nor factivity were predictive of responsivity across the entire set of verbs. However, a correlation emerges when verb frequency is factored in: more frequent verbs show correlations between veridicality and factivity, while less frequent verbs do not. White & Rawlins note that this pattern diverges from a well-known result in the morphological literature, where low-frequency forms exhibit strong correlations with rule-based generalizations.

In an acceptability judgement task, Cremers and Chemla (2016) asked whether sentences such as (43) allow for weak, intermediate, or strong exhaustive readings, in contexts where different readings were made true or false. Their results confirmed that *know* gives rise to strong exhaustive readings (as anticipated), but showed that *know* also permits both intermediate and weak exhaustive readings. The verb *predict* gives rise to all three readings.

(43) John {knew/predicted} which squares were blue.

Sensitivity to false answers has been a focus of recent investigations from the semantic perspective (van Rooij & Schulz, 2004; Spector, 2005; Klinedinst & Rothschild, 2011; Theiler et al., 2016, 2018). Phillips & George (2018) experimentally examined the effect of false answers on judgements of *know* reports, and found that participants judge these reports to be *more* acceptable when the proportion of false to true beliefs that the agent holds is lower, and *less* acceptable when the proportion is higher.

Cremers and Chemla (2017) tested a range of embedding verbs to examine grammaticality with different complements and semantic properties, including monotonicity and the range of exhaustivity permitted. Their main focus was on three observations about emotive factives such as *(be) surprise(d)*. First, these verbs do not seem to license strong exhaustive inferences (repeated below): the inference from (a) to (b) does not hold in (44) the way it seems to in (45) (Groenendijk & Stokhof, 1982, 1984; Berman, 1991; Heim, 1994).

(44) a. It surprised Dana who came to the party
b. $\not\vDash$ It surprised Dana who didn't come to the party.
(45) a. Dana knows who came to the party
b. $\vDash$ Dana knows who didn't come to the party.

At the same time, it has been observed that *whether* complements are only possible with embedding verbs that are strongly exhaustive (Nicolae 2013, 2015; Guerzoni & Sharvit 2014). Indeed, emotive factives are generally ungrammatical with *whether* complements, as shown in (46):

(46) a. Dana knows whether Fox came to the party
b. *It surprised Dana whether Fox came to the party.

Finally, emotive factives appear to be non-monotonic and do not license NPIs (recall the discussion of (37)-(40)).

There have been many different explanations proposed as to why emotive factives exhibit these patterns, attempting to link their selectional restrictions to their entailment properties (Guerzoni &

Sharvit, 2007/2014; Abels, 2007; Guerzoni, 2007; Sæbø, 2007; Herbschrift, 2014; Nicolae, 2015; Roelofsen et al., 2018). Cremers & Chemla compared monotonicity, the availability of strong exhaustive readings, and the acceptability of *whether*-clauses, to determine whether these properties were linked. Across all verbs, the selectional properties were consistent with those reported in the literature. However, emotive factives were only found to be degraded with *whether*-questions, rather than completely ungrammatical. As for monotonicity, generally verbs patterned as predicted by the literature, with the exception of the emotive factives (*be happy* and *surprise*). Though these were claimed to be non-monotonic, *be happy* patterned with upward entailing verbs, while *be surprised* patterned with downward-entailing verbs. Finally, they found that *be surprised* licensed strong exhaustive readings, contrary to the predictions from the literature.

Chemla & George (2017) tested sentences with *agree* as in (47)-(48) in a variety of situations where two agents' beliefs about the colors of letters were aligned either completely or partially.

(47) John and Mary agree {on/about} which letters are blue.
(48) John and Mary don't agree {on/about} which letters are blue.

Participants judged (47) to be true and (48) false when John and Mary's beliefs about the blue letters matched, regardless of whether they were ignorant of or had false beliefs about the other letters. These results suggest that *agree* licenses intermediate exhaustivity. It is clear that these various lines of experimental work not only confirm and enrich the theory, but also reveal variability among participant judgments and linguistic categories that is not easily captured within existing theoretical proposals.

SEMANTICS AND PRAGMATICS IN QUESTIONS: NON-EXHAUSTIVITY

There has been considerable debate about what exactly licenses non-exhaustive answers, and whether there is a semantic mechanism that can explain non-exhaustivity. Imagine that a tourist on the street asks the question in (49).

(49) Where can I find an Italian newspaper?

The most natural answer is one that provides a non-exhaustive (or *mention-some*) answer (Hintikka, 1976; Groenendijk & Stokhof ,1982, 1984). However, this does not mean that an exhaustive answer is *ungrammatical*; it is simply not felicitous or optimal in this context. Consider another context, where the questioner is interested in the local newspaper market. Now, an exhaustive answer seems to be preferred. It would seem that changing the context or the goals of the speaker posing the question influences which answers are preferred, thereby implicating pragmatics.

(Non-)exhaustivity appears to co-vary with the type of *wh*-question posed: *who* questions are most often associated with an exhaustive answer, while *where*, *why*, or *how* questions with a non-exhaustive answer (Hintikka, 1976; Ginzburg, 1995; Asher & Lascarides, 1998). Compare (50) to (51).

(50) Who came to the party?
(51) How do I get to the train station?

However, this pattern appears to be more of a preference or an interpretational default, rather than a categorical distinction. One can easily come up with examples of *who* questions that permit non-exhaustive answers. Imagine a smoker asking *Who has a light?* Or, following Asher & Lascarides, a gossip columnist asking (50) when they are interested in the whereabouts of a relevant celebrity, but not the stage crew or personal assistants. Asher & Lascarides (1998) have suggested that these preferences may be overridden by contexts that make explicit a questioner's goals and mental state. Further, these preferences may be enhanced or cancelled by particles like *for example* (e.g., *Who, for example, came to the party?*) or *all* (e.g., *Who all came to the party?*) in languages such as English, German, Dutch among others (see Reis, 1992; Beck, 1997; Beck & Rullmann, 1999; Zimmerman, 2007; Fekete, Schulz, & Ruigendijk, 2018).

There are two main types of proposals to account for non-exhaustive readings. One line of approaches (Groenendijk & Stokhof, 1982, 1984; Asher & Lascarides, 1998; van Rooij, 2003) argues that there is a single underlying semantic representation corresponding to the phonological string associated with a question. What exactly this single representation is or encodes differs between theories. For Groenendijk & Stokhof, the representation is a partition, and the mechanism that derives non-exhaustivity is purely pragmatic. A speaker may accept a non-exhaustive answer in a context if it satisfies their goals, although this will not constitute a complete (semantic) answer to their question. Other single representation approaches (Ginzburg, 1995; Asher & Lascarides, 1998; van Rooij, 2003), propose that exhaustivity is only determined relative to contextual parameters (for example, the speaker's goal, decision problem, or mental state). Without values for those parameters, a question's underlying representation is underspecified for (non-)exhaustivity.

For Ginzburg (1995), an answer is defined by what resolves the questioner's goals. 'Resolvedness' is pragmatic relation between a potential answer, the question, and contextual parameters, including the questioner's goal and mental state. Asher & Lascarides (1998) dynamically model the interaction between discourse, sentence meaning, and compositional semantics. Their theory also employs contextual variables (notably, the questioner's cognitive state and plan), which factor into the calculation of exhaustivity. They encode a non-exhaustive semantic meaning that may be enriched to an exhaustive one through integration with context-sensitive variables. However, in contrast to Ginzburg (1995), they implement this meaning compositionally using Segmented Discourse Representation Structures, which allow for discourse structures to be dynamically captured, including discourse referents and discourse relations (Asher 1993; Asher & Lascarides 1994).

Van Rooij (2003) includes an operator sensitive to the speaker's decision problem, which is a formal mechanism that originates in Bayesian decision theory. According to this theory, the decision problem determines which answers are most useful in a given context and the operator ranks answers according to how relevant and useful they are to solving the problem. However, the utility of a mention-some reading will never exceed the utility of the mention-all reading (van Rooij 2004, p10). If this is right, hearers should never prefer a non-exhaustive reading over an exhaustive one.

The second line of approaches proposes multiple underlying representations for a question (Beck & Rullmann, 1999; Lahiri, 2002; George, 2011; Nicolae, 2014; Fox, 2014/2018; Xiang, 2016). While Heim's theory does not explicitly derive non-exhaustive readings (since the two Ans operators only account for weak and strong exhaustivity), Beck and Rullmann (1999) include two Ans operators for weak and strong exhaustivity, plus a *third* operator for non-exhaustivity. Lahiri's operator includes a variable that restricts a Hamblin set, based on the lexical semantics of embedding verbs, or the context more generally.

George (2011, Ch. 2) argues that the data that have been used in support of weak exhaustive answers provide evidence for the non-exhaustive answer. In George's semantics, a question's base denotation is a Hamblin set, which derives the non-exhaustive answer. Inquisitive Semantic approaches also fall in the multiple representation category, since under this framework, a question may correspond to either a non-exhaustive or strong exhaustive proposition. (Recall (23) and Figure 5.)

A subset of multiple representation theories claims that non-exhaustivity is semantically licensed only in particular questions (George, 2011, Ch. 6; Nicolae, 2013; Fox, 2014; Xiang, 2016). Consider the embedded and root questions in (52) and (53).

