Exhaustivity, Questions and Plurals in Update Semantics

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1 Introduction

Update Semantics —more than related dynamic frameworks such as DRT— offers a promise of being able to integrate that part of pragmatics that is rule governed with semantics. Moroever, it has a very natural interpretation: it tells what is the change in an information state under the influx of linguistic input, i.e. it can be interpreted without any further ado as a theory of what happens to language users when they are exposed to the utterances of a speaker. When the information states are interpreted as the common grounds between participants in a conversation, the theory gives an account of what information is established during a conversation.

This paper presents an exhaustification operator in update semantics and discusses a series of applications of this operator. The exhaustification operator takes an open formula and assigns (if this is possible) values to the free variables such that the formula is true as a result and entails all versions of the formula that can be obtained from the formula by assigning other values to the free variables for which the formula is true.

The first application of the operator is to provide an (update) semantics for questions. The Wh-elements of the question are represented as discourse markers and the discourse markers are exhaustified with respect to the content of the question. Positive answers to the question present extra constraints on the same discourse markers. The theory merges semantic and pragmatic questions and can reduce the exhaustivity of answers to the semantics of the question.

Question+answer updates are then used to formalize the theory of topic and focus that equates the topic with a question and the focus with its answer. As we use a standard DRT-like representation of the complete sentence to represent the focus, the semantic effect of the topic-focus division is that certain discourse markers in the sentence receive an interpretation that is exhaustive with respect to the topic. The same assumption also makes it possible for the theory to allow multiple topics for the same sentence. The topic-focus theory is applied to obtain certain scalar implicatures and to explain the Evans-effects. The indeterminacy of the topic-focus division is exploited to explain the "cancellation" of the scalar implicatures and the definiteness effects.

The same mechanism is used to salvage an almost forgotten theory of plural NPs within DRT, in which they are very similar to singular NPs. Cancellable exhaustivity provides the properties that the original theory could not deal with. An advantage is the reduction of the number of different meanings that need to be assumed in the classical view and —where that cannot be avoided— a mechanism for resolving the ambiguities.

Why use update semantics? It will be clear from the discussion that it is quite possible to define exhaustification operators outside the context of an update semantics. Elsewhere (in Zeevat and Scha (1992)), we have defended the view that update semantics is particularly suited for developing pragmatics and semantics within a single theory. The first istance of that is a successful treatment of presuppositions in update semantics due to Karttunen (1974) with important additions by Heim (1983b). Certain pragmatic implicatures of assertions have been shown by Stalnaker (1979) to be directly expressible as conditions on updates. Here, I attempt to do the same for certain implicatures arising from quantity and relevance.

Information states are here conceived as in Stalnaker (1979) to be a representation of the apparent common ground between speaker and hearer(s): that body of information which partners have purported to accept in the conversation. Some have proposed to take the hearer's information or the hearer's picture of the common ground, but that position —like the one where it is the speaker's common ground— does not make much difference from the formal perspective. My aim is to describe the common ground as a parameter that influences the behaviour of the participants in a dialogue. It affects both the way in which they interpret the incoming utterances by others and the way they plan their own utterances. It is not really relevant for this enterprise whether speakers and hearers are right in their picture of the common ground, unless one wants to analyse communication failure.

2 Exhaustification

What is the exhaustive interpretation of a variable in a formula? Intuitively, it is that value for the variable such that taking it to be the value rather than something else makes the formula true and makes it entail all the true formulas that can be obtained by assigning another value to the same variable. If one thinks of the free variable as something that can have many values, it is the strongest true interpretation that the open formula allows. Of course, there need not exist an exhaustive interpretation for a formula. This is indeed a common situation. Suppose five boys are asleep. It is then impossible to have an exhaustive reading for sentences like (1a/b) . (I use lower case variables for sets of objects, singular objects are represented by their singleton sets).

(1) a. One boy sleeps.
$x \wedge boy(x) \wedge \#x = 1 \wedge sleep(x)$
b. Less than three boys sleep.
$x \wedge boy(x) \wedge \#x < 3 \wedge sleep(x)$

None of the values we can find for these sentences is exhaustive: if x denotes one sleeping boy, x can also denote another sleeping boy without there being a logical connection between the statement about the one boy and the other. The same holds if x denotes sets with cardinality less than three: there are variants for the denotation of x that are logically unconnected.

Exhaustification is thereby a combination of the statement that exhaustive readings are possible together with the assignment of the exhaustive value to the free variable[1]. When exhaustification is possible, it gives minimal or maximal elements with respect to some order, e.g. the inclusion order on sets or the natural order on natural numbers.

It is not standard to let an open formula entail other versions of it on the same model. Entailment involves quantifying over models and within a single model, the same formula normally has a single meaning. The following construction is an attempt to make it precise.

Let K be a class of models which contains the expansions to a language L of a given model M_0 for a language $L_0 \subseteq L$. The given model fixes the domain and some privileged relations. For the examples I consider, it suffices to take the basic model M_0 to have a domain which is the powerset of some given non-empty set (without $\emptyset$) together with the natural numbers (without 0), with the privileged relations *inclusion* ($\subseteq$) between the sets, *smaller than* ($<$) between the numbers and the *cardinality* operator ($\#$) relating sets and numbers. Object variables will range over sets of objects, number variables over numbers. A reasonable extension would be the inclusion of quantities of stuff and reals among the domain entities with the basic relations between the two. Part-whole relationships and measurement are other obvious candidates. In addition, K must obey a set MP of postulates about the non-privileged relations. $|$ is the restriction operator.

$K = \{M : M \models MP \text{ and } M|L_0 = M_0\}$.

Now let φ be a formula with a free variable x and K a class of models M as described above. The exhaustive value of φ in K with respect to the variable x is that object u in the domain U_M of M such that (2).

(1) $M \models \varphi < u >$ and
(2) $\forall v \in U_M \forall M' \in K(M \models \varphi < v >$ and $M' \models \varphi < u >$
$\Rightarrow M' \models \varphi < v >)$.

Example 1.

Let K be as described above. Let MP contain:

$Px \wedge y \subseteq x \rightarrow Py$

(gloss: If John has sheep x then John has sheep y for $y \subset x$.)

Let φ be Px

Then an exhaustive value for x in the model M is the set of all P in M. (gloss: John's sheep.)

Example 2.

The postulates are given by:

$Pn \wedge m > n \rightarrow Pm$

[1]Classically, we would have to say that exhaustification binds the variable. That the variable is available as a name for the exhaustive value outside the scope of the operator is a non-classical dynamic effect. Unlike systems like DPL, we do not assume that the variable only functions in this way to the right of the scope of the operator.

(gloss: If John runs the mile in n minutes then John runs it in m minutes if $m > n$)

Let φ be Pn

The exhaustive value is the smallest number m such that Pm holds in M. (gloss: John's time for the mile.)

Example 3.

$Pn \wedge n > m > 0 \rightarrow Pm$

(gloss: If Bill has four chairs then Bill has three chairs.)

The exhaustive value is the largest number m such that Pm. (gloss: the number of Bill's chairs.)

2.1 Update Semantics

Update semantics is a general name for any theory of language that explains the semantic properties of its expressions in terms of the information change that they bring about on information states.

There is room for a general theory of update semantics: one that tries to abstract from any assumptions about the nature of the information states and the changes that they allow. (See Veltman (1996)). Notions of logical consequence typically belong to this level. A natural notion is to define $\varphi_1, \ldots, \varphi_n \models \psi$ as $\forall\sigma\sigma[\varphi_1]\ldots[\varphi_n][\psi] = \sigma[\varphi_1]\ldots[\varphi_n]$ (for other notions, see Veltman). $\sigma \models \varphi$ abbreviates $\sigma[\varphi] = \sigma$.

Another distinction that can be made is the one between monotonic systems, allowing only updates, and non-monotonic systems that allow the information state to decrease. The latter kind are important for theories of belief revision and have also been used for giving an update semantics for DPL (Groenendijk and Stokhof (1991)). I will stick to a monotonic system.

Two main options are possible. The information states grow as they acquire new information. This is the constructive approach. A classical model would be to take complete theories in some logic. Information growth would be the addition of a new sentence to the theory and closing off under logical consequence. (Another model of this approach is given in the DRS construction algorithm: the natural language defines the updates, the information states are ever larger DRSs.) The other road starts from taking a set of information carriers as given and proceeds by eliminating carriers. This is eliminative update logic. A third approach is a combination of elimination and construction. This has been considered by Dekker (1993), in the footsteps of Heim (1983a).

The approach here is purely eliminative. In an eliminative update semantics, the information in an information state increases by eliminating information carriers: those in which the new information does not hold. Both the appearance of new discourse markers and the appearance of new facts will be modelled by elimination[2].

[2]This is closely related to modelling epistemic operators with a Kripke style semantics. The set of belief alternatives is the set of possible worlds that the belief subject cannot recognise as wrong, by not having a belief that rules out the alternative.

Information carriers for a language $L =< P, F, C >$ (with P a set of relations, F a set of function symbols, and C a set of constant symbols) will be models for languages $L' =< P, F, D >$ with $D \subseteq C$. C is made up of two sorts: sets of objects and natural numbers. There are no variables. Among the ranges of the individual terms we do not include the empty set and the number zero. (This reflects natural language: there is no group of zero elephants.)

The language for defining updates is a version of the DRT-formalism, where discourse referents are treated as conditions meaning: this object exists.

(2) Terms:
a. basic terms for numbers and sets.
b. $ft_1,\ldots,t_n$ is a term iff $t_1,\ldots,t_n$ are terms, f is a function symbol and $t_1,\ldots,t_n$ match the signature of f.

Formulas are defined in (3).

(3) Formulas:
a. basic terms are formulas
b. $t_1 = t_2$ is a formula iff t_1 and t_2 are terms of the same sort.
c.$Pt_1,\ldots,t_n$ is a formula iff $t_1,\ldots,t_n$ are terms, P is a predicate symbol and $t_1,\ldots,t_n$ match the signature of P.
d. $\neg\varphi$, $\varphi \wedge \psi$, $\varphi \rightarrow \psi$ are formulas iff φ and ψ are.

The function of the terms as formulas is similar to the discourse markers of Kamp (1981). The definition below is syntactic, but a semantic definition will be used later on.

(4) Discourse Markers: $DM(x) = \{x\}$
$DM(\varphi) = \emptyset$ if φ is atomic or $\varphi = \neg\psi$ or $\varphi = \psi \rightarrow \chi$
$DM(\varphi \wedge \psi) = DM(\varphi) \cup DM(\psi)$

Information states are sets of information carriers. The update $\sigma[\varphi]$ of an information state σ by a formula φ can be defined as follows.

1. $\sigma[x] = \{i \in \sigma : ix \text{ defined}\}$

2. $\sigma[Pt_1, \ldots, t_n] = \{i \in \sigma : \neg < it_1,\ldots it_n > \notin iP\}$

3. $\sigma[t_1 = t_2] = \{i \in \sigma : \neg\exists u \exists v(it_1 = u, it_2 = v \wedge u \neq v)\}$

4. $\sigma[\varphi \wedge \psi] = \sigma[\varphi][\psi]$

5. $\sigma[\neg\varphi] = \mathbf{neg}(\sigma[\varphi], \sigma)$

6. $\sigma[\varphi \rightarrow \psi] = \sigma[\neg(\varphi \wedge \neg\psi)]$

The negation needs definition (5),

(5) $\mathbf{neg}(\sigma, \tau) = \tau \setminus \sigma^{dm(\sigma,\tau)}$

which needs (6) and (8) in its turn.

(6) $\sigma^X = \{i : \exists j \in \sigma \; i =_X j\}$

(6) makes use of (7) and (8) .

(7) $i =_X j$ iff $\forall a$ ($a \notin X \Rightarrow$ ($ia = ja$ or ia and ja are both undefined.))

(8) $dm(\sigma, \tau) = \{c \in C : \sigma \models c \wedge \tau \not\models c\}$

The first three clauses of the definition of update are set up in such a way that there is a distinction between an atomic formula (with *free* terms) eliminating information carriers and updating the *conjunction* of those free terms with the atomic formula: only in the latter case it is guaranteed that each of the constants will be defined throughout the information state. The atomic formulas only eliminate those carriers that overtly contradict them. This allows a notion of the discourse markers of an information state: the terms that are everywhere defined in that information state and, thereby, of the negation of an information state σ_1 with respect to another information state σ: the subtraction of the closure of the first information state σ_1 with respect to those of its discourse markers that are not markers of σ from σ. This semantic definition allows the development of the semantics as a proper algebra over information states.

The treatment of discourse markers may cause some worries. An update with a term c makes the term into a complete object, but does not add interesting claims about it, other than that it is an object. On arbitrary σ, we can add $square(c)$, then $\neg square(c)$ without causing σ to become the inconsistent information state. Only when we add c as a final update, will inconsistency be reached. Natural language names are of course quite different, as their use presupposes their existence. Here, the update with c is the presupposed existence, the other occurrences do not presuppose existence.

The fact that the update c is so uninteresting makes the update $\neg c$ necessarily inconsistent. $\sigma[\neg c] = \sigma \setminus \sigma[c]^c = \emptyset$. $\neg\neg c$ consequently is the trivial update.

Information states can be in three minds about a discourse marker: they can contain it, i.e. $\sigma \models c$, they can reject it ($\sigma[c] = \emptyset$) and they can accept it as possible ($\emptyset \subset \sigma[c] \subset \sigma$).

Accessibility as in Kamp and Reyle (1993) can be faithfully expressed as $\sigma \models c$. This should not be confused with the property of being an old discourse marker which is much weaker. That notion cannot be defined along these lines, since one can be old by being a non-accessible discourse marker or by being constrained without being a discourse marker.

2.2 Exhaustive Updates

Exhaustive updates are updates with a formula whose discourse markers in the update are exhaustified with respect to the formula. The marker is just another constant. We eliminate the information carriers in which the formula does not hold and those in which the carrier does not give an exhaustive value to the constant. The first elimination is as always, for the second, a new update needs to be defined.

Information carriers are models. Quantification is dealt with by considering other information carriers in the information state which are exactly the same except for the value assigned to certain constants. For exhaustiveness, a relation will be introduced similar to variation with respect to a set of constants, but which allows other things to vary instead.

The relation is necessary for making sure that the interpretation of the relevant constants stays the same, not just formally the same, but also with respect to their place in the ontology. I will call it an ontological alternative (OA) and will use OA_i for the ontological alternatives of i and $OA(i,j)$ to say that i and j are ontological alternatives of one another. The relation will be important later on, when answers are discussed. The relation involves three things. First of all, it must be possible to say of basic continuants that they are the same object. That means —at least for me— that normal criteria of reidentification of continuants must obtain from which it seems to follow that the ontological alternatives must share a past: they should be identical up to a certain moment of time. Second, the relation must preserve basic structural relations, such as set membership, cardinality, "part of" and so on. Third, the individual constants of the language must have the same interpretation. Most of the second criterion follows from the first criterion, but the preservation of "part of" does not. If my bicycle is stolen, so are its parts, e.g. the bell. But I might have fitted a different bell on my bicycle. In a world where that is the case, the bell on my bycle is not stolen, at least not as part of my bicycle being stolen.

The first two demands are expressing that the alternatives share objects and that these objects form the same complex objects in the same way. The third is there to make it possible to talk about the objects in the the update language. Earlier on, I thought it was enough to have the same domains, the same structure and the same interpretation of constants, but that notion runs into problems when one tries to explain how Wh-questions can be answered on an information state. Modal accessibility, following the concept of Kripke (1972) is proposed as an alternative in Butler (2002), but that runs into the problem that it does not work for "part of" and other non-necessary relations. As it stands, two and three can be defined as in (9). The first condition would require a notion of time in the model.

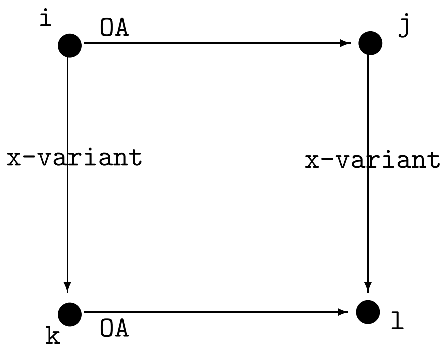
(9) 2. $\forall u\ v \in D_i \cap D_j < u, v > \in iR$ iff $< u, v > \in jR$ for $R \in \{\in,$ part_of, cardinality, etc. $\}$
3. $\forall u \in D_i \cap D_j \forall x \in C(ix = u \Rightarrow jx = ix)$

As before, the information state (i.e. every carrier in it) to satisfy a set of meaning postulates *MP*.

The following is the definition. OA specifies the relevant alternatives for entailment, x-variance gives the range of the other possible values for x.

i is exhaustive for x iff whenever i has an x-variant i_x and an OA variant i_o in $\sigma[\varphi]$ then i_o has an x-variant $i_{ox} \in \sigma[\varphi]$ that is OA to i_x.

The following diagram shows the demand of exhaustiveness on the constant x to fail with respect to i in the information state $\sigma[\varphi]$.



i : $sleepers = \{j, b, m\}$
$x = \{j, b\}$

j : $sleepers = \{j, b\}$
$x = \{j, b\}$ (OA i)

k : $sleepers = \{j, b, m\}$ (x-var. i)
$x = \{j, b, m\}$

l : $sleepers = \{j, b\}$ (x-var. j)
$x = \{j, b, m\}$ (OA k)

So, l does not satisfy $sleep(x)$

Exhaustivity Diagram

To see that this is correct, consider what we mean by exhaustive values. φ according to i should entail all of the φ-meanings in x-variants i_x of i. When would it not do so? If the carrier i has an x-variant i_x, but there is a world w, in which φ is the same as in i, but which lacks the corresponding x-variant.

OA here guarantees two things: it guarantees that the same value is given to x and that x is not just formally the same: it plays the same role in the ontology of the other world. So w must be OA to i. The corresponding x-variant must similarly be OA to i_x. A counterexample to i being exhaustive for x and φ with respect to some σ is therefore an x-variant i_x and an OA i_o, both in σ, which lack an element i_{ox} that is OA to i_x and x-variant to i_o.

To go back to our earlier example of John having sheep x.

We need the meaning postulate (10):

(10) $z \wedge y \wedge Pz \wedge y \subseteq z \rightarrow Py$

i.e. we assume that (11)

(11) $\sigma[z \wedge y \wedge Pz \wedge y \subseteq z \rightarrow Py] = \sigma$

and $\varphi = Px$. x must be new to the information state, i.e. $\sigma \not\models x$.

Suppose i assigns $pow(A)$ to P, and $B \subset A$ to x. Take i_x such that i_x assigns A to x. $i_x \in \sigma[Px]$ since x is new and by the assumption.

Consider i_o such that i_o assigns $pow(B)$ to P. $i_x \in \sigma[Px]$ as x is new.

Then there is no i_{ox} such that $i_{ox} \in \sigma[Px]$, i_{ox} is an x-variant of i_o and i_{ox} is object-identical to i_x.

By OA: i_{ox} assigns A to x.

By x-variance: i_{ox} assigns $pow(B)$ to P.

But then $i_{ox} \notin \sigma[Px]$

So x must be the maximum if i is exhaustive.

The other examples follow by the same reasoning.

An exhaustification operator q can be defined with the above semantics. The operator will take the discourse referents of a formula and deliver an exhaustive interpretation for all of them if tha tis possible. By the semantic definition of discourse markers, the discourse markers of the argument of the operator are the same as those of the result.

(12) $\sigma[q(\varphi)] = \{i \in \sigma[\varphi] : \forall j, k \in \sigma[\varphi]\ (j =_{dm(\sigma[\varphi],\sigma)} i \wedge k \text{ is OA to } i\ \exists l \in \sigma[\varphi]\ (l =_{dm(\sigma[\varphi],\sigma)} k \wedge l \text{ is OA to } j))\}$

Update semantics —or dynamic semantics— is not the only framework that allows an exhaustivity operator. Butler (2002) gives the purely classical definition: $\varphi(x_1, \ldots, x_n) \wedge \forall y_1, \ldots y_n(\varphi(y_1, \ldots y_n) \rightarrow \Box(\varphi(x_1, \ldots, x_n) \rightarrow \varphi(y_1, \ldots, y_n))$. Provided that the semantics of $\Box$ is Kripkean (or really OA), this is gives the same result. Other definitions by Szabolczi or Groenendijk and Stokhof go for the largest values instead of the informationally strongest. Though it is not difficult to repair these definitions, they are aimed at another notion of exhaustivity: changing normal NP meanings into exhaustive NP meanings. In this paper, that will be reduced to exhaustivity as above.

3 Questions

The aim of this section will be to consider the combination of exhaustivity and update semantics as a tool for formulating a theory of questions. My aim is to have something that is comparable to the theory of Groenendijk en Stokhof on questions. I will however only treat direct questions with only a brief consideration of indirect questions.

In the theory of Groenendijk and Stokhof (1984)(GS henceforth), the standard answer to a question is true, exhaustive and rigid. The meaning of the question is the function that assigns to every possible world the appropriate standard answer, i.e. the question is the concept of its standard answer. This is equivalent to a characterisation of the question as a partition: two worlds are equivalent if they give the same standard answer.

The informational perspective and the employment of update semantics precludes taking over the Montague grammar formulation of these concepts. In update semantics, there are only expressions of type t and e, and it is only by information change that meaning can be defined. Within monotonic update semantics, it holds that if questions mean anything at all, this meaning is characterised in terms of the new information they bring to the information state.

The theory of questions I am proposing is simple: it applies the exhaustification operator to the formula representing the question that contains the question's Wh-elements as its discourse markers. A question update is an auxiliary update with the formula so obtained. The answer will determine how to proceed with the auxiliary information state.

An auxiliary update leaves the original information state intact and constructs a second information state. An example is the treatment of negation, in which the information state is updated with the negated formula, to determine the full update in terms of the information state so obtained and the original information state.

For questions, there are three ways in which one can deal with the auxiliary state: it can be negated with respect to the original information state, in case the answer is negative (e.g *no one, no, no animals*), one can replace the original state by the auxiliary state updated by the answer if it is positive and, finally, it can be forgotten, if the interlocutor does not know the answer. The ignorance of the interlocutor will be part of the common ground, which makes it strictly speaking wrong to just obliterate the question update in the last case. But I am not modelling the interlocutors here.

The following two examples illustrate these three cases.

(13) Did John come to the party?
a. Yes.
b. No.
c. I do not know.

(14) Who came to the party?
a. John's friends.
b. Nobody.
c. I do not know.

A positive answer can be reconstructed as a sentence (by some mechanism for ellipsis resolution), or one can assume a mechanism for interpreting sentence fragments. In both cases, only one thing is needed: that the discourse markers for the referents of the expressions in the answer corresponding to the Wh-expressions in the sentence are the same (by unification) or are stated to be identical. A positive answer adds its contents to the auxiliary information state, which then replaces the original information state. In the following table (15), we give the sequence of events for a question that is asked and then positively answered, negatively answered or declined.

(15) **Positive answers**
1. σ
2. $\sigma.\sigma$
3. $\sigma[question].\sigma$
4. $\sigma[question][answer].\sigma$
5. $\sigma[question][answer]$

In step (1), the conversation partners have a common ground σ. The fact that a question is asked puts (2) a copy of the common ground to the foreground, keeping the original information state in the background (the dot indicates the stack forming operation). The foreground is now updated (3) with the question and with the positive answer (4). Acceptation of the positive answer makes the foreground into the new common ground (5).

(16) **Negative answers.**
1. σ
2. $\sigma.\sigma$
3. $\sigma[question].\sigma$
4. $neg\ \sigma[question].\sigma$

In (16) , steps (1) to (3) are the same. In (4), the new common ground becomes the negation of the foreground, with respect to the background. Denied answers (Not me!) apply step 4 of the negative answer to the result of step 4 for the positive answer.

(17) **Declining to answer.**
1. σ
2 $\sigma.\sigma$
3. $\sigma[question].\sigma$
4. σ

In (17) , finally step (4) reverts to the information state of (1).

The model allows for intervening questions and answers, by building longer sequences of auxiliary information states.

3.1 Adapting Questions

The choice between giving a positive answer and declining to answer is not always a sharp one: one can know the answer only partially. One strategy is to tacitly change the question. In case the question was *Who is asleep?* and it is only known that John sleeps but nothing is known about the others, it is possible to answer the weaker question *Is John asleep?*. In this case, it is necessary to indicate that a different question is answered. Twiddly intonation on *John* is one of these devices, but also more elaborate locutions may be chosen (e.g. *John is asleep, but I do not know about the others*). One answers a subquestion and declines to answer the rest.

Overanswering is the phenomenon that the answer gives more information than the question was -strictly speaking- asking for. This again is a question of tacitly changing the question, sometimes combined with an answer to the original question.

(18) Did any stock rise yesterday?
Yes, Alcatel and Telefonos Mexicanos.

In (18) the answer to the *yes-no*-question is followed by an answer to the Wh-question *Which stock rose yesterday?*, a question that was not explicitly asked, but one which the interpreter obviously thought would be the next one the speaker would ask. Within this treatment that question must be reconstructed in order to obtain the exhaustivity effect.

Questions come with an obvious order. The weakest ones are the yes-no-questions. Stronger questions can be obtained by replacing standard NPs by Wh-elements and by replacing more restricted Wh-phrases by less restricted ones. Underanswering can be seen as answering a question derived from the original one by filling in a more concrete Wh-element for one of the Wh-elements in the question or by replacing it by an non-Wh-element altogether. Overanswering can analogously be understood as adding Wh-elements to the question or as making the Wh-elements less specific. The ordering strongly resembles the unification semilattice of the elements subsuming a given ground term. The semi-lattice can be grounded in semantics as well: knowing the answer to a stronger question always entails knowing the answer to the weaker question, under the assumption that the knowledge subject knows that the stronger question is stronger than the weaker one.

Of course, a speaker does not change the question without good cause. Going to a weaker question is allowed if the speaker cannot reply to the stronger question or if the speaker realises that her partner is really looking for an answer to the weaker question. Answering a stronger question results from the realisation of the speaker that she can do so and that the stronger question is the one her conversation partner is really after. Recognising the speaker's intention is as important in understanding a question as it is in understanding an assertion.

An application of question shifting are non-exhaustive answers: they can be understood as answers to a weaker question. The topic of a non-exhaustive answer is a weakening of the explicit question. The exchange (19):

(19) Where can I get some coffee?
One floor down, second door left.

does not entail that coffee cannot be had elsewhere (though sometimes it does). We can explain this by assuming an implicit condition *around here* inside the *where* or a more specific meaning of the word *where*: *which is the closest place where* to obtain a weaker Wh-question or a shift to the yes-no-question: Can I get some coffee one floor down,second door left? The intention of the questioner is to get some coffee, an intention recognised from her question. The extra information in a full answer would not contribute to achieving the intention.

3.2 Wh-elements

A logical representation of questions needs to have a question operator and a way for marking Wh-elements.

Wh-phrases can be represented as indefinites: a new discourse marker and possibly a new condition. That they are Wh-markers is then indicated by the fact that they are bound by the q-operator. The meaning of the q-operator is to give an exhaustive interpretation to the discourse markers that it binds. Within a DRT-context, the main syntactic problem is then to protect possible indefinites occurring in the syntactic scope of the Wh-phrase from being bound as well. A simple proposal is to add an operator that closes off the syntactic scope of the Wh-phrase, to the semantics of the Wh-phrase. Operators with this property are readily available: the double negation or $\mathbf{true} \rightarrow \varphi$. The q-operator itself is unsuitable.

A disadvantage of this procedure is that it makes those indefinites unavailable for future anaphora. This is incorrect because such anaphora does occur when the question is answered in a positive way. This is a strong argument for following GS in assuming full propositional answers using ellipsis resolution for constituent answers and unifying the discourse markers deriving from the Wh-phrases the relevant discourse markers in the answer. The semantic representation of the answer could then be standard, i.e. omitting both the q-operators and the double negation(s).

(20) Who ate the cake?
$q(x \wedge \neg\neg eat(x, y))$
John.
$john(x) \wedge eat(x, y)$
A boy.
$boy(x) \wedge \#x = 1 \wedge eat(x, y)$
The boys.
$x = BOY \wedge eat(x, y)$
Some boys.
$boy(x) \wedge \#x \geq 2 \wedge eat(x, y)$

The question establishes x as a discourse referent pointing to the set of eaters of the contextually given cake y. In the answers, x is further constrained: it has the name John, it is a boy, the (contextually given) boys, or some of those. In combination with the question semantics, it follows that nobody but John ate the cake, nobody else except one boy ate the cake, that the cake eaters and the contextualy given boys coincide or the cake eaters coincide with a plural subset of those boys. This means that there is no need for the "exhaustivity of answers": it follows from the exhaustivity of the questions. In this respect, the treatment here gives an improvement of GS[3] .

The syntactic mechanism required is akin to resolving VP ellipsis as described by e.g. Prüst *et al.* (1994), Gardent (1991) or Dalrymple *et al.* (2002): if the answer is a sentence fragment its semantics must be completed by material from the question semantics, and —also if the answer is a full sentence— the referents of the answering NPs must be unified or identified with the referents of the Wh-constituents. It is quite possible to envisage other mechanisms to achieve the same effect: feature percolation in a discourse grammar transporting Wh-constants and question abstracts and putting exhaustification in the semantics of answers rather than relying on the dynamics. I want to claim that my approach based on matching and dynamics is simple and economical, not that it is the only possible one.

The question can remain as proposed here, with the indefinites unavailable, but as they are repeated in the answer, they become available after a positive answer. Demanding full propositional answers is a solution. The assumption of multiple topics in the next section gives another argument for propositional answers: if there are multiple topics for a single sentence, constituent answers cannot be the basic case.

This gives us the representation (21) for a Wh-phrase.

(21) $q(x_1 \wedge \ldots x_n \wedge \neg\neg(A))$

[3] exh(Q) = $\{A \in Q : \neg\exists B(Q(B) \wedge B \neq A \wedge \Box(Q(B) \rightarrow Q(A))\}$ is an improved version of the GS operation making the NP Q exhaustive. It is provable that: $\sigma \models exh(Q)(A) \Leftrightarrow \sigma \models q(A) \wedge Q(x)$, at least for simple choices of Q. Here A is the question abstract, $q(A)$ the exhaustivity statement derived from the question abstract and $Q(x)$ the statement that for the variable x constrained by Q, $Q(\lambda yy = x)$ is true. It must be admitted though that the exhaustivity of questions —unlike in GS— does not play any other role.

Here A combines a restriction possibly incorporated in the Wh-phrase and the scope of the Wh-phrase. I will in the sequel, often write $q(dm, \varphi)$ where dm is the set of discourse markers and φ is A.

Yes-no-questions can be incorporated into this scheme as $(\emptyset, \neg\neg\varphi)$. We can let quantifiers[4] have wider scopes than Wh-phrases. In this way, we can obtain the two readings of (22a) . Some examples:

(22) a. Which woman does every man like most?
$x \wedge x = MAN \wedge dist(x, q(y \wedge woman(y) \wedge like\_most(x, y)))$
$q(y \wedge woman(y) \wedge \neg\neg(x \wedge x = MAN \wedge dist(x, like\_most(x, y))))$
b. Who meets a professor?
$q(x \wedge \neg\neg(y \wedge professor(y) \wedge meet(x, y)))$
c. Who meets which professor? (embedding)
$q(x \wedge dist(x, q(y \wedge professor(y) \wedge \neg\neg meet(x, y))))$
d. Who meets which professor?(lumping)
$q(x \wedge y \wedge professor(y) \wedge \neg\neg meet(x, y))$

The scheme for dealing with questions and answers supports these embedded cases: (22a) opens an auxiliary update within an auxiliary update. The hearer's contribution "his mother" applies to that second auxiliary state.

(23) A. σ
B. $\sigma[x \wedge man(x)]$
C. $\sigma[x \wedge man(x)][q(y \wedge \neg\neg woman(y) \wedge love\_most(x, y))]$
D. $\sigma[man(x)]$
$[q(y \wedge \neg\neg woman(y) \wedge love\_most(x, y))]$
$[mother(y, x) \wedge love\_most(x, y)]$
E. $A \setminus (B \setminus D^{dm(D,B)})^{dm(B,A)}$

Here A is the starting state and E the result. B sets up an auxiliary state with an arbitrary man, C sets up an auxiliary state based on B for the question, D is C updated with the positive answer "his mother". E uses A, B and D to determine the update of the whole exchange.

It is much the same in (22c) but it is a technical challenge to regulate things in such a way that the two answers: " Maria professor Groenendijk. Anna professor Stokhof." manage to update the two auxiliary information states in the correct way: $x = \{Maria, Anna\}, y$ is G if x (under dist) refers to Maria and S if x points to Anna.

Multiple answers are a problem anyway and it is not solved by just lumping the contributions of the individual into sets since one loses dependencies this way. I have defended a proposal in which multiple answers each answer a subquestion where the subquestions together form an exhaustive splitting up of the proper question. That approach would work for this case.

We predict that (24) has two readings.

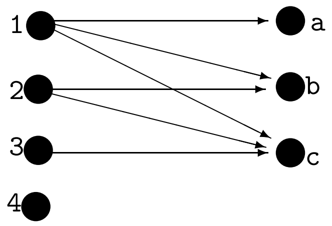
[4] That (non-plural) indefinites always have a narrower scope than Wh-phrases needs an explanation. Perhaps this must be found in the nature of such indefinites (indefinites like to be bound) or in the unsuitability of asking about things the speaker knows but the hearer does not know yet.

(24) Who loves who?

In the first case, we obtain a representation (25).

(25) $q(x \wedge q(y \wedge love(x, y))$

Let us consider the double operation on a small domain. The internal q-operator gives us the interpretation under step 1. Possible interpretations like $\{1\} : \{a, b\}$ or $\{2\} : \{b\}$ are eliminated.



step 1	step 2
$\{1\} : \{a, b, c\}$	$\{1\} : \{a, b, c\}$
$\{2\} : \{b, c\}$	
$\{3\} : \{c\}$	
$\{1, 2\} : \{b, c\}$	$\{1, 2\} : \{b, c\}$
$\{1, 3\} : \{c\}$	
$\{2, 3\} : \{c\}$	
$\{1, 2, 3\} : \{c\}$	$\{1, 2, 3\} : \{c\}$

Fig. 2 Love in carrier i

The doubly exhaustive reading makes for a compact representation of the positive part of the relation as a relation between sets.

The other reading of the question is (26):

(26) $q(x \wedge y \wedge love(x, y))$

The ∀∃∀∃-MP (see section 4) gives the assignment : $x = \{1, 2, 3\}$ and $y = \{a, b, c\}$. If *love* is interpreted under this MP, that will be the only exhaustive assignment.

3.3 Answering

There are two obstacles to adopting the GS theory of answering a question directly in the framework of this paper, apart from the obvious one of lacking the appropriate types. GS is couched in terms of the model theory of Montague, a type-logical generalisation of the modal semantics of Kripke. This semantics was set up with the specific aim of incorporating of Kripke's theory of names as rigid designators, cerain Aristotelian views about nouns and identity, Kaplan's theory of direct reference and accounts of quantifying in that rely on variables with a rigid interpretation.

Moving to an epistemic framework leads to two problems. One is the following: humans cannot distinguish objects beyond qualitative differences and spatiotemporal position. This means that knowledge of identities between the spatio-temporal objects in the different possibilities of our information states is not possible in the absence of ways to see the object as continuous between the two possibilities. The second problem is that the most natural way of looking at the relation between possibilities and linguistic expressions is not the two-level distinction of Kaplan's character (context determines content, content determines truth value) but the corresponding diagonal: a possibility is both context and circumstance of evaluation. This has to do with the reason why a possibility is in an information state: the information represented by the information does not suffice to rule it out that the possibility is the actual world. But for that criterion to apply, the possibility must —like the actual world— both determine the content and decide whether that content is true. If it does not, the subject knows that it is not a candidate for being the actual world.

The consequence is that the concept of direct reference or the concept of rigid designation seems to lose any interesting content. They are at best notions that pay a role in the evaluation of modal statements. If a possibility has access to a set of ontologically possible worlds, an expression can have a rigid interpretation with respect to that set of possible worlds or be directly referential by the possibility fixing its reference.

A purely formal definition of OA is only an approximation of that notion. It fixes the objects, the constants referring to those objects and the structural relations between the objects. A formal ontological alternative does not really need to be ontologically possible, since it may not be a way the world could have been. Essential properties and relations need not be preserved (e.g. fatherhood, sortal properties). It is also too strict in that it does not allow for objects disappearing and coming into being.

But the major problem is that a formal notion is completely unable to explain how objects can be fixed by purely qualitative information. Let u be "the F" in i. If there is a least one other object v and u and v are structurally similar (assume they are both singleton sets) there should be an j with the same objects, constants and structural relations in which u and v have swapped their qualititive role (u takes all properties of v, v all properties of u). Which means that i and j are not distinguishable for any belief subject and that *the* F does not identify any object. But F was arbitrary and it follows that unless there are situations in which the swap is impossible, there is no way of tying a constant to an object (even relative to a possibility).

It seems therefore that the formal notion is not a good basis for studying answerhood. And it is the reason for adopting OA, in which the possibility accessible for i must be another development of some common past. This gives a criterion of identity for continuants and makes sense of the idea that continuant objects in different worlds are the same.

Diagonality also has a bearing on the ontological alternatives. Other ways the world could have been include ways where devices that fixed the reference of names, uses of demonstratives and of deictical devices would have picked out different referents from the ones that they actually picked out. To the extent that those names and uses of demonstratives and deicticals are present in the information state, they will be discourse referents and by our stipulations on OA, the same constant will refer to the same object in all OA worlds. The consequence of diagonality is that there is a restriction on those worlds: not just the constant is the same for the same object, but also the way in which the reference was fixed.

Otherwise, OA would give alternatives that are disharmonic in the sense that Tom could have another name in the alternative, that that book could be something that was not pointed at when the demonstrative NP was used and I could not have been speaking. Such phenomena are suitable to rule out the alternative as a candidate for being the actual world.

OA allows a reconstruction of the GS account of answering. OA is a partition over the information state. The cells of the partition are like the Kripke/Montague model and can be partitioned by a question $q(dm, \varphi)$ as follows for an equivalence class OA_k of σ (there can also be a cell where $\neg(dm \wedge \varphi)$ holds).

$\{\{j \in OA_k : j =_{dm} i\} : i \in \sigma[q(dm, \varphi] \wedge i \in OA_k\}$

And σ answers $q(dm, \varphi)$ iff every OA_k of σ is partitioned by $q(dm, \varphi)$ into a singleton partition. This can be stated more simply as:

$\forall i \in \sigma\ \forall j \in \sigma\ \forall k \in \sigma[q(dm, \varphi)]\ \forall l \in \sigma[q(dm, \varphi)]\ (OA(i, j) \wedge i =_{dm} k \wedge j =_{dm} l \Rightarrow \forall c \in dmkc = lc)$.

Is this ever satisfied? And if it is, does it correspond to the natural notion of knowing the answer to a question?

I offer the following metaphysