The Partition Semantics of Questions, Syntactically

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Abstract. Groenendijk and Stokhof (1984, 1996; Groenendijk 1999) provide a logically attractive theory of the semantics of natural language questions, commonly referred to as the partition theory. Two central notions in this theory are entailment between questions and answerhood. For example, the question Who is going to the party? entails the question Is John going to the party?, and John is going to the party counts as an answer to both. Groenendijk and Stokhof define these two notions in terms of partitions of a set of possible worlds.

We provide a syntactic characterization of entailment between questions and answerhood. We show that answers are, in some sense, exactly those formulas that are built up from instances of the question. This result lets us compare the partition theory with other approaches to interrogation—both linguistic analyses, such as Hamblin’s and Karttunen’s semantics, and computational systems, such as Prolog. Our comparison separates a notion of answerhood into three aspects: equivalence (when two questions or answers are interchangeable), atomic answers (what instances of a question count as answers), and compound answers (how answers compose).

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1 The partition theory of questions

An elegant account of the semantics of natural language questions from a logical and mathematical perspective is the one provided by Groenendijk and Stokhof (1984). According to them, a question denotes a partition of a logical space of possibilities. In this section, we give a brief summary of this influential theory, using a notation slightly different from Groenendijk’s (1999) presentation.

A question is essentially a first order formula, possibly with free variables. We will denote a question by $?\phi$, where $\phi$ is a first order formula. (We will also denote a set of questions by $?\Phi$, where $\Phi$ is a set of first order formulas.) An answer is also a first order formula, but one that stands in a certain answerhood relation with respect to the question, spelled out later in this section. For example, the statement Everyone is going to the party ($\forall x.Px$) will turn out to answer the question Who is going to the party? ($?Px$).

We assume that equality is in the language, so one can ask questions such as Who is John? ($?x \approx j$). We also assume that, for every function symbol—including constants—it is indicated whether it is interpreted rigidly or not. Intuitively, for a function symbol to be rigid means that its denotation is known. For example, under the notion of answerhood that we will introduce below, it is only appropriate to answer Who is going to the party? ($?Px$) with John is going to the party ($Pj$) if it is known who John is—in other words, if $j$ is rigid. Also, for Who is John? ($?x \approx j$) to be a non-trivial question, John must have a non-rigid interpretation.

Questions are interpreted relative to first order modal structures with constant domain. That is, a model is of the form $(W, D, I)$, where $W$ is a set of worlds, $D$ is a domain of entities, and $I$ is an interpretation function assigning extensions to the predicates and function symbols, relative to each world. Furthermore, we only consider models that give rigid function symbols the same extension in every world. Relative to such a model $M = (W, D, I)$, a question $?\phi$ expresses a partition of $W$, in other words an equivalence relation over $W$:

$$(1.1) \quad [?\phi]_M = \{ (w, v) \in W^2 \mid \forall g : M, w, g \models \phi \iff M, v, g \models \phi \} .$$

Roughly speaking, two worlds are equivalent if one cannot tell them apart by means of the question $?\phi$, in other words if $\phi$ is never true in one world and false in the other. In general, any set of questions $?\Phi$ also expresses a partition of $W$, namely the intersection of the partitions expressed by its elements:

$$(1.2) \quad [?\Phi]_M = \bigcap_{\phi \in \Phi} [?\phi]_M$$

$$\quad = \{ (w, v) \in W^2 \mid \forall \phi \in \Phi : \forall g : M, w, g \models \phi \iff M, v, g \models \phi \} .$$

Entailment between questions is defined as a refinement relation among partitions (i.e., equivalence relations): An equivalence relation $A$ is a subset
of another equivalence relation $B$ if every equivalence class of $A$ is contained in a class of $B$.

(1.3) \[ ?\Phi \models ?\psi \iff \forall M : [?\Phi]_M \subseteq [?\psi]_M . \]

The intuitive interpretation of $?\Phi \models ?\psi$ is that resolving the questions $?\Phi$ implies (requires) resolving the question $?\psi$. In other words, the questions $?\Phi$ distinguish between more worlds than the question $?\psi$ does.

