Homogeneity, Trivalence, and Embedded Questions*

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Abstract

Plural predication is known for the homogeneity property: 'Adam wrote the books' is true if Adam wrote (roughly) all of the books, but its negation is true only if he wrote (roughly) *none* of them. Embedded questions show in many ways analogous behaviour: 'Agatha knows who was at the party' is intuitively true if Agatha is fully informed about who the guests were, whereas its negation 'Agatha doesn't know who was at the party' conveys that she has pretty much no idea who was there. We argue that the properties of questions in this connection can be explained as a direct consequence of the homogeneity of plural predication once the latter is viewed through the lense of trivalent logic.

1 Introduction

Sentences with definite plurals are known for the property of *homogeneity*:[1]

(1) a. Mr. Benfleet published the books. ⇝ Mr. Benfleet published **all** of the books.
b. Mr. Benfleet didn't publish the books. ⇝ Mr. Benfleet published **none** of the books.

Sentences with embedded questions show an analogous homogeneity effect:[2]

(2) a. Agatha knows who was at the party.
⇝ For **everybody** who was at the party, Agatha knows that they were there.
b. Agatha doesn't know who was at the party.
⇝ For **nobody** who was at the party does Agatha know that they were there.

The main goal of this contribution is to demonstrate that once homogeneity with plurals is viewed through the lense of trivalent logic, an explanation for the facts with embedded question arises naturally due to the fact that the answers to the question, which are propositions of the form *x was at the party*, are trivalent propositions when x is instantiated by a plurality of individuals.

2 Pluralities and Homogeneity

The facts with plural definites can be conceptualised naturally in terms of trivalent logic. If we assume, as is standard, that negation simply switches truth and falsity, but leaves the third truth value untouched, we arrive at the following diagnosis:

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[1] Cf. [18], [15], [6], [16], [10], among others.

[2] See [21] for experimental corroboration.

(3) Mr. Benfleet published the books.

true iff Mr. Benfleet published all of the books.
false iff Mr. Benfleet published none of the books.
neither otherwise (i. e. if he published some, but not all of the books).

If we further assume, as is standard since [14], that definite plurals denote plural individuals, so that these sentencs are simple predicational structures with no quantification involved, we can state for following generalisation to capture the pattern according to which (distributive) predicates, as applied to pluralities, are trivalent.[3]

(4) **Homogeneity for Distributive Predicates**
A (distributive) predicate P is true of a plurality a iff it is true of all parts of a, and false iff it is false of all parts of a. Otherwise it is undefined.

2.1 Quantifiers and Homogeneity Removers

A natural question to ask, then, is how quantifiers (ranging over atomic individuals) behave in this trivalent world, which was empirically investigated by [12]. What they found was this: A quantifier is true of its scope predicate iff it is true no matter how the undefined cases of the scope predicate are resolved, and false iff it is false no matter how the undefined cases of the scope predicate are resolved.[4]

Consider, for example, the sentence (5) when there are three publishers a, b, and c.

(5) Every publisher is P.

Assume that P is as below, with # as the third truth value. There are two ways of resolving the undefined case of P, yielding P^1 and P^0.

$$P = \begin{bmatrix} a \mapsto 1 \\ b \mapsto 1 \\ c \mapsto \# \end{bmatrix} \quad P^1 = \begin{bmatrix} a \mapsto 1 \\ b \mapsto 1 \\ c \mapsto 1 \end{bmatrix} \quad P^0 = \begin{bmatrix} a \mapsto 1 \\ b \mapsto 1 \\ c \mapsto 0 \end{bmatrix}$$

The universal quantifier is true of P^1, but false of P^0. Thus, it matters which way the undefined cases are resolved and the universal quantifier is undefined of P.

Considering the alternative situation below, however, it does not matter how the undefined case is resolved, since in either case there is at least one individual of which the predicate is false, so that the universal quantification is automatically fase.

$$P = \begin{bmatrix} a \mapsto 1 \\ b \mapsto 0 \\ c \mapsto \# \end{bmatrix} \quad P^1 = \begin{bmatrix} a \mapsto 1 \\ b \mapsto 0 \\ c \mapsto 1 \end{bmatrix} \quad P^0 = \begin{bmatrix} a \mapsto 1 \\ b \mapsto 0 \\ c \mapsto 0 \end{bmatrix}$$

We thus arrive at the following pattern for the universal quantifier:

(6) Every publisher is P.

true iff P is true of all publishers.
false iff there is at least one publisher of whom P is false.
undef. otherwise.

[3] In what follows, we will assume that we live in a walled garden where no collective predicates exist. See [9] for a discussion of homogeneity with collective predicates.

[4] For first-order definable monotonic quantifiers, this amounts to Strong Kleene logic.

If we instantiate P with *accepted the books*, we obtain the following:

(7) Every publisher accepted the books.

true iff all publishers accepted all the books.
false iff at least one publisher accepted none of the books.
undef. otherwise (i. e. iff every publisher accepted at least some of the books, but at least one publisher didn't accept all of the books).

Ignoring collective predication, we can assume that *all* is just a universal quantifier over atomic individuals: It turns a plural predication into quantification over the parts of the plurality.

(8) a. $[\![\text{The students came}]\!] = \mathit{came}(\iota x.\mathit{students}(x))$
b. $[\![\text{All the students came}]\!] = \forall x' \preceq_{AT} \iota x.\mathit{students}(x) : \mathit{came}(x')$

If we look at predicates that are defined for all atomic individuals, such as simple intransitive verbs, then we find that *all* effectively functions as a homogeneity remover ([15]). (8b), for example, has the same truth conditions as (8a), but is false whenever (8a) is either false or undefined, and never undefined. Thus, the effect of *all* is to collapse undefinedness into falsity.

(9) Mr. Benfleet published all the books.

true iff Mr. Benfleet published all of the books.
false iff there is at least one book that Mr. Benfleet didn't publish.
neither never.

We will further assume that there is no difference between *all* in adnominal position and *all* in adverbial position, so that (10a) and (10b) are semantically equivalent.

(10) a. All the students came.
b. The students all came.

3 Embedded Questions

Assume that embedded questions semantically have the weakly exhaustive reading. Then viewing questions from the same perspective, we arrive at the following description:

(11) Agatha knows Q.

true iff Agatha knows all the true answers to Q.
false iff Agatha knows none of the true answers to Q.
neither otherwise (i. e. if she knows some, but not all true answers).

Some languages, like German, Dutch, and Chinese,[5] have elements which, when added *within* the question, remove homogeneity:

(12) a. Agatha weiß nicht, wer auf der Feier war.
Agatha knows not who at the party was
roughly: 'Agatha has no idea who was at the party.'
b. Agatha weiß nicht, wer aller auf der Feier war.
Agatha knows not who all at the party was
'There is somebody who Agatha doesn't know was at the party.'

[5] Yimei Xiang (p. c.) on *dou*.

Depending on the *wh*-word, these elements may take different forms (*aller*, *alles*, *überall*; there is also some speaker variation), but they always correspond to the adverbial universal quantifier over the respective type which can also appear in declarative clauses.

3.1 Knowledge of Trivalent Answers

The above effects can be explained as a consequence of the fact that the answers to questions are trivalent propositions.[6] The way that the Hamblin set of a question is usually obtained is, intuitively, by replacing the *wh*-word with various individuals of the relevant sort. These individuals can be atomic individuals or pluralities, and in the latter case, the resulting proposition is trivalent. Thus, the Hamblin set of (13a), given in (13b), contains many trivalent propositions, namely all those where x is instantiated by a plurality of persons.

(13) a. Who came?
b. $\{\lambda w.came_w(x) \mid x \text{ is a person or plurality of persons}\}$

In order to see the further consequences of this, we first have to look at what happens when *know* is applied to a trivalent declarative complement.

(14) Agatha knows that the girls came to the party.

On the usual analysis, *know* is a universal quantifier over worlds, its scope argument being, in this case, the proposition *that the girls came to the party*. This proposition is a trivalent predicate of worlds: it is true in those world where all the girls came, false in those worlds where none of the girls came, and otherwise undefined. Thus, we can apply the established behaviour of the universal quantifier as applied to a trivalent scope predicate and obtain the following prediction (for the *de re* reading, and ignoring the presupposition), which appears reasonable enough:[7]

(15) $\lambda w.\forall w' \in \mathrm{Dox}_w(Agatha) : came_{w'}(\iota x.girl_w(x)))$

true iff all of the y. p. came in all of Agatha's belief worlds.
false iff in at least one of Agatha's belief words, none of the y. p. came.
undef. otherwise

On the weakly exhaustive reading, *know* Q is always extensionally equivalent to *know* p for a particular p, namely the strongest true member of the Hamblin set. Thus, to know who came is to know *that* x *came*, where x is the maximal plurality of people who actually came. Since this is a trivalent proposition (if more than one person came), we can apply the pattern from (15) and immediately obtain a prediction for truth and falsity conditions as well as cases of undefinedness.

(16) Agatha knows who came ≡ Agatha knows that those came who did, in fact, come.
$\lambda w.\forall w' \in \mathrm{Dox}_w(Agatha) : came_{w'}(\iota y.came_w(y))$

true in w iff in all of Agatha's belief worlds, all the people who came in w came.
false in w iff in at least one of Agatha's belief worlds, none of the people who came in w came.
undef. otherwise.

[6] Particular thanks are due to Benjamin Spector for encouraging me to explore this idea.
[7] The presupposition of *know* is, of course, being ignored here.

Note that beyond the view on the trivalence of plural predication presented above, no additional assumptions were needed to obtain these effects with embedded questions — in fact, extra assumptions would be needed to prevent them!

Since the homogeneity effects with embedded questions are a consequence of the fact that the answers to the question are trivalent propositions, we now have an avenue for explaining how universal adverbials within the question manage to remove homogeneity. They do just what they do in declarative sentences as well: They replace plural predication by universal quantification over atoms and thereby remove homogeneity, making the members of the Hamblin set bivalent.

(17) a. Wer ist aller gekommen?
who is all come
b. $\{\lambda w.\forall y : y \preceq_{AT} x \rightarrow \mathit{came}_w(y) \mid x \text{ is a person or plurality of persons}\}$

With a bivalent proposition — *that all the people came who did, in fact, come* — as the argument of *know*, no undefinedness arises.

(18) Agatha knows who all came ≡ Agatha knows that all the people came who did, in fact, come.

true in w iff in all of Agatha's belief worlds, all the people who came in w came.
false in w iff in at least one of Agatha's belief worlds, at least one of the people who came in w didn't come.
undef. never.

3.2 More on Homogeneity Removers

Besides being able to explain how a universal adverbial quantifier within the question causes the homogeneity effect to disappear, we can make sense of a number of further facts regarding the behaviour of adverbial quantifiers within questions.

We observe that *mostly* and *partly* do not have question-internal correlates. In particular, we do not know of any language in which the following is possible:[8]

(19) #Agatha weiß, wer großteils gekommen ist.
Agatha knows who mostly came
'For most of the people who came, Agatha knows they came.'

Our theory would predict the following meaning for a question containing the adverbial *mostly*:

(20) a. #Wer ist großteils gekommen?
who is mostly come
b. $\{\lambda w.\text{most}(\lambda y.y \preceq_{AT} x)(\lambda y.\mathit{came}_w(y)) \mid x \in D_{\mathtt{e}}\}$

This Hamblin set has no unique strongest member, which many theories of question embedding take to give rise to a *mention some*-reading, predicting the following meaning:

[8] [2] point out German *so*, which has a somewhat unclear effect that may be seen as lying in this direction.

(i) Agatha weiß, wer so auf der Feier war.
Agatha knows who SO at the party was
'Agatha has a pretty good idea about who was at the party.'

We are not aware of any similar items, and not convinced that this single example isn't to be analysed in some entirely different fashion. Note also that *so* is entirely unrelated to the German existential adverbial quantifier *teilweise* 'partly'.

(21) #Agatha weiß, wer großteils gekommen ist.
Agatha knows who mostly came
'There is a plurality x such that most members of x came and Agatha knows that most of x came.'

This is a decidedly odd meaning, which intuitively doesn't conform to the way in which we normally package information. Thus, while we have no formal constraint to propose that would rule it out, it seems quite natural that such a statement would tend to be perceived as infelicitous.[9] In the case of *partly*, we predict that knowledge of the question collapses into knowledge of the corresponding existential statement, which could plausibly be infelicitous due to some blocking or manner effect.

The lack of alternatives to adverbial universal in normal questions also explains why the homogeneity removers in questions cannot be contrastively stressed:

(22) #Agatha weiß nicht, wer ALLER gekommen ist, aber sie weiß, dass Miles da war.
Agatha knows not who all come is but she knows that Miles there was
'Agatha doesn't know about ALL the people who came, but she knows Miles was there.'

Finally, it follows that *aller* and its ilk do not have their homogeneity-removing effect with rogative verbs, since their homogeneity, if they show any, cannot be due to the trivalence of the answers. This is correct: (23) still means that Peter has no influence over who comes. It seems that *aller* is essentially vacuous here (though not unacceptable).

(23) Es hängt nicht von Peter ab, wer aller kommt.
it depends not from Peter PRT who all comes
not: 'There is somebody whose coming doesn't depend on Peter.'

3.3 An Odd Prediction?

The analysis just presented actually predicts a stronger meaning for negated sentences with embedded questions than we have presented at the outset. According to it, (24a) entails not only (24b), but the stronger (24c).

(24) a. Agatha doesn't know which girls came.
b. Agatha doesn't know of any of the girls who in fact came that they came.
c. Agatha doesn't know that any of those girls came who in fact came.

If this prediction is wrong, then one should be able to find a sentence which under some conditions is predicted to be undefined, but is actually true. It is not clear that such a case can be identified.

If it is assumed that *all* the girls came, (25a) is predicted to entail (25b).

(25) a. Agatha doesn't know which girls came.
b. Agatha doesn't know that any of the girls came.

[9] Questions with *mostly* become marginally possible on a reading with higher-order plurals or contextually partitioned plurals, which is expected on our theory:

(i) Context: *There are three groups of students. One group consists mostly of women.*
??Agatha knows which students are mostly female.
'Agatha knows which group of students is the one that is mostly women.'

Consequently, (26a) should be undefined in such a situation. And indeed, the sentence would seem to be somewhat unnatural in this case, (26b) being a preferred way of describing the situation.

(26) a. Agatha knows that at least some of the girls came, but she doesn't know which ones.
b. Agatha knows that at least some of the girls came, but she doesn't know that all of them did.

There is a plausible independent explanation for this: (26) has a stronger presupposition (that all the girls came) than (25), and it is well-known that sentences with stronger presuppositions are preferred as long as those presuppositions are true ([7] and many thereafter). Thus, we cannot take the oddness of (25) to *confirm* our theory of homogeneity in embedded questions. However, it doesn't disconfirm it, either, since the sentence is, after all, odd in the context in question.

Consider, alternatively, a situation in which both Nina and Mary came. Then (27a) cannot be true — it can only be either false or undefined. And indeed, the sentence does seem to have a slightly contradictory flavour about it, unlike the perfectly acceptable (27b).

(27) a. ??Agatha doesn't know which girls came, but she knows that at least one of Nina and Mary came.
b. Agatha doesn't know exactly which girls came, but she knows that at least one of Nina and Mary came.

This is similar to the analogous case with definite plurals.

(28) a. ??Mr. Benfleet didn't publish the books, but he published the autobiography.
b. Mr. Benfleet didn't publish all the books, but he published the autobiography.

However, (27) seems equally odd when it is not presupposed that both Nina and Mary came, although our theory doesn't predict this. The explanation for this oddness effect is therefore likely a different one, potentially to do with a requirement for contrastive stress, so that, again, the predictions of our theory are masked and prevented from being conclusively put to the test.

In the face of this empirical unclarity, we might at least ask if we *could* avoid the strong meaning (24c) and replace it with the weaker meaning in (24b), should we wish to do so. Since the behaviour of embedded questions is, on our account, tied to the behaviour of declarative complements of *know*, this would require that if a definite plural is embedded in a declarative under *know*, the sentence should have a reading on which the definite plural effectively takes distributive scope over *know*.

(29) Agatha doesn't know that the young people came.
a. $\lambda w.\neg\forall w' \in \mathrm{Dox}_w(\mathit{Agatha}) : \mathit{came}_{w'}(\mathit{typ}_w))$
$\vDash$ Agatha doesn't know that any of the y. p. came.
b. $\lambda w.\mathrm{Dist}(\mathit{typ}_w)(\lambda x.\neg\forall w' \in \mathrm{Dox}_w(\mathit{Agatha}) : \mathit{came}_{w'}(x))$
$\nvDash$ Agatha doesn't know that any of the y. p. came.
$\vDash$ For none of the y. p. does Agatha know that they came.

It seems doubtful that this reading actually exist, and indeed definite plurals are known to not normally take distributive inverse scope ([20]):

(30) Two students read the books.

not: 'For every book, there are two boys who read it.'

Assuming, however, that the reading in question for (29) does exist, in order to harness it for questions, we would need a semantic, not a syntactic way for the plurality to take distributive wide scope, since in the case of the embedded question, there is no constituent that denotes a plurality and could, for example, undergo quantifier raising. The development of a system that allows this, but also allows low-scope readings of pluralities, and perhaps even disallows distributive inverse scope over regular quantifiers, posits a significant technical challenge for which no obvious solution is currently in sight (see [17] for some of the problems involved).

Pending further technical developments, the weaker reading is therefore not accessible for our approach — and, we repeat, it is not even clear that it needs to be accessible.

4 A Non-Alternative

The way we superficially described the data in (11), repeated here as (31), suggests a quite different approach to the one that we have taken. It seems that one could take the complement of *know* to be a complex algebraic object and have *know* be a homogeneous distributive predicate, as per (4), with respect to this object.

(31) Agatha knows Q.

true iff Agatha knows all the true answers to Q.
false iff Agatha knows none of the true answers to Q.
neither otherwise (i. e. if she knows some, but not all true answers).

And indeed, the use of algebraic ideas in the treatment of embedded questions is not a new idea: it has been used to approach the phenomenon of quantificational variability effects ([4], [13], [3]).

(32) Agatha mostly knows who was at the party.
$\rightsquigarrow$ For most people who were at the party, Agatha knows they were there.

According to Lahiri, there is an algebra of answers and quantification is over (atomic) true answers.

(33) Agatha mostly knows who was at the party.
'For most true p of the form x *was at the party* (x an atom), Agatha knows p.'

If the object of *know* is the plurality of true answers to the question, then this is just analogous to adverbial quantification with definite plurals:[10]

(34) The books were mostly published. $\approx$ Most of the books were published.

We will call this approach to homogeneity with embedded questions — which conceives of the argument of *know* as an algebraic object and assumes that homogeneity holds with respect to that algebra, and identifies that algebra with the one used to analyse QVE — as the QVE approach to homogeneity. This approach has indeed been taken in [5].

A number of problems for the QVE approach is posed by the homogeneity-removing adverbials within the question. The first puzzle that these items raise is why they are inside the

[10] On Beck & Sharvit's analysis of QVE, the question would instead be viewed as a plurality of subquestions. This difference is immaterial for the present discussion.

question and clearly within the scope of the *wh*-word, while normal adverbial quantifiers are in the matrix clause. On the QVE approach, some compositional mechanism would have to be devised by which question-internal *all* manages to turn the question (or perhaps worse, if one follows Lahiri, an answer) into a universal quantifier over its parts.

This, however, leads to the second puzzle: If question-internal *all* works this way, why does it not have counterparts with different quantificational strength? Why is there no question-internal counterpart to *mostly* and *partly*, as discussed in section 3.2 above?

The third and most severe problem for the QVE approach is that the question-internal homogeneity remover can, in fact, co-occur with a quantificational adverb in the matrix clause. This is very much unlike the case of definite plurals, where an adverbial quantifier cannot associate with a quantificational noun phrase.

(35) a. *Alle Buben sind großteils gekommen.
all boys are mostly come
b. Agatha weiß großteils, wer aller auf der Feier war.
Agatha knows mostly who all at the party was
c. Wer aller zugelassen wird, hängt großteils (ausschließlich) von diesem
who all admitted is depends mostly (exclusively) on this
Komitee ab.
committee PRT

We take these facts to indicate that, tempting as it may be, quantificational variability effects and homogeneity with embedded questions should not be unified.

5 Conclusion and Outlook

We have argued that once the homogeneity property of plural predication in natural language is viewed as a phenomenon of logical trivalence, homogeneity effects with embedded questions follow immediately due to the fact that the answers to *wh*-questions are trivalent propositions (when pluralities are involved). This has the additional benefit of explaining how adverbial universal quantifiers *within* the question can remove the homogeneity effect: they simply turn the answers into bivalent propositions, in the same way that they do when inserted into declarative clauses. A number of further properties of these adverbial homogeneity-removers within questions can also be made sense of. It is this feature which makes our approach superior to one which attempts to unify homogeneity and quantificational variability effects in embedded questions, as the latter cannot account for these question-internal adverbial quantifiers.

Yet a number of open questions remain. One aspect of adverbial universal is not explained on our theory: Why can they not occur inside questions in all language, but are often infelicitous, such as in most varieties of English?

(36) a. The young people will all come.
b. *Who/Which people will all come?

Furthermore, we identified an empirical unclarity concerning the particular truth and falsity conditions that our theory predicts for sentences with embedded questions, which might turn out to be too strong. Should these predictions turn out to be wrong, a serious technical challenge for our approach would arise.

Finally, it is unclear at this point how our approach to homogeneity effects fares beyond the case of weakly exhaustive readings. It would seem that the present trivalent semantics

would be most easily combined with an approach that derives stronger readings from weakly exhaustive ones through some sort of exhaustification ([8]), but no fully satisfactory account of this kind has been given. The exploration of possible trivalent versions of partition semantics also remains as a task for future research.

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