(52) a. Who are some of the party-goers? EXISTENTIAL QUANTIFIERS
b. Dana knows who some of the party-goers are.

(53) a. Where can we find coffee? (EXISTENTIAL) MODAL VERBS
b. Dana knows where we can find coffee.

The existential *some* in the partitive construction in (52) and the modal *can* in (53) are often argued to give rise to grammaticalized non-exhaustivity. George (2011, Ch. 6) proposes that existential elements can syntactically scope over the exhaustivity operator X by undergoing Quantifier Raising (QR) (May, 1985). Nicolae (2013) suggests that the existential (or in the case of a modal, the *wh*-word) can be reinterpreted as a complex quantifier, and undergo QR twice. As a result, it quantifies into a subset of the *wh*-domain such that, for each possible subset, it constitutes a maximally informative answer. This reinterpretation is licensed when the context fails to provide a unique maximally informative answer.

Several problems have been identified with these approaches, as noted by Fox (2014) and Nicolae herself. The main objection is that while existential quantifiers undergo QR, modals do not. See Fox (2014) and Dayal (2016) for discussion. In contrast to these two syntactic approaches, Xiang's proposal achieves a scope effect without syntactic movement of the modal.[5] First, the *wh*-word is raised to a higher type via a type-shifting operator. This operator is modified from the operator employed in continuation-based grammars (Barker, 2002; Barker and Shan, 2014; Shan, 2004; Shan and Barker, 2006), whose roots are Partee's (1986) LIFT. A type-lifted *wh*-trace out-scopes the modal to derive the exhaustive reading; while the non-exhaustive reading arises when the *wh*-trace is out-scoped by the modal. Across these accounts, while the grammar outputs two different scope relations, which scope relation a given question has is determined by pragmatic factors.

Additional evidence for the role of the modal comes from a comparison of examples such as those in (54) (George, 2011; Nicolae, 2013; Fox, 2014; Dayal, 2016; Xiang, 2016; Xiang & Cremers, 2017).

(54) a. Dana knows where I found coffee.
b. Dana knows where I can find coffee.
c. Dana knows where to find coffee.

While (55a) seems to require (or prefer) an exhaustive answer, (55b) and (55c) do not. The modal *can* in (55b) is claimed to contribute both existential quantificational force and a context-sensitive component (the conversational background comprised of the modal base and ordering source, Kratzer 1981). This provides a goal-oriented interpretation. While there is no overt modal in (55c), Bhatt (1999) has proposed that infinitival clauses contain covert existential modals, which have a contextual restriction on the modal base which is anaphoric to a contextual goal.

So far, we have discussed three surface-level cues that are linked to the acceptability of the non-exhaustive reading: the embedding verb, the *wh*-word, and modality or finiteness—all of which in turn interact with the role of the conversational context. Moyer & Syrett (2019) sought to obtain experimental evidence for each of these surface-level cues. They presented vignettes to participants, paired with a question and a hearer's answer. Participants were asked to assess a report containing an embedded question in light of the answer in the vignette (and implicitly, in light of the linguistic form of the question). As predicted, participants accepted non-exhaustive answers in non-finite *know* sentential targets more often than with finite targets. However, finite targets were accepted above chance—a surprising result if non-exhaustivity depends upon the presence of a modal. Moreover, non-exhaustive answers were more acceptable for *where* than *who* questions. Finally, non-exhaustive answers were more acceptable than exhaustive answers in situations where the contextual stakes were low. These results confirm the importance of discourse context for what counts as an appropriate answer. The context provides the information relevant to resolving the question, including the questioner's goal. The goal determines how much information is needed, thus specifying which answers are most informative for achieving that goal.

[5] While Nicolae's solution involves syntactic movement of the quantifier, it is similar to Xiang's later proposal in that there is no syntactic movement of the modal itself, but rather the higher-order *wh*-phrase.

In recent years, there has been interest in the questions from a computational perspective, using Bayesian inference for cognitive modeling. Formally, this involves conditionalization (or update) through iterated application of Bayes' rule. The Rational Speech Acts (RSA) framework of Goodman & Frank (2012) models pragmatic reasoning as a recursive Bayesian inference whereby when one encounters an utterance (data), one updates one's beliefs about the state of the world (hypotheses), given what one believes the utterance to mean (convey about the world). It has been extended to model question-answer dynamics (Hawkins, et al., 2015). Their model takes the basic RSA model and adds parameters to capture the sensitivity of answers to questioner goals. They found that the model which includes inference about the speaker's goal is best able to capture the behavioral data collected about how human participants answer in response to questions.

CONCLUSION

In this paper, we have reviewed theoretical, experimental, and computational approaches to the meaning of questions. We first introduced the challenges a truth conditional approach to questions encounters, then turned to discuss the history of formal semantic accounts of the meaning of questions. We then reviewed the different ways these theories handle a variety of question types, and the particular problem that non-exhaustivity poses to formal accounts. Finally, we transitioned into presenting how our understanding of question meaning has been enriched and extended by recent experimental and computational approaches.

Much remains to be discovered about the meaning of questions. What is the division of labor between syntax, semantics, and pragmatics in question interpretation, and answer licensing? How can (non-) exhaustivity best be captured? What role does the lexical semantics of the embedding verb play in determining the logical properties of a question and restrictions on complementation? These questions will no doubt fuel future research on this topic.

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ADVANCED REVIEW

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Abstract

Asking questions is a fundamental aspect of human nature. Languages all around the world encode interrogative constructions. It is therefore incumbent upon semanticists to capture the meaning of questions. However, achieving this goal faces a challenge under a truth conditional approach to meaning, since questions cannot easily be assigned a truth value. Moreover, it is not sufficient to focus only on the questions themselves; one must also determine what counts as a felicitous and informative answer, and how this relates to a speaker's intention in posing a question in a discourse context. How then do semanticists approach an investigation of questions? In this article, we present the core issues inherent to question-answer dynamics, review the main approaches to question-answer meaning, highlight how questions are situated in a discourse context, and explore extensions of questions that highlight the connection between semantics, pragmatics, and human reasoning.

INTRODUCTION

Asking questions is a fundamental aspect of human nature. It is a way of gathering information about the world and our interlocutors. For these reasons, all of the world's languages encode question constructions. However, there are challenges inherent to the study of question-answer dynamics, which go beyond the already complex syntactic variability observed within and across languages. These issues emerge when we try to identify the semantic contribution of questions.

Questions introduce a wrinkle for truth-conditional semantics, since one cannot straight-forwardly evaluate their truth value. If we are to assign questions truth values, how is this done? Once this hurdle is overcome, further questions arise. What problems result from a compositional semantic approach to questions? What happens when questions are embedded in larger structures? Once these questions have been answered, questions regarding the dynamics of question-answer exchanges come into play. Here, we can focus both on asking questions, and on answering them. Our goals influence the way we pose questions; these goals are therefore reflected in the form-meaning mapping. Each question posed by a speaker licenses different types of answers, and a listener must then decide among these possible answers when responding and continuing the conversational exchange.

These issues in turn raise questions about methodologies employed in investigating the meaning of questions. How do we model the question-answer relation formally? How can experimental and computational methods elucidate the border between semantics and pragmatics in questions? What roles do the discourse context and cognitive reasoning play in question-answer dynamics? In short, there are numerous avenues for researchers investigating the semantics of questions.

In this paper, we review these key issues that stand at the heart of the study of questions. A number of researchers have addressed these issues over the years, driving foundational work and exciting work still being done in the field of linguistics today. Our hope is that we can lay out the main issues and challenges in a way that allows advanced students to appreciate what is at stake in the formal study of questions, and become engaged in theoretical, experimental, and computational research on the semantics and pragmatics of questions that shapes the field for years to come.

THE FORCE AND FUNCTION OF QUESTIONS

Questions serve many purposes. For example, they allow us to signal to our interlocutors that we lack basic information that we need or want, and that we think they are in a position to supply it, as in (1). We call these *information-seeking questions*.

(1) a. How do I get to the train station?
b. Who brought which dish to the potluck?
c. What is the value of *x* in this equation?

We can identify different types of information-seeking questions based on both their syntactic form, and the kind of answer they require. For example, *yes-no* or polar questions, as in (2), have a characteristic fronted auxiliary verb and are answered with a *yes* or a *no*. *Wh*-questions, which involve a moved constituent (a *wh*-word in English), as in (4), and typically are answered with the missing information (e.g., *Commonwealth* or a pair-list answer such as *Dana read Commonwealth, Fox read Bel Canto*, etc.).

(2)	Did Dana read *Commonwealth*?	*YES-NO*
(3)	Did Dana read *Commonwealth* or *Bel Canto*?	ALTERNATIVE
(4)	What/which book did Dana read?	*WH*
(5)	Who read which book for the book club?	MULTIPLE *WH*

Questions allow us to elicit justifications or explanations in cases of disagreement or uncertainty, as in (6). And they can even allow us to move beyond mere information elicitation to create solidarity among interlocutors, as in (7).

(6) a. Why did you say that?
b. Why does he think that?
(7) a. Wasn't that strange?
b. You don't think it will rain on the picnic, do you?

While there are many more question types worth discussing,[1] we restrict our focus here to information-seeking questions (in both their root and embedded form), since there is much to be said about their semantic properties and their connection to the discourse context.

CAPTURING THE MEANING OF QUESTIONS

A long tradition of semantic research stemming from mathematics and logic analyzes the meaning of a proposition expressed by a declarative in terms of its truth-conditions, evaluated with respect to the

[1]Other question types include, for example, rhetorical questions (*Now what I am going to do?*), tag questions (*You like chocolate, don't you?*), or echo questions (*He said what?*).

world. If one asserts (8), we can assess whether the proposition expressed is true or false, given information we can collect in the world regarding the book(s) Dana read.

(8) Dana read *Commonwealth*.

A question, as opposed to a declarative, however, does not *prima facie* have truth conditions. What would it mean to look into the world to determine that any of the questions in (1)-(4) is true? In the sections that follow, we review the major approaches to question meaning set against this backdrop.

Proposition Set Semantics

Hamblin (1973) proposed that the meaning of a question is the set of its answers, and consequently, that knowing a question is equivalent to knowing what counts as an answer to the question.

(9) a. ⟦What did Dana read?⟧
b. $\lambda p.\exists x \in book.p = \lambda w.read_w(x)(Dana)$

Hamblin treats *wh*-words as existential indefinites (hence, ∃x) with implicitly restricted domains depending on the *wh*-word: *what* ranges over (non-animate) things, *who* over people, etc. Here we will assume that *what* is restricted to books; its extension can be written as: {x | book(x)}. Given Hamblin's proposal, the question in (9a) can be thought of as denoting the set described in (9b) By substituting in for *x* each entity in the extension of *what*, we can generate a set of propositional answers to the question concerning propositions about the things that Dana read, and determine the truth or falsity of each one.

Hamblin provided a formal mechanism to generate this set of answers called *Point-wise Function Application* (subsequently referred to as Hamblin Function Application). Point-wise Function Application is an operation that combines each element of one set with each element of a second set. The output is then collected up into a set. In the case of a question like (9a), the first set is a set of entities that the *wh*-word ranges over {x | book(x)}, and the second is the set containing the function $\lambda x.\lambda w.read_w(x)(Dana)$. The result is a set of propositions—the output of saturating the function denoted by the predicate with each entity in the *wh*-word's domain. These semantic, or congruent, answers are intended to be syntactically and semantically identical to the question (or as close as possible), with the missing information filled in. Figure 1 shows graphically how this works for the question, *"What did Dana read?"* The formal definition follows in (10). Point-wise Function Application takes each element b from the set of things β, and feeds them one-by-one to the (singleton) element in the set α, and returns the set of propositional answers, γ.

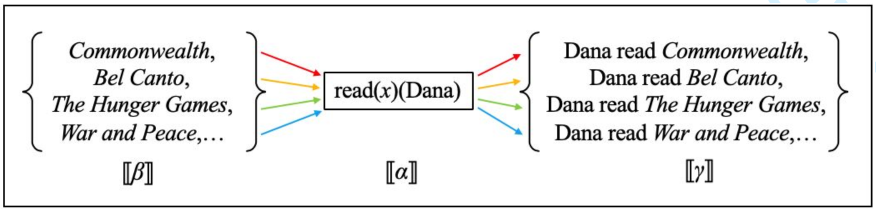

Figure 1: Graphical representation of Hamblin Point-wise Function Application for the question, *What did Dana read?*

~~(9)~~(10) If {α,β} is in the set of γ's daughter nodes, $⟦\alpha⟧^w \subseteq D_{\langle\sigma,\tau\rangle}$ and $⟦\beta⟧^w \subseteq D_\sigma$, then $⟦\gamma⟧^w = \{a(b) \mid a \in ⟦\alpha⟧^w \wedge b \in ⟦\beta⟧^w\}$

Hamblin's proposal in turn gives us a way to assign truth values to sentences in which questions are embedded in a matrix clause, as shown in (11a), where the matrix verb *know* takes an interrogative complement. As a result, we can treat the meaning of the root question and the corresponding embedded question the same. Belnap (1982) later referred to this as the *Equivalency Thesis*. While

Hamblin himself did not give a semantics for embedded questions, an extension of his analysis to (11a) might resemble (11b).

(11) a. ⟦Fox knows what Dana read⟧
b. Fox knows $\lambda p.\exists x \in book.p = \lambda w.read_w(x)(Dana)$

In this case, Fox is said to know the set of possible answers to the question. But now, we might ask additional questions. What ~~answers should~~ characterizes what counts as *possible* answers? Do all interrogative-embedding verbs impose the same truth conditions on their set of answers?

In the years following Hamblin's seminal proposal, semanticists have grappled with these very issues. A number of competing theories have developed in response to capture which answers (and which question readings) are licensed. Karttunen (1977) argued that (11) made the wrong predictions, and then refined Hamblin's semantics by imposing a requirement on the set of answers, namely that they must include only *true* answers (and not just *possible* answers). We can describe this as in (12).

(12) $\lambda p.\exists x.[book(x) \wedge p(w_0) \wedge p = \lambda w.read_w(x)(Dana)]]$

The formula in (12) denotes the set of propositions *p*, such that for some book *x*, the proposition *p* is true in the actual world, and *p* is equal to the proposition that Dana read *x*. As we mentioned earlier, a question and an answer should share some information: if you ask what Dana read, the answer should correspond to what Dana read. Thus, there is an inherent connection between the question itself and the answers. A *question radical* is the aspect of the formal meaning of the question that is shared between the question and the answer. Here, this would be the function $\lambda x.\lambda w.read_w(x)(Dana)$.

Karttunen treats *wh*-words as existential quantifiers: *what* denotes $\lambda P.\exists x.[book(x) \wedge P(x)]$. Interestingly, this move finds empirical support in the fact that in some languages, existential quantifiers and *wh*-words are homophonous, as with *nani* in Japanese. The logical form in (12) can be expressed graphically, as in Figure 2 below. This figure captures the fact that answers may be overlapping, because a question might have more than one true answer in a world.

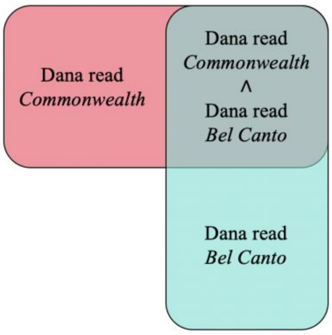

Figure 2: Graphical representation of (Karttunen) proposition sets.

Commented [MOU1]: I've made all the graphs consistent in color.

Karttunen does not employ Hamblin Function Application in question composition. First, the declarative base of the question is shifted to a *proto-question*, $\lambda p.[[p = \lambda w.read_w(x)(Dana)] \wedge p(w_0)]$, which combines with the existential quantified *what* via a *wh*-quantification rule, and returns the set of true answers. Despite these compositional differences, Hamblin- and Karttunen-style theories are classified together as *propositional set approaches* or often as *alternative semantics*, because the meaning of a question is the set of its propositional answers, or the alternatives. We refer the reader to Chapter 2 of Dayal (2016) for more details about the composition.

Partition Semantics

A different approach to question meaning analyzes questions as *partitions* on worlds (Higginbotham & May 1981, Groenendijk & Stokhof 1982, 1984). We can express it formally for our target sentence as in (13).

~~(10)~~(13) a. $[\![\text{What did Dana read?}]\!]$
b. $\lambda w_i.\lambda w_j.[\lambda x.\text{read}_{wi}(x)(\text{Dana}) = \lambda x.\text{read}_{wj}(x)(\text{Dana})]$

Intuitively, a partition can be thought of as a filter that chunks possible worlds into mutually exclusive parts, as represented graphically in Figure 3. When the partition chunks two worlds together, it treats them as indistinguishable. If Dana read only *Bel Canto* in two worlds, a partition semantics will group those worlds in the same partition (here, bottom right). This partition will be different from the one that groups worlds where Dana read *Commonwealth* and *Bel Canto* (here, top right). Thus, a question's meaning in partition semantics is a single proposition that is the complete true answer, rather than a set of propositions.

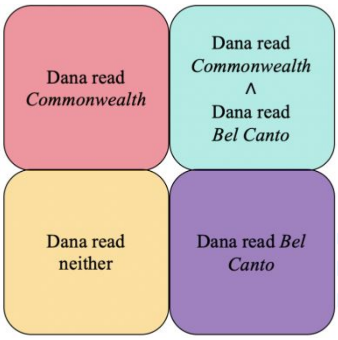

Figure 3: Graphical representation of partitions.

Groenendijk & Stokhof introduced an operator that delivers a particular cell of the partition, identifying the unique true answer to the question (1984, pp. 299). The operator has a meaning equivalent to *only*, essentially rendering the answer set *mutually exclusive and exhaustive*. It forms the basis of the EXH operator which many later theories employ to derive strong exhaustivity.

Functional Semantics

In contrast to these accounts of question semantics are *functional theories* of questions (Krifka 2001, Hagstrom 1998) (sometimes called Structured Meaning or Categorical theories). On these accounts, questions are taken to denote open functions. In Krifka's (2001) semantics, the open function is combined with a speech-act operator QUEST whose meaning is a request for the addressee to provide the missing information.

~~(11)~~(14) a. $\lambda x.\lambda w.\text{read}_w(x)(\text{Dana})$
b. QUEST $(\lambda x.\lambda w.\text{read}_w(x)(\text{Dana}))$

Compositional Issues in Questions

As we move beyond simple root questions, capturing question semantics becomes more complicated. Some more challenging questions include multiple *wh*-questions (15), alternative questions (16), and alternative-polar questions (17). (See Dayal (2016).)

~~(12)~~(15) Who brought what to the party?
~~(13)~~(16) Did Dana read *Bel Canto* or *Commonwealth*?

~~(14)~~(17) Did Dana read *Bel Canto* or not?

Coordinated questions, as in (18), highlight some of the differences between the theories discussed above, and the difficulties of giving a unified semantics for all questions and question types. Conjunction is assumed to only coordinate objects of the same type (for example, one cannot grammatically conjoin an NP and a VP). These sentences are acceptable, despite the fact that two different sorts of objects are conjoined.

~~(15)~~(18) a. Dana knows who ate cheese and that they acquired it illegally.
b. Dana knows who ate cheese and whether Fox danced the waltz.

Proposition set theories assign different semantic types to propositions and to questions. Thus, to explain the acceptability of the sentences in (18), these theories must abandon a longstanding standard assumption about constraints on conjunction. In contrast, functional theories have no trouble with (18a), but deliver a type mismatch with conjunction of different questions, as in (18b)

Let us explore the problem posed by (18) for a simple Hamblin semantics. Standardly, conjunction is treated as set intersection, while disjunction as set union (one or the other, and perhaps both).

Consider the sentence in (19), which features the conjunction of two propositions in a declarative sentence. Intuitively, this sentence should pick out the set of worlds where Dana both went to the party and she ate pizza last night, which therefore requires an intersection of the propositions (sets of possible worlds) that are associated with the two conjuncts, as captured in Figure 4. In contrast, set union would allow for a disjunctive meaning, where Dana may or may not have come to the party and may or may not have eaten pizza.

(19) Dana went to the party and ate pizza last night.

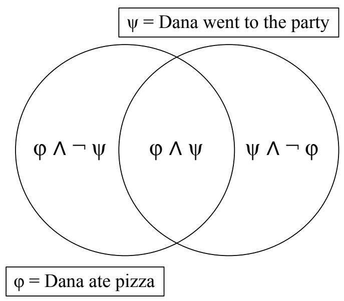

Figure 4: Graphical representation of (19), *Dana went to the party and ate pizza last night.*

Proposition set theories give a uniform semantic type for different questions (sets of propositions). So we should be able to conjoin questions using set intersection. However, because the sets of answers to two different question conjuncts may have no proposition in common, an intersective treatment of conjunction would deliver an empty set for the conjoined question. For example, consider the toy model in (20) for (18b), including two people, Dana and Fox. (20a) corresponds to the first conjunct, and (20b) to the second one. (20c) shows the result of intersecting these two sets.

~~(16)~~(20) a. ⟦who ate cheese⟧ = { Dana ate cheese, Fox ate cheese }
b. ⟦whether Fox danced the waltz⟧ = { Fox danced the waltz, ¬Fox danced the waltz }
c. ⟦who ate cheese⟧ ∩ ⟦whether Fox danced the waltz⟧
= { Dana ate cheese, Fox ate cheese } ∩ { Fox danced the waltz, ¬Fox danced the waltz }

= { }

The derived meaning in (20c) is not the intuitive meaning of (18a). Intuitively, the meaning should include the answers to each question conjunct. At first glance, a solution to this problem might be to treat conjunction as set union instead, as in (21). Set union seems to deliver the intuitively correct meaning of (18a). However, upon more consideration, this solution still does not work. A union-based semantics incorrectly predicts that (18b) is true if Dana knows the answer to one of the questions, but not the other: that she and Fox ate cheese but not whether Fox danced the waltz, as in (21). Further, it would seem quite odd to have a procedure where conjunction is treated as set intersection for declaratives and as set union for interrogatives.

~~(17)~~(21) ⟦who ate cheese and whether Fox danced the waltz⟧
= ⟦who ate cheese⟧ ∪ ⟦whether Fox danced the waltz⟧
= { Dana ate cheese, Fox ate cheese, Fox danced the waltz, ¬Fox danced the waltz }

Solutions within the proposition-set framework involve type-shifting answerhood operators, like those proposed by Dayal (1994, 1996), Lahiri (1991, 2002), or Heim (1994) (to be introduced in the section "Answers to Questions"). Such an operator shifts the meaning of a question (a set of propositions) into a proposition, which allows us to treat conjunction uniformly as intersection for declaratives and questions. Another solution is proposed by the Inquisitive Semantics framework, which radically alters the meaning of both declaratives and interrogatives. We turn to this approach in the next section.

Inquisitive Semantics

Inquisitive Semantics (Ciardelli, 2009; Groenendijk & Roelofsen, 2009; Ciardelli, Groenendijk & Roelofsen, 2013, 2019) models the relationship between interrogatives and declaratives by defining key properties (*inquisitiveness* and *informativeness*) that track how these two clause types make differing contributions to conversations. The semantic content of a question (or a declarative) is its *resolution conditions*.

Under Stalnaker's (1978, 1999) model of conversations, asserting p updates the context with the content of p, a proposition, which can be thought of as a set of worlds. Inquisitive Semantics builds upon this picture in order to capture the conversational effects of both declaratives and interrogatives. Under this approach, assertions and questions both express propositions, but propositions are modeled as *sets of sets of worlds*.

As a result of this richer type space, Inquisitive Semantics allows for a simplification of embedding verb semantics (see, e.g., Theiler, 2014; Uegaki, 2015; Theiler et al., 2018), and a unified treatment of the logical connectives (Roelofsen, 2013; Ciardelli, et al., 2017). Thus, Inquisitive Semantics offers a solution to the problems discussed in the previous section: conjunction and disjunction are treated as set intersection and union, respectively, and independent of what kinds of clauses are conjoined or disjoined Additionally, it allows questions to be resolved by a variety of answers, accounting for several question types that prove difficult for partition theories (e.g., non-exhaustive, conditional, and disjunctive questions). The difference between clauses lies not in their *type*, but in the *internal properties* of the higher-order propositions that they express.

Let us take a closer look at this approach to question semantics. In Inquisitive Semantics, a proposition p is *downward closed*: for any proposition $q \in p$, if $q' \subset q$, then $q' \in p$. Essentially, if a proposition q resolves the issue raised by a sentence meaning ($q \in p$), then any stronger proposition ($q' \subset q$) will do so too ($q' \in p$). The informative content of a proposition is the union of all the information states in the proposition, info(p) = $\cup p$. A proposition p is *informative* just in case it establishes some non-trivial information (22a). A proposition p is *inquisitive* in case the information it establishes does not settle the issues that have been raised (22b). Essentially, if a proposition p is inquisitive, info(p) will contain multiple maximal elements, or alternatives. In what follows, $\mathcal{W}$ is the set of all possible worlds.

~~(18)~~(22) a. **INFORMATIVE**
A proposition p is *informative* iff info(p) $\neq \mathcal{W}$.
b. **INQUISITIVE**
A proposition p is *inquisitive* iff info(p) $\notin p$.

The distinction between declaratives and interrogatives is thus captured through these properties: the proposition expressed by a declarative is informative but not inquisitive, while the proposition expressed by a question is inquisitive but not informative. Put another way, the proposition expressed by a declarative contains a single alternative, while the one expressed by an interrogative contains multiple alternatives. Using these notions, we can now see how the propositions associated with the sentence types in (23) are distinguished.

~~(19)~~(23) a. Dana went to the party. DECLARATIVE
b. Did Dana go to the party? *YES-NO* QUESTION
c. Who went to the party? *WH*-QUESTION (NON-EXHAUSTIVE)
d. Who went to the party? *WH*-QUESTION (STRONG EXHAUSTIVE)

Assume a model with only four logically possible worlds: one where Dana and Fox both come to the party (w_1), one where Dana comes to the party and Fox does not (w_2), one where Fox comes to the party but Dana does not (w_3), and a final where neither one comes to the party (w_4). The set of all worlds, $\mathcal{W}$, is thus $\{w_1, w_2, w_3, w_4\}$. Each box in Figure 5 (a)-(d) represents the proposition expressed by the respective sentences in (23). The groups of text correspond to a world (w_1 top left, w_2 top right, w_3 bottom left, w_4 bottom right), and the colored bubbles around the worlds represent the maximal element(s) or each proposition (the alternatives). Given downward closure, a full elaboration of each proposition would include all the subsets of the included alternatives.

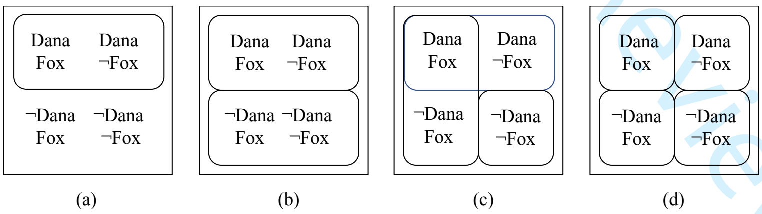

Figure 5: Graphical representation of the meanings of (23) in Inquisitive Semantics.

The proposition expressed by the declarative in (23a) can be fully elaborated as the (downward closed) set in (24).

~~(20)~~(24) $A = \{\{w_1, w_2\}, \{w_1\}, \{w_2\}, \varnothing\}$

Recall that the informative content of A, info(A) is $\cup A$, the set, $\{w_1, w_2\}$. (23a) is not inquisitive because info(A) is an element of the set in (24), However, A is informative because info(A) $\neq \mathcal{W}$. For another example, the *yes-no* question in (23b) is inquisitive, because info(B) = $\{w_1, w_2, w_3, w_4\}$ and $\{w_1, w_2, w_3, w_4\} \notin B$. However, it is not informative because info(B) = $\mathcal{W}$.

~~(21)~~(25) $B = \{\{w_1, w_2\}, \{w_3, w_4\}, \{w_1\}, \{w_2\}, \{w_3\}, \{w_4\}, \varnothing\}$

Finally, (23c) and (23d) are both inquisitive, but not informative. Note the similarity between the picture in Figure 5d, which represents a strong exhaustive set and the graph of a partition in Figure 3. We will introduce and discuss strengths of exhaustivity in the next section.

Because both declarative and interrogative sentence meanings are modeled as non-empty, downward-closed sets, entailment orderings may be defined for both inquisitive and informative content (i.e., between questions as well as declaratives). In virtue of these orderings, the logical notions for coordination may be preserved: *and* can be treated as a join operator (intersection), while *or* can be treated as a meet operator (union). Thus, coordination is treated consistently regardless of clause type or question type. See Roelofsen (2013) for algebraic details.

Commented [MOU2]: So I decided to remove the following paragraph from this section so that I don't have to leave anyone hanging in this section. Later, in the section on embedded cases, I briefly mention that Inquisitive semantics can side-step some of the selectional issues. I thought about putting this paragraph there but I think it's sufficient to mention as is and not add additional information for simplicity's sake. If people want more, they can read the papers.

"A unified treatment of clauses allows a simplification of embedding verb semantics (see, e.g., Theiler, 2014; Uegaki, 2015; Theiler et al., 2018, 2019). A slight amendment is needed in the case of embedded interrogatives to account for facts about veridicality (which will be discussed in the next section). These are not treated in terms of simple resolution conditions in the way that root questions are. Rather, embedded complements denote functions from worlds to truthful resolutions, via application of an operator. (See Theiler (2014) and Theiler et al. (2018, 2019) for formal details and motivation.)"

ANSWERS TO QUESTIONS

Earlier we emphasized the relation between a question's meaning and the answers it permits. Hintikka (1976) proposed that questions permit both an existential and a universal reading, and corresponding answers. Take the embedded question captured in the italicized part of (26). (26) actually has multiple truth conditions, captured in (27). (27a) is the existential reading: it requires that Fox knows of *at least one book that Dana read it.* (27b) is the universal reading: it requires that he know of *all of the books that Dana read, that she read them*. The existential reading is called the *non-exhaustive* reading, while the universal reading is called the *exhaustive* one. In this section, we focus on exhaustive readings, and come back to the non-exhaustive reading in a later section.

~~(22)~~(26) Fox knows *what Dana read*.

~~(23)~~(27) a. $\exists x$ [Dana read x $\wedge$ Fox knows that Dana read x]

b. $\forall x$ [Dana read x $\rightarrow$ Fox knows that Dana read x]

Karttunen (1977) took issue with the non-exhaustive reading, pointing out that if (27a) were a possible reading of (26), then in a situation in which Dana read multiple books, one of which was *Bel Canto*, (28) would be acceptable. However, (28) is a contradiction, according to Karttunen: if Fox knows what Dana read, this entails that he knows that she read *Bel Canto*, in addition to any other book that she read.

~~(24)~~(28) # Fox knows what Dana read, but he doesn't know that she read *Bel Canto*.

Karttunen argued that question meaning should encode *true* answers, which captures *weak exhaustivity*. In contrast, a Groenendijk & Stokhof style approach encodes question meanings as partitions on logical space. As we indicated earlier, partitions deliver mutually exclusive answers: once the true partition is determined, all other partitions are ruled out, thereby yielding *strong exhaustivity*. Thus, to know *what Dana read* entails knowing all of the books she read, and also knowing what she did not read.

Consider a world in which Dana read only *Commonwealth* and *Bel Canto*. Figure 2 presented us with a graphical representation of proposition set semantics, while Figure 3 presented us with partitions. Figure 2 does not encode any information about negative answers; all it provides is two overlapping answers: that Dana read *Commonwealth* and that Dana read *Bel Canto*. One of the key differences between proposition set semantics (weak exhaustivity) and partition semantics (strong exhaustivity) is what is encoded in the explicit answers delivered. In proposition set semantics, the statement *Dana read Bel Canto* is neutral as to whether Dana read *Commonwealth*, while partition semantics delivers answers that make determinations about every object in the domain. Thus, is it not possible to know what Dana read without knowing whether *Commonwealth* was read. Strong exhaustive semantics then tracks Groenendijk & Stokhof's intuitions about what is required of subjects in embedded-*wh* reports.

Many have proposed type-shifting operators to reconcile the descriptive insights of Hamblin, Karttunen and Groenendijk & Stokhof, and to account for various empirical facts. For example, Dayal (1994, 1996) proposed one to account for cross-linguistic facts about scope marking, and presuppositions associated with number marking in questions. Lahiri (1991, 2002) covered quantificational variability effects. These authors have argued that in these phenomenon, the correct interpretation depends on the availability of a Hamblin set---thus, their operators take as input a Hamblin set ($\lambda p.\exists x.[p = \lambda w'.\text{read}_{w'}(x)(\text{Dana})]$), and derive from that more restricted answer sets.

Heim's operators are presented in (29). ANS$_1$ delivers weak exhaustivity, while ANS$_2$ delivers strong exhaustivity. In contrast to Dayal and Lahiri's operators, Q denotes an intensionalized Karttunen set, $\lambda w.\lambda p.\exists x.[\text{book}(x) \wedge p(w) \wedge p = \lambda w'.\text{read}_{w'}(x)(\text{Dana})]$.

~~(25)~~(29) a. $[\![\text{ANS}_{\text{HEIM}1}\ Q]\!] = \lambda w.\bigcap Q(w)$ WEAK EXHAUSTIVE
b. $[\![\text{ANS}_{\text{HEIM}2}\ Q]\!] = \lambda w_i.\lambda w_j.[\text{ANS}_1(Q)(w_i) = \text{ANS}_1(Q)(w_j)]$ STRONG EXHAUSTIVE

ANS$_1$ yields the intersection of the true answers, and ANS$_2$ yields a partition. Note that ANS$_2$ is defined in terms of ANS$_1$; the weak exhaustive meaning is more primitive than the strong exhaustive one. An embedding predicate may select for one operator or the other. Heim suggested that *know* selects for ANS$_2$ (and therefore gives rise to strong exhaustivity). We return to this point below. Beck & Rullmann (1999) modified Heim's two operators, and include a third one that delivers a non-exhaustive meaning to account for their observations about degree questions.[2]

George's (2011) derives the two readings not from two different operators, but via the presence or absence of an exhaustivity operator, X, as shown by the two LFs in (30). The Q operator existentially quantifies over the question abstract to derive a Hamblin set (and non-exhaustive readings), while the X operator (only present in (b)) returns an exhaustified set of propositions.

~~(26)~~(30) a. $[\![\text{Q [what Dana read] }]\!] =$ NON-EXHAUSTIVE
$\lambda p_{\langle s,t\rangle}.\exists\beta_e.[p = \lambda w.\text{read}_w(\beta)(\text{Dana})]$
b. $[\![\text{Q [X [what Dana read]] }]\!] =$ STRONG EXHAUSTIVE
$\lambda p_{\langle s,t\rangle}.\exists\beta_{\langle e,t\rangle}.[p = \lambda w.[\beta = \lambda x.\text{read}_w(x)(\text{Dana})]]$

Similar to Heim, George posits that different embedding verbs may select for the X operator or not. Unlike Hamblin/Karttunen and other proposition set theories, George treats *wh*-words as lambda abstractors rather than as existentials.

Strong and weak exhaustivity are not the only possibilities. Another is *intermediate exhaustivity* (Spector 2005, Klinedinst & Rothschild 2011). A weak exhaustive semantics would predict that (26) is true in a situation where Fox knows the true answers, but is either ignorant about the books Dana didn't read, or falsely believes that Dana read a book that she actually did not read. This reading is sometimes described as being *false-answer sensitive*, referring to a more general effect whereby judgements of *know-wh* reports are rejected when the attitude holder has false beliefs about the false answers.

Klinedinst & Rothschild (2011) propose that an exhaustivity operator may be applied in two different places in the LF of a declarative with an embedded question, as shown by the LFs in (31), where α stands for a question-embedding verb, and *s* stands for a subject. Q denotes a weak exhaustive set.

---

[2]We might say that these theories appeal to a *covert ambiguity*, because the phonological string associated with a question alone does not distinguish between the multiple abstract semantic representations which correspond to different meanings. Further, it is a *lexical ambiguity* because the representations differ only in *which* ANS operator is present, rather than its position at LF. In contrast, accounts like George (2011), Nicolae (2014), or Xiang (2016) would count as *structural ambiguity*, because they attribute different readings to the structural differences in the underlying LF.

~~(27)~~(31) a. $[_{TP}\ s\ [_{VP}\ \alpha\ [_{CP}\ \textbf{EXH}\ \textbf{Q}\ ]\ ]\ ]$ STRONG EXHAUSTIVE
b. $[_{CP}\ \textbf{EXH}\ [_{TP}\ s\ [_{VP}\ \alpha\ [_{CP}\ \textbf{Q}\ ]\ ]\ ]\ ]$ INTERMEDIATE EXHAUSTIVE
c. $[_{CP}\ [_{TP}\ s\ [_{VP}\ \alpha\ [_{CP}\ \textbf{Q}\ ]\ ]\ ]\ ]$ WEAK EXHAUSTIVE

The intermediate exhaustive reading is derived via matrix exhaustification, (31b), and the strong exhaustive reading via embedded exhaustification, (31a). Finally, the weak exhaustive reading is derived when there is no exhaustivity operator present in the LF, (31c). This proposal thus has the benefit of capturing Heim's insight that weak exhaustivity is primitive, and strong exhaustivity is derived.

Exhaustivity and embedding predicates

Given a question-declarative pair such as the one in (32), a key question is, to what extent the answers permitted in the embedded question are linked to or constrained by the matrix verb?

~~(28)~~(32) a. What did Dana read?
b. Fox knows what Dana read.

It is well known that verbs have both syntactic subcategorization restrictions and semantic selectional restrictions on their arguments (Grimshaw, 1979). For example, a verb like *know* can embed either an interrogative or a declarative proposition, as in (33), a verb like *wonder* can only embed a question, as shown in (34), and a verb like *think* can only embed a declarative, as shown in (35). For a typological distinction within interrogative-taking verbs, see Figure 6.

~~(29)~~(33) a. Fox knows where Dana bought coffee.
b. Fox knows that Dana bought coffee.
~~(30)~~(34) a. Fox wondered where Dana bought coffee.
b. *Fox wondered that Dana bought coffee (at Stumptown).
~~(31)~~(35) a. *Fox thinks where Dana bought coffee.
b. Fox thinks that Dana bought coffee (at Stumptown).

Many researchers have attempted to provide a unified explanation of embedding predicates (Karttunen, 1977; Groenendijk & Stokhof, 1982; Ginzburg, 1995; Lahiri, 2002; Egré, 2008; Theiler, 2014; Romero, 2015; Spector & Egré, 2015; Uegaki, 2015; Theiler, Roelofsen, & Aloni, 2019; Mayr, 2019; Uegaki & Sudo, 2019, a.o.). Some researchers connect selectional restrictions to semantic properties of the embedding verb (e.g., factivity or veridicality). Responsive predicates in particular are troublesome because they allow both declarative and interrogative complements, yet their semantic properties do not always appear consistent across complements. For example, *tell* is non-veridical when it embeds a proposition, but appears to be veridical when it embeds an interrogative. While this point originated with Karttunen (1977), many recent scholars have questioned it (see Spector & Egré (2015)).

One question that arises is how to articulate the lexical entry for these verbs, and whether to proliferate entries for each syntactic frame a verb takes. Many treat the declarative-embedding use as basic, and attempt to reduce the interrogative-embedding uses to this basic one. This can be achieved in a number of ways: by separate lexical entries for each complement (cf. Spector & Egré, 2015; Karttunen, 1977), or by positing operator(s) that type-shift interrogatives to declaratives (Heim, 1994; Dayal, 1996; Beck & Rullmann, 1999; Lahiri, 2002). Still others take a different approach. ~~Not all researchers assume~~ ~~*reduction*~~ Uegaki (2015) argues for a *reduction* in the other direction.~~,~~ George (2011) derives both uses from a common lexical entry. Inquisitive Semantic accounts like Theiler et al. (2018, 2019) avoid the problem all together because declaratives and interrogatives have the same semantic type. See Theiler et al. (2018), and Uegaki (2019) for thorough reviews of this issue.

Many theoreticians have suggested that the distributional differences in exhaustivity of embedded questions arise from either semantic selection restrictions or the verb's lexical semantics (see George, 2011; Guerzoni & Sharvit, 2007; Heim, 1994; Klinedinst & Rothschild, 2011; Lahiri, 2002; Spector and Egré, 2015; Uegaki, 2015; Theiler, 2014; Mayr, 2019, Uegaki, 2019). For example, it has frequently been claimed that *know* selects for strong exhaustivity (Groenendijk & Stokhof, 1982, 1984; Berman, 1991; Heim, 1994; George, 2011; Schulz & Roeper, 2011). However, there are clearly cases where strong exhaustivity is not required for *know*, as in (36).

(36) a. Dana knows where Fox can get a cup of coffee.
b. Dana knows how to get to Quantico.

Indeed, Hintikka (1976) and Asher & Lascarides (1998) have argued for a non-exhaustive semantics for questions on the basis of *know-how*-questions, Beck & Rullmann (1999) on the basis of degree questions (*know how much/many*), and Lahiri (2002) on the basis of quantificational variability effects (sentences like, *Fox mostly knows what Dana read*).

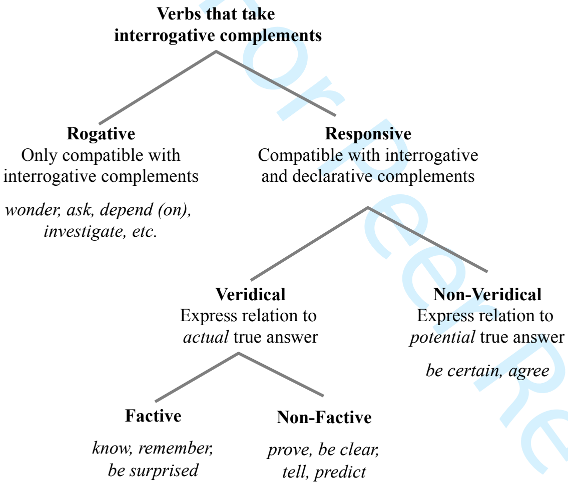

Figure 6: Typology of verbs, after Lahiri (2002)

Emotive factives such as *be surprised* or *be happy*, are often presented in support of a Karttunen-style semantics. These verbs seem to robustly allow weak exhaustivity, and perhaps even disallow strong exhaustivity (in contrast to *know*) (Berman, 1991; Beck and Rullmann, 1999; Heim, 1994; Sharvit, 2002). Lahiri (2002), Uegaki (2015), and others have argued that emotive factives do not allow for strong exhaustivity, because of their monotonicity properties. Monotonicity is defined for a relation between two sets that either preserves or reverses an ordering. Here, the relevant ordering is entailment. Consider the simple entailments between the sentences in (37). The truth of (37a) entails the truth of (37b). However, the truth of (37a) does not entail the truth of (37c).

~~(32)~~(37) a. Cezi is a grey cat.
b. Cezi is a cat.
c. Cezi is a grey tabby cat.

An upward monotone function preserves truth from a subset to a superset (e.g., from *cute cat* to *cat*). A downward monotone function preserves truth from superset to subset (e.g., from *cute cat* to *cute* *tabby cat*).[3] Consider what happens when sentences like those in (37) are embedded, as in (38) and (39).

~~(33)~~(38) a. It surprised Dana that Cezi is a grey cat.
b. It surprised Dana that Cezi is an cat.
c. It surprised Dana that Cezi is a grey tabby cat.[4]

~~(34)~~(39) a. Dana knows that Cezi is a grey cat.
b. Dana knows that Cezi is a cat.
c. Dana knows that Cezi a grey tabby cat.

Despite the fact that (37a) entails (37b), this entailment is not preserved when these sentences are embedded under *surprise*, as in (38), but it *is* when they are when embedded under *know*. This is because *know* is upward monotonic on its complement, while *surprise* is non-monotonic. However, recent literature has suggested that strong exhaustivity may indeed be available with emotive predicates. (Klinedinst & Rothschild 2011, Theiler 2014, Cremers & Chemla 2017; Uegaki & Sudo 2019).

Negative Polarity Items (NPIs) have been argued to be licensed in downward-monotone/entailing environments (Ladusaw, 1979). Thus, their acceptability might present a diagnostic for exhaustivity. Observe the contrast in (40): *surprise* licenses NPIs with a declarative complement but not with an interrogative complement ((40a) v. (40b)). This suggests that the problem is tied to the *wh*-clause. However, the contrast between (40a) and (40c) suggests that (40a) is not ungrammatical because of the embedded question *per se*, but rather because of the interaction of *(be) surprise(d by)* with the embedded question.

~~(35)~~(40) a. * Dana is surprised by who has **ever** been to Paris.
b. Dana is surprised that Fox has **ever** been to Paris.
c. Dana knows who has **ever** been to Paris.

Given this pattern, Guerzoni & Sharvit (2007) argue that emotive factives with embedded questions do not license NPIs, because they are weakly exhaustive. Only a strongly exhaustive operator can create a downward monotonic environment that licenses NPIs. Other explanations are given by Nicolae (2013) and Mayr (2013). For Nicolae, the exhaustivity operator that creates a downward entailing environment is optional, therefore explaining why (41a) is ungrammatical with NPIs. See also Schwarz (2017) for arguments against accounts which posit a covert exhaustivity operator.

Klinedinst & Rothschild (2011) argue that non-factive verbs (in particular, *tell* and *predict*) provide evidence for the intermediate exhaustive reading. Consider (41) in a situation where Frank and Emilio are the only people who sang.

~~(36)~~(41) John predicted/told me who sang.

Klinedinst & Rothschild report (following Spector 2005, 2006) that if John predicts/tells me that Frank and Emilio sang, but has no opinions about anyone else, then (41) seems intuitively true. Thus, *predict* and *tell* do not appear to require strong exhaustivity. However, if John predicts/tells me that Frank, Emilio, *and Ted* sang, (41) is reported to be false.

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[3] The relevant notion for NPI licensing is actually Strawson entailment (von Fintel 1999) not classical entailment as presented in (38)-(40). *p entails q* if and only if every context where *p* is true, *q* is also true. But *p Strawson entails q* iff *p* classically entails *q* and all the presuppositions of *p* and *q* are met.
[4] One might argue that (38a) Strawson entails (38c), to the extent that the presupposition that Dana finds out that Cezi is a tabby when she finds out that Cezi is a cat is satisfied.

Some verbs do not distinguish between true and false answers. For example, the non-factive verbs *agree* and *be certain* are argued to permit false answers (Berman 1991; Lahiri 1991, 2002; Beck & Rullmann, 1999; Spector, 2005; George, 2011; Spector & Egre, 2015; Theiler et al., 2018), as shown in (42). In (42a), Dana and Fox could have the same beliefs about who was elected, but they need not be accurate. The same can be said for (43b): Dana could be certain about who attended the party without being correct. Some have provided analyses of *be certain* to account for these non-veridicality facts, while maintaining a strongly exhaustive semantics (see Uegaki, 2015; Theiler et al., 2018).

~~(37)~~(42) a. Dana and Fox agree on who was elected.
b. Dana is certain (about) who was at the party.

Experimental evidence for multiple readings of embedded questions

Given the various claims about the readings licensed by different embedding verbs, and disagreements about exhaustivity, researchers in recent years have turned to experimental methods in an attempt to understand which readings are available. By recruiting these methods to achieve more robust data, these researchers hope to clarify the theoretical landscape to determine a proper treatment of question semantics.

White & Rawlins (2016, 2018) have elucidated our understanding of attitude verb selectional restrictions by conducting large-scale acceptability judgements on over 1000 English clausal embedding verbs in dozens of different syntactic frames (the "MegaAttitude dataset"). Their computational model of selection encodes systematic mappings from semantic type to syntactic distribution. They trained this model on the acceptability data, and found that it derived selectional patterns consistent with many of the theoretical claims in the literature discussed above. White & Rawlins (2018) tested hypotheses about the relationship between the ability of a verb to embed a question (responsivity) and veridicality/factivity, and found that neither veridicality nor factivity were predictive of responsivity across the entire set of verbs. However, a correlation emerges when verb frequency is factored in: more frequent verbs show correlations between veridicality and factivity, while less frequent verbs do not. White & Rawlins note that this pattern diverges from a well-known result in the morphological literature, where low-frequency forms exhibit strong correlations with rule-based generalizations.

In an acceptability judgement task, Cremers and Chemla (2016) asked whether sentences such as (43) allow for weak, intermediate, or strong exhaustive readings, in contexts where different readings were made true or false. Their results confirmed that *know* gives rise to strong exhaustive readings (as anticipated), but showed that *know* also permits both intermediate and weak exhaustive readings. The verb *predict* gives rise to all three readings.

~~(38)~~(43) John {knew/predicted} which squares were blue.

Sensitivity to false answers has been a focus of recent investigations from the semantic perspective (van Rooij & Schulz, 2004; Spector, 2005; Klinedinst & Rothschild, 2011; Theiler et al., 2016, 2018). Phillips & George (2018) experimentally examined the effect of false answers on judgements of *know* reports, and found that participants judge these reports to be *more* acceptable when the proportion of false to true beliefs that the agent holds is lower, and *less* acceptable when the proportion is higher.

Cremers and Chemla (2017) tested a range of embedding verbs to examine grammaticality with different complements and semantic properties, including monotonicity and the range of exhaustivity permitted. Their main focus was on three observations about emotive factives such as *(be) surprise(d)*. First, ~~–~~ ~~given~~ these verbs do not seem to license strong exhaustive inferences (repeated below): the inference from (a) to (b) does not hold in (44) the way it seems to in (45) (Groenendijk & Stokhof, 1982, 1984; Berman, 1991; Heim, 1994).

~~(39)~~(44) a. It surprised Dana who came to the party

b. ⊭ It surprised Dana who didn't come to the party.

~~(40)~~(45) a. Dana knows who came to the party

b. ⊨ Dana knows who didn't come to the party.

At the same time, it has been observed that *whether* complements are only possible with embedding verbs that are strongly exhaustive (Nicolae 2013, 2015; Guerzoni & Sharvit 2014). Indeed, emotive factives are generally ungrammatical with *whether* complements, as shown in (46):

~~(41)~~(46) a. Dana knows whether Fox came to the party

b. *It surprised Dana whether Fox came to the party.

Finally, emotive factives appear to be non-monotonic and do not license NPIs (recall the discussion of (37)-(40)).

There have been many different explanations proposed as to why emotive factives exhibit these patterns~~.~~, attempting to link their selectional restrictions to their entailment properties (Guerzoni & Sharvit, 2007/2014; Abels, 2007; Guerzoni, 2007; Sæbø, 2007; Herbschrift, 2014; Nicolae, 2015; Roelofsen et al., 2018). Cremers & Chemla compared monotonicity, the availability of strong exhaustive readings, and the acceptability of *whether*-clauses, to determine whether these properties were linked. Across all verbs, the selectional properties were consistent with those reported in the literature. However, emotive factives were only found to be degraded with *whether*-questions, rather than completely ungrammatical. As for monotonicity, generally verbs patterned as predicted by the literature, with the exception of the emotive factives (*be happy* and *surprise*). Though these were claimed to be non-monotonic, *be happy* patterned with upward entailing verbs, while *be surprised* patterned with downward-entailing verbs. Finally, they found that *be surprised* licensed strong exhaustive readings, contrary to the predictions from the literature.

Chemla & George (2017) tested sentences with *agree* as in (47)-(48) in a variety of situations where two agents' beliefs about the colors of letters were aligned either completely or partially.

~~(42)~~(47) John and Mary agree {on/about} which letters are blue.

~~(43)~~(48) John and Mary don't agree {on/about} which letters are blue.

Participants judged (47) to be true and (48) false when John and Mary's beliefs about the blue letters matched, regardless of whether they were ignorant of or had false beliefs about the other letters. These results suggest that *agree* licenses intermediate exhaustivity. It is clear that these various lines of experimental work not only confirm and enrich the theory, but also reveal variability among participant judgments and linguistic categories that is not easily captured within existing theoretical proposals.

SEMANTICS AND PRAGMATICS IN QUESTIONS: NON-EXHAUSTIVITY

There has been considerable debate about what exactly licenses non-exhaustive answers, and whether there is a semantic mechanism that can explain non-exhaustivity. Imagine that a tourist on the street asks the question in (49).

~~(44)~~(49) Where can I find an Italian newspaper?

The most natural answer is one that provides a non-exhaustive (or *mention-some*) answer (Hintikka, 1976; Groenendijk & Stokhof ,1982, 1984). However, this does not mean that an exhaustive answer is *ungrammatical*; it is simply not felicitous or optimal in this context. Consider another context, where the questioner is interested in the local newspaper market. Now, an exhaustive answer seems to be preferred. It would seem that changing the context or the goals of the speaker posing the question influences which answers are preferred, thereby implicating pragmatics.

(Non-)exhaustivity appears to co-vary with the type of *wh*-question posed: *who* questions are most often associated with an exhaustive answer, while *where*, *why*, or *how* questions with a non-exhaustive answer (Hintikka, 1976; Ginzburg, 1995; Asher & Lascarides, 1998). Compare (50) to (51).

~~(45)~~(50) Who came to the party?
~~(46)~~(51) How do I get to the train station?

However, this pattern appears to be more of a preference or an interpretational default, rather than a categorical distinction. One can easily come up with examples of *who* questions that permit non-exhaustive answers. Imagine a smoker asking *Who has a light?* Or, following Asher & Lascarides, a gossip columnist asking (50) when they are interested in the whereabouts of a relevant celebrity, but not the stage crew or personal assistants. Asher & Lascarides (1998) have suggested that these preferences may be overridden by contexts that make explicit a questioner's goals and mental state. Further, these preferences may be enhanced or cancelled by particles like *for example* (e.g., *Who, for example, came to the party?*) or *all* (e.g., *Who all came to the party?*) in languages such as English, German, Dutch among others (see Reis, 1992; Beck, 1997; Beck & Rullmann, 1999; Zimmerman, 2007; Fekete, Schulz, & Ruigendijk, 2018).

There are two main types of proposals to account for non-exhaustive readings. One line of approaches (Groenendijk & Stokhof, 1982, 1984; Asher & Lascarides, 1998; van Rooij, 2003) argues that there is a single underlying semantic representation corresponding to the phonological string associated with a question. What exactly this single representation is or encodes differs between theories. For Groenendijk & Stokhof, the representation is a partition, and the mechanism that derives non-exhaustivity is purely pragmatic. A speaker may accept a non-exhaustive answer in a context if it satisfies their goals, although this will not constitute a complete (semantic) answer to their question. Other single representation approaches (Ginzburg, 1995; Asher & Lascarides, 1998; van Rooij, 2003), propose that exhaustivity is only determined relative to contextual parameters (for example, the speaker's goal, decision problem, or mental state). Without values for those parameters, a question's underlying representation is underspecified for (non-)exhaustivity.

For Ginzburg (1995), an answer is defined by what resolves the questioner's goals. 'Resolvedness' is pragmatic relation between a potential answer, the question, and contextual parameters, including the questioner's goal and mental state. Asher & Lascarides (1998) dynamically model the interaction between discourse, sentence meaning, and compositional semantics. Their theory also employs contextual variables (notably, the questioner's cognitive state and plan), which factor into the calculation of exhaustivity. They encode a non-exhaustive semantic meaning that may be enriched to an exhaustive one through integration with context-sensitive variables. However, ~~different~~ in contrast ~~from~~ to Ginzburg (1995), they implement this meaning compositionally using Segmented Discourse Representation ~~Structures~~Structures, which allow for discourse structures to be dynamically captured, including discourse referents and discourse relations (Asher 1993; Asher & Lascarides 1994).

Van Rooij (2003) includes an operator sensitive to the speaker's decision problem, which is a formal mechanism that originates in Bayesian decision theory. According to this theory, the decision problem determines which answers are most useful in a given context and the operator ranks answers according to how relevant and useful they are to solving the problem. However, the utility of a mention-some reading will never exceed the utility of the mention-all reading (van Rooij 2004, p10). If this is right, hearers should never prefer a non-exhaustive reading over an exhaustive one.

The second line of approaches proposes multiple underlying representations for a question (Beck & Rullmann, 1999; Lahiri, 2002; George, 2011; Nicolae, 2014; Fox, 2014/2018; Xiang, 2016). While Heim's theory does not explicitly derive non-exhaustive readings (since the two ANS operators only account for weak and strong exhaustivity), Beck and Rullmann (1999) include two ANS operators for weak and strong exhaustivity, plus a *third* operator for non-exhaustivity. Lahiri's operator includes a variable that restricts a Hamblin set, based on the lexical semantics of embedding verbs, or the context more generally.

George (2011, Ch. 2) argues that the data that have been used in support of weak exhaustive answers provide evidence for the non-exhaustive answer. In George's semantics, a question's base denotation is a Hamblin set, which derives the non-exhaustive answer. Inquisitive Semantic approaches also fall in the multiple representation category, since under this framework, a question may correspond to either a non-exhaustive or strong exhaustive proposition. (Recall (23) and Figure 5.)

A subset of multiple representation theories claims that non-exhaustivity is semantically licensed only in particular questions (George, 2011, Ch. 6; Nicolae, 2013; Fox, 2014; Xiang, 2016). Consider the embedded and root questions in (52) and (53).

~~(47)~~(52) a. Who are some of the party-goers? EXISTENTIAL QUANTIFIERS
b. Dana knows who some of the party-goers are.

~~(48)~~(53) a. Where can we find coffee? (EXISTENTIAL) MODAL VERBS
b. Dana knows where we can find coffee.

The existential *some* in the partitive construction in (52) and the modal *can* in (53) are often argued to give rise to grammaticalized non-exhaustivity. George (2011, Ch. 6) proposes that existential elements can syntactically scope over the exhaustivity operator X by undergoing Quantifier Raising (QR) (May, 1985). Nicolae (2013) suggests that the existential (or in the case of a modal, the *wh*-word) can be reinterpreted as a complex quantifier, and undergo QR twice. As a result, it quantifies into a subset of the *wh*-domain such that, for each possible subset, it constitutes a maximally informative answer. This reinterpretation is licensed when the context fails to provide a unique maximally informative answer.

Several problems have been identified with these approaches, as noted by Fox (2014) and Nicolae herself. The main objection is that while existential quantifiers undergo QR, modals do not. See Fox (2014) and Dayal (2016) for discussion. In contrast to these two syntactic approaches, Xiang's proposal achieves a scope effect without syntactic movement of the modal.[5] First, the *wh*-word is raised to a higher type via a type-shifting operator. This operator is modified from the operator employed in continuation-based grammars (Barker, 2002; Barker and Shan, 2014; Shan, 2004; Shan and Barker, 2006), whose roots are Partee's (1986) LIFT. A type-lifted *wh*-trace out-scopes the modal to derive the exhaustive reading; while the non-exhaustive reading arises when the *wh*-trace is out-scoped by the modal. Across these accounts, while the grammar outputs two different scope relations, which scope relation a given question has is determined by pragmatic factors.

Additional evidence for the role of the modal comes from a comparison of examples such as those in (54) (George, 2011; Nicolae, 2013; Fox, 2014; Dayal, 2016; Xiang, 2016; Xiang & Cremers, 2017).

~~(49)~~(54) a. Dana knows where I found coffee.
b. Dana knows where I can find coffee.
c. Dana knows where to find coffee.

While (55a) seems to require (or prefer) an exhaustive answer, (55b) and (55c) do not. The modal *can* in (55b) is claimed to contribute both existential quantificational force and a context-sensitive component (the conversational background comprised of the modal base and ordering source, Kratzer 1981). This provides a goal-oriented interpretation. While there is no overt modal in (55c), Bhatt

[5] While Nicolae's solution involves syntactic movement of the quantifier, it is similar to Xiang's later proposal in that there is no syntactic movement of the modal itself, but rather the higher-order *wh*-phrase.

(1999) has proposed that infinitival clauses contain covert existential modals, which have a contextual restriction on the modal base which is anaphoric to a contextual goal.

So far, we have discussed three surface-level cues that are linked to the acceptability of the non-exhaustive reading: the embedding verb, the *wh*-word, and modality or finiteness—all of which in turn interact with the role of the conversational context. Moyer & Syrett (2019) sought to obtain experimental evidence for each of these surface-level cues. They presented vignettes to participants, paired with a question and a hearer's answer. Participants were asked to assess a report containing an embedded question in light of the answer in the vignette (and implicitly, in light of the linguistic form of the question). As predicted, participants accepted non-exhaustive answers in non-finite *know* sentential targets more often than with finite targets. However, finite targets were accepted above chance—a surprising result if non-exhaustivity depends upon the presence of a modal. Moreover, non-exhaustive answers were more acceptable for *where* than *who* questions. Finally, non-exhaustive answers were more acceptable than exhaustive answers in situations where the contextual stakes were low. These results confirm the importance of discourse context for what counts as an appropriate answer. The context provides the information relevant to resolving the question, including the questioner's goal. The goal determines how much information is needed, thus specifying which answers are most informative for achieving that goal.

In recent years, there has been interest in the questions from a computational perspective, using Bayesian inference for cognitive modeling. Formally, this involves conditionalization (or update) through iterated application of Bayes' rule. The Rational Speech Acts (RSA) framework of Goodman & Frank (2012) models pragmatic reasoning as a recursive Bayesian inference whereby when one encounters an utterance (data), one updates one's beliefs about the state of the world (hypotheses), given what one believes the utterance to mean (convey about the world). It has been extended to model question-answer dynamics (Hawkins, et al., 2015). Their model takes the basic RSA model and adds parameters to capture the sensitivity of answers to questioner goals. They found that the model which includes inference about the speaker's goal is best able to capture the behavioral data collected about how human participants answer in response to questions.

CONCLUSION

In this paper, we have reviewed theoretical, experimental, and computational approaches to the meaning of questions. We first introduced the challenges a truth conditional approach to questions encounters, then turned to discuss the history of formal semantic accounts of the meaning of questions. We then reviewed the different ways these theories handle a variety of question types, and the particular problem that non-exhaustivity poses to formal accounts. Finally, we transitioned into presenting how our understanding of question meaning has been enriched and extended by recent experimental and computational approaches.

Much remains to be discovered about the meaning of questions. What is the division of labor between syntax, semantics, and pragmatics in question interpretation, and answer licensing? How can (non-) exhaustivity best be captured? What role does the lexical semantics of the embedding verb play in determining the logical properties of a question and restrictions on complementation? These questions will no doubt fuel future research on this topic.

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