A more fine-grained notion of entailment is as follows (Groenendijk 1999). Let $\chi$ be a first order formula with no free variables, and let $M \models \chi$ mean that $M, w \models \chi$ for all $w$.

(1.4) \[ ?\Phi \models_{\chi} ?\psi \iff \forall M : M \models \chi \Rightarrow [?\Phi]_M \subseteq [?\psi]_M . \]

Pronunciation: The questions $?\Phi$ entail the question $?\psi$ in the context of $\chi$ (or, given $\chi$). The context $\chi$ is intended to capture assertions in the common ground: If it is commonly known that everyone who got invited to the party is going, and vice versa ($\forall x (Ix \leftrightarrow Px)$), then the questions Who got invited? ($?Ix$) and Who is going? ($?Px$) entail each other.

This entailment relation between questions allows us to define a notion of answerhood.

**Definition 1 (Answerhood).** Let $?\phi$ be a question and $\psi$ a first order formula without free variables. We say that $\psi$ is an answer to $?\phi$ if $?\phi \models ?\psi$.

According to this notion (termed licensing by Groenendijk (1999) and aboutness by Lewis (1988)), Everyone is going to the party ($\forall x Px$) is an answer to Who is going to the party? ($?Px$), because $?Px \models ?\forall x Px$.

Note that, under this definition, any contradiction or tautology counts as an answer to any question. Groenendijk and Stokhof (1984) define a stricter notion of being a partial semantic answer (pertinence in Groenendijk 1999), which excludes these two trivial cases by formalizing Grice’s Maxims of Quality and Quantity, respectively. In this paper, however, we will stick to the simpler criterion of answerhood as defined above, which can be seen to formalize Grice’s Maxim of Relation. This is not because we believe the tautology and the contradiction to be appropriate answers, but rather because they are trivial cases that do not play a very interesting role in a theory of answerhood, merely complicating the picture by requiring a syncategorematic treatment. By the way, the inappropriateness of tautological and contradictory assertions is not specific to the case of questions and answers.

We now have a semantic notion of answerhood, that of Definition 1, telling us what counts as an answer to a question. For practical purposes, it is useful to also characterize this notion syntactically. Can one give a simple syntactic property that is a necessary and sufficient condition for answerhood? The next section shows how.
2 A syntactic characterization of answerhood

First, let us look at a partial result discussed by Groenendijk and Stokhof (1984) and Kager (2001). Define rigidity of terms and formula instances in the following straightforward way.

**Definition 2 (Rigidity).** A term is *rigid* if it is composed of variables and rigid function symbols. A formula $\phi$ is a *rigid instance* of another formula $\psi$ if $\phi$ can be obtained from $\psi$ by uniformly substituting rigid terms for variables. An identity statement $s \approx t$ is *rigid* if the terms $s$ and $t$ are rigid.

For example, if $c$ is a rigid constant, then rigid instances of $Px$ include $Pc$ and $Px$. The identity statement $c \approx x$ is also rigid. Notice that rigid instances are not necessarily rigid: If $c$ is rigid, then $Rcd$ is a rigid instance of $Rxd$ even if the constant $d$ is not rigid.

Groenendijk and Stokhof and Kager observed that rigid instances of a question constitute answers to that question. By a simple inductive argument, one can generalize this a bit.

**Definition 3 (Development).** A formula $\psi$ is a *development* of another formula $\phi$ (written $\phi \leq \psi$) if $\psi$ is built up from rigid instances of $\phi$ and rigid identity statements using boolean connectives and quantifiers. In other words, the developments of $\phi$ are the formulas $\psi$ generated by

$$
(1.5) \quad \psi := \phi^\sigma \mid t_1 \approx t_2 \mid \neg \psi \mid \psi_1 \land \psi_2 \mid \psi_1 \lor \psi_2 \mid \exists x \psi \mid \forall x \psi,
$$

where $t_1$ and $t_2$ are rigid terms, and $\sigma$ substitutes rigid terms for variables. For example, if $c$ and $d$ are rigid constants, then both $Pc \land Pd$ and $\exists x (Px \land \neg (x \approx c))$ are developments of $Px$.

**Theorem 1.** If $\phi \leq \psi$ then $?\phi \models ?\psi$.

*Proof. By induction on the size of $\phi$. ■*

Theorem 1 says that every development of $\phi$ is an answer to $?\phi$. We can prove a converse of sorts: Every answer to $?\phi$ is equivalent to a development of $\phi$. The proof proceeds roughly as follows. Recall that answerhood is defined in terms of question entailment. Suppose that $\psi$ is an answer to the question $?\phi$. Then $?\phi \models ?\psi$. Using a certain translation procedure, we can turn this question entailment into an ordinary first order entailment $?\phi^\# \models ?\psi^\#$. Next, we apply Craig’s interpolation theorem for first order logic to obtain an interpolant $\vartheta$, from which we can recover an answer to the original question $?\phi$. Finally, we show that this answer is in fact equivalent to $\psi$, and a development of $\phi$.

Before we present the theorem and its proof in more detail, we will mention the procedure that we use to translate question entailment into
first order entailment. For any first order formula $\phi$, let $\phi^*$ be the result of priming all non-rigid non-logical symbols. For example, if $c$ is a rigid constant symbol and $d$ is a non-rigid constant symbol, and

$$
\phi = \exists x (Pxc \land \neg Pyd) ,
$$

then

$$
\phi^* = \exists x (P'xc \land \neg P'yd') .
$$

Next, translate any question $?\phi$ with free variables $x_1, \ldots, x_n$ to the formula

$$
?\phi# = \forall x_1 \ldots \forall x_n (\phi \leftrightarrow \phi^*) .
$$

For instance, the example question $?\phi$ translates to

$$
?\phi# = \forall y (\exists x (Pxc \land \neg Pyd) \leftrightarrow \exists x (P'xc \land \neg P'yd')) .
$$

Then the question entailment $?\phi \models ?\psi$ is valid iff the first order entailment $?\phi#, \chi, \chi^* \models ?\psi#$ is valid. A detailed proof is given elsewhere (ten Cate and Shan 2003), based on a one-to-one correspondence between first order models for the enriched signature (with primed copies of the non-rigid non-logical symbols) and first order modal structures for the original signature that contain exactly two worlds.

Using this translation, we can now formulate and prove the following converse-modulo-equivalence of Theorem 1.

**Theorem 2.** Suppose that $?\phi \models ?\psi$, and let $\bar{y}$ be the free variables of $\psi$. Then there exists some formula $\theta$ with no free variables beside $\bar{y}$ such that $\phi \leq \theta$ and $\chi \models \forall \bar{y}(\psi \leftrightarrow \theta)$.

**Proof.** First, we will prove the special case where $\phi$ is an atomic formula, say $P\bar{x}$. Suppose that $?P\bar{x} \models ?\psi(\bar{y})$. Then, using the translation procedure discussed above,

$$
\forall \bar{x} (P\bar{x} \leftrightarrow P'\bar{x}), \chi, \chi^* \models \forall \bar{y}(\psi(\bar{y}) \leftrightarrow \psi^*(\bar{y})) .
$$

As a fact of first order logic, we can replace the universally quantified variables in the consequent by some freshly chosen constants $\bar{c}$. This results in

$$
\forall \bar{x} (P\bar{x} \leftrightarrow P'\bar{x}), \chi, \chi^* \models \psi(\bar{c}) \leftrightarrow \psi^*(\bar{c}) ,
$$

and, from this,

$$
\forall \bar{x} (P\bar{x} \leftrightarrow P'\bar{x}), \chi^* \models \psi(\bar{c}) \narrow \psi(\bar{c}) .
$$

By Craig’s interpolation theorem for first order logic, we can construct an interpolant $\vartheta(\bar{c})$ such that

$$
\forall \bar{x} (P\bar{x} \leftrightarrow P'\bar{x}), \chi^* \models \vartheta(\bar{c}) ,
$$

$$
\forall \bar{x} (P\bar{x} \leftrightarrow P'\bar{x}), \chi^* \models \psi(\bar{c}) ,
$$

$$
\vartheta(\bar{c}) \narrow \psi(\bar{c}) ,
$$
and the only non-logical symbols in $\vartheta(\vec{c})$ are those occurring on both sides of (1.12). From the way the translation procedure $(\cdot)^*$ is set up, it follows that the only non-logical symbols that $\chi^*$ and $\psi^*$ on the one hand, and $\chi$ and $\psi$ on the other hand, have in common, are rigid function symbols. Thus, $\vartheta(\vec{c})$ contains no non-logical symbols beside $P, \vec{c},$ and rigid function symbols.

Removing primes uniformly from all predicate and function symbols in (1.13), we get $\chi \models \psi(\vec{c}) \rightarrow \vartheta(\vec{c})$. From (1.14), we get the converse: $\chi \models \vartheta(\vec{c}) \rightarrow \psi(\vec{c})$. Together, this gives us

\begin{equation}
(1.15) \quad \chi \models \psi(\vec{c}) \leftrightarrow \vartheta(\vec{c}).
\end{equation}

Since the constants $\vec{c}$ do not occur in $\chi$, we can replace them by universally quantified variables. This results in

\begin{equation}
(1.16) \quad \chi \models \forall \vec{y} (\psi(\vec{y}) \leftrightarrow \vartheta(\vec{y})).
\end{equation}

Furthermore, $\vartheta(\vec{y})$ contains no non-logical symbols beside $P$ and rigid function symbols. This means that $\vartheta(\vec{y})$ is built up from instances of $P\vec{x}$, rigid identity statements, $\top$, and $\bot$ using the boolean connectives and quantifiers. As a last step, we replace $\top$ by $\forall \vec{x} P\vec{x} \land \neg \forall \vec{x} P\vec{x}$ and $\bot$ by $\forall \vec{x} P\vec{x} \land \neg \forall \vec{x} P\vec{x}$. The result is a development of $P\vec{x}$.

As for the general case, suppose $?\phi(\vec{x}) \models_{\chi} ?\psi$. Choose a fresh predicate symbol $P$ with the same arity as the number of free variables of $\phi$. Then it follows that $?P\vec{x} \models_{\chi \land \forall \vec{y}(P\vec{y} \leftrightarrow \phi(\vec{y}))} ?\psi$. Apply the above strategy to obtain a development $\vartheta$ of $?P\vec{x}$ such that $\chi \land \forall \vec{y}(P\vec{y} \leftrightarrow \phi(\vec{y})) \models \forall \vec{y}(\vartheta \leftrightarrow \psi)$. Let $\vartheta'$ be the result of replacing all subformulas in $\vartheta$ of the form $P\vec{z}$ by $\phi(\vec{z})$. Then $\vartheta'$ is a development of $\phi$, and $\chi \models \forall \vec{y}(\psi \leftrightarrow \vartheta')$.

Thus, the syntactic notion of development corresponds precisely to the semantic notion of entailment between questions.

As an example, suppose that it is commonly known that everyone who got invited to the party is going, and vice versa ($\chi = \forall x (Ix \iff Px)$), and the identity of John is known ($j$ is rigid). In response to the question Who is going to the party? ($?\phi = ?Px$), it is appropriate to answer John is invited ($\psi = Ij$). As assured by Theorem 2, the answer $\psi$ is equivalent to some development $\vartheta$ of $\phi$ given $\chi$; in this example, we can take $\vartheta = Pj$.

Recall that the formula $\chi$ represents an assertion in the common ground. If there is no assertion in the common ground (i.e., $\chi = \top$), then Theorems 1 and 3 reduce to the following syntactic characterization of answerhood.

**Corollary 1.** A formula $\psi$ without free variables is an answer to $?\phi$ iff $\psi$ is equivalent to a development of $\phi$.

This result easily generalizes from entailment by a single question to entailment by a set of questions. (A development of a set of formulas $\Phi$
is a formula built up from rigid instances of elements of $\Phi$ and rigid identity statements using boolean connectives and quantifiers) Likewise, if we eliminate equality from the logical language, then the characterization still applies. (The appropriate notion of development is then a formula built up from rigid instances using boolean connectives and quantifiers)

This syntactic characterization is useful for at least two purposes. First, it makes possible a thorough investigation of the predictions made by Groenendijk and Stokhof’s theory of answerhood: It shows what their semantic theory really amounts to, syntactically speaking. Second, this result opens the way to practical question answering algorithms: A question answering system can operate purely by symbolic manipulation without referring to the semantics. The remainder of this paper will concentrate on the first application: We will use our characterization to clarify the relation between the partition theory and other theories on the semantics of questions.

3 Comparing theories of questions

So far, we have provided a syntactic characterization of the partition theory notion of answerhood. Our characterization affords us a new perspective on exactly what assumptions are made by the partition theory, because from its statement we can directly read off three aspects of a notion of answerhood:

**Equivalence** When are two questions or answers interchangeable? The partition theory considers formulas modulo logical equivalence.

**Atomic answers** What instances of a question count as answers? The partition theory admits rigid instances of the question as answers.

**Compound answers** How do answers compose? The partition theory builds up answers using boolean connectives and quantifiers.

We can now examine each aspect of answerhood in turn, and compare the partition theory (in particular its notion of licensing) with other theories of answerhood.

3.1 Equivalence

In response to the question *Is John friendly?,* all theories agree that (1.17a) counts as an answer and (1.17b) does not (or only in a very specific context). But what about the responses in (1.18)?

(1.17)  a. John is friendly.
       b. It is raining.

(1.18)  a. John is not unfriendly.
       b. If $2 + 2 = 4$ then John is friendly, otherwise it is raining.
Theories that base meanings on propositions as sets of possible worlds equate the logically equivalent sentences (1.17a), (1.18a), and (1.18b), so they predict that the three sentences are all acceptable answers. These theories include Hamblin’s (1973) and Karttunen’s (1977) proposals, where each question denotes a set of answers, as well as Groenendijk and Stokhof’s partition theory. By contrast, theories such as that of Higginbotham and May (1981), where meanings are based on the syntactic form of formulas, treat the same three sentences as distinct and unrelated, thus predicting only the answer (1.17a). As Higginbotham and May (1981) phrase it themselves:

On the view of questions developed here they are individuated by their linguistic form, and count as distinct even if their content is in some sense the same. This identity criterion contrasts with that emerging most naturally from possible worlds semantics as applied to questions, in which they would be individuated by their propositional content; see, for example, Karttunen (1977). An immediate consequence of this latter approach is that the question whether $p$ and the question whether $q$ are identical if $p$ and $q$ are necessarily equivalent. Similarly, What is the sum of 16 and 2? and What is the product of 3 and 6? will express the same question. This consequence does not follow for the view sketched here; it remains for us an explicative task to analyse the relation obtaining between questions when they are equivalent propositionally, but not notationally.

Thus, if we want to rule in (1.17a) and (1.18a) as answers yet rule out (1.18b), then propositional equivalence faces the problem of logical omniscience, and notational equivalence faces the problem of syntactic variation.

How the partition theory handles equivalence is clear in the statement of Corollary 4, which bestows answerhood on not just developments of the question but also all logically equivalent formulas. We could change this definition of answerhood to use a finer-grained notion of formula equivalence. For instance, we might adopt some notion of ‘strong equivalence’ under which (1.17a) and (1.18a) are equivalent to each other but not to (1.18b). In this way, we can separate concerns specific to answerhood from the general problem of logical omniscience, and render the partition theory comparable to, say, Higginbotham and May’s treatment of questions. (Alternatively, one could invoke Grice’s Maxim of Manner to rule out answers such as (1.18b).)

Equivalence depends on the context in which questions and answers occur. For example, if it is known that Sue and Bill are John’s parents, then one can answer (1.19a) with (1.19b).

(1.19) a. I know that Bill left, but did John’s mother leave?
    b. Sue left as well.

The partition theory naturally handles such contexts: The formula $L(s)$ answers the question $\presym L(m(j))$ given the context $\chi = s \approx m(j)$, in that the entailment $\presym L(m(j)) \models \chi \presym L(s)$ is valid, as is easily seen through Theorem 3.
This example illustrates that what questions and answers are equivalent depends on the common ground between the questioner and the answerer. This dependence is easier to capture in the partition theory, which specifies an entailment relation between questions and answers, than in theories where each question completely determines its answers, as a set of propositions or closed formulas.

3.2 Atomic answers

Everybody agrees that the question *Who left?* can be answered with statements of the form [*...* left], but it is unclear what noun phrases can fill the blank.

(1.20)  
\begin{itemize}
  \item a. John left.
  \item b. The owner of US passport 126392058 left.
  \item c. John’s mother left (but I’m not sure who she is).
\end{itemize}

If the identity of John is known, then (1.20a) is usually an acceptable answer, unlike (1.20b), which is usually unacceptable because the hearer is unlikely to know the denotation of the noun phrase the owner of US passport 126392058. Responses like (1.20c) fall in a gray area. Note also that the question alone does not completely determine the acceptable noun phrases: The question *Who is the president of Mali?* calls for a different answer at a class exam than at a high party (Aloni 2000). Ginzburg (1995a,b) has raised important objections to simple-minded theories of answerhood, by arguing that pragmatics plays a role in determining what counts as an answer in a given context. As he argues, not only does common ground knowledge (whether the denotation of a term is known) play a role, but also the goals and the intentions of the questioner.

As shown by our syntactic characterization, the partition theory mandates that the acceptable descriptions are precisely the rigid ones. That is, only rigid instances of the question can be used to build up an answer. On this issue of acceptable descriptions, most other semantic accounts of interrogation remain silent at best (Hamblin 1973; Karttunen 1977; Higginbotham and Max 1981; Krifka 2001). Take for example Karttunen’s theory, among the more precisely specified of the alternatives. It assigns denotations to interrogative clauses by quantifying over individual concepts, not individuals. In principle, this move opens the door for non-rigid descriptions. However, perhaps since he was not conscious of the move, Karttunen does not specify exactly which concepts to quantify over, in other words exactly which descriptions to allow. (To indiscriminately quantify over all concepts would incorrectly predict that almost nobody knows the full answer to any question.)

Which terms are rigid depends on the context. In general, as the common ground increases, more and more terms become rigid—the denotation of more and more terms becomes known. Given that the appropriateness of
answers depends on rigidity, it is expected that what is allowed as an answer depends on the amount of information that is common ground. The partition theory nicely accounts for this, as we saw in Sect. 3.1.

We view the rigidity criterion as an attempt to approximate whether a description ‘specifies’ an entity. This approximation is not perfect, as shown by the following exchange (provided to us by a referee).

(1.21) [The Amsterdam Marathon course has been altered.]

A: Who will these changes affect most?
B: The winner. He will be annoyed to have to run the last kilometer on cobblestones.

B’s answer above is perfectly acceptable even before the marathon takes place and the winner becomes known (rigid). Such examples, together with Ginzburg’s (1995a,b) observations, motivate us to refine how our definition of answerhood models specification. Aloni (2000) has taken up this point by extending the partition theory with the notion of conceptual covers to allow for much more fine-grained control over what instances count as atomic answers. Her theory also accounts for questions such as Who is who?

So far, we have not discussed another kind of atomic answers predicted by the partition theory, namely (rigid) identity statements. Identity statements by themselves are usually trivial and infelicitous as answers, but they are essential in compound answers such as Only John is coming to the party ($\forall x (Px \rightarrow x \approx j)$). Perhaps the definition of development could be improved by excluding identity statements of the form $x \approx y$, where both $x$ and $y$ are variables. This would exclude the problematic answer $\exists x \exists y \neg(x \approx y)$ (“there exist at least two entities”).

### 3.3 Compound answers

All theories agree that the conjunction of two answers still counts as an answer (if the conjuncts are mutually consistent). For example, because John left and Mary left are both answers to Who left?, the conjunction John left and Mary left is again an answer. Oftentimes (as in Hamblin 1973; Karttunen 1977; Higginbotham and May 1981), when questions are analyzed as denoting a set of answers, the set is actually construed to contain the atomic answers only: the proposition that John left and the proposition that Mary left, say, but not the proposition that John left and Mary left. It is then explicitly stated or implicitly understood that, not only are elements of this set appropriate answers, but their conjunctions are as well.

The partition theory takes rigid instances of the question to be atomic answers. However, it goes far beyond licensing conjunctions of atomic answers: As Corollary 1 makes clear, it allows arbitrary propositions composed from rigid instances using boolean connectives and quantifiers. Consequently, it predicts that all of the following are appropriate answers.
(1.22)  a. John left.
b. John left and Mary left.
c. Either John left, or Mary left.
d. John did not leave.
e. If anyone left, then John did.
f. Everyone left.
g. Nobody left except John.
h. Somebody left.
i. Somebody other than John didn’t leave.

The view that developments approximate the logical compositionality of answers thus prompts us to refine how our definition of answerhood models composition.

On one hand, the boolean connectives illustrated in (1.22b–d) are easy to deal with in a theory of interrogation where the meaning of each question determines a set of atomic answers. For instance, if we wish to permit disjunctions like (1.22c) as answers, we can simply let the set of appropriate answers be the closure of the set of atomic answers under disjunction in addition to conjunction.

On the other hand, quantifiers as illustrated in (1.22e–i) are harder to treat in any theory where (atomic) answers are closed formulas: To build up the proposition that everyone left ($\forall x Lx$), we cannot just combine formulas expressing that specific individuals left ($Lj, Lm, \ldots$). That free variables are necessary is reflected in our definition of rigid terms, which includes variables. If we wish to treat questions as sets of atomic answers while maintaining closure of answerhood under quantification, one would have to introduce atomic answers that are not propositional, in other words semantic objects that correspond to logical formulas with free variables.

A move in the direction of non-propositional atomic answers has been made by the so-called functional or “structured meaning” approach to interrogation. Under this approach, which has a long history, “question meanings are functions that, when applied to the meaning of the [short] answer, yield a proposition” (Krifka 2001; a recent exposition). For instance, the meaning of Who left? is

$$\lambda x. Lx,$$

which when applied to John yields the proposition John left, as in (1.22a). To generate compound answers, this approach can be turned on its head: by viewing the responsive phrase as the operator, as Ginzburg (1996) puts it, the meaning of everyone becomes the functional $\lambda c. \forall x c(x)$, which when applied to (1.23) yields the proposition $\forall x Lx$, as in (1.22f). In this way, generalized quantifiers can form compound answers as well as atomic ones.
Incidentally, notice that the answers in (1.22a–g) seem more appropriate than those in (1.22h–i). These two groups of answers are distinguished by the following criterion: On one hand, the answers in (1.22a–g) correspond to formulas built up from atomic answers and negations thereof using conjunction, disjunction, and universal quantification (but not existential quantification). On the other hand, the answers in (1.22h–i) are not of this type, as they essentially involve existential quantification. A simple modification of the definition of development allows us to capture these observations.

4 Conclusion

We presented a syntactic characterization of a notion of answerhood for the partition semantics of questions. In terms of the partition theory itself, this result explains the meaning of a question in terms of the form of its answers. Moreover, in relation to other theories of interrogation, this result lets us separate a notion of answerhood into three aspects:

1. equivalence (when two questions or answers are interchangeable),
2. atomic answers (what instances of a question count as answers), and
3. compound answers (how answers compose).

Organized along these three dimensions, theories of questions can then be compared in a principled way. In particular, theories differ in their notions of compound answers, and hence in how they hypothesize answers compose.

Apart from a more detailed comparison of theories of questions, we are investigating two directions for further research. First, as we mentioned already in Sect. 2, our result bears on computational question answering algorithms. For example, we conceive of Prolog as a question answering algorithm in the partition theory sense (ten Cate and Shan 2002).

Second, we suggested several ways in which the definition of development might be adjusted to better reflect our intuitions concerning what counts as an answer to a question. These adjustments, like our original definition of development, were stated syntactically, but we naturally wonder whether they correspond to sensible variants of the (model-theoretic) semantics given in (1.4). To illustrate briefly, consider again the alternative definition of developments suggested at the end of the previous section, according to which compound answers must be built up from atomic answers without existential quantification. A well-known model-theoretic result states that the first order properties that can be expressed without existential quantification are precisely the ones that are preserved under taking generated submodels. We leave it as an open question whether this model-theoretic requirement can be given an intuitive linguistic motivation. Perhaps this also explains why John left is intuitively a good answer to the question Did anybody leave?.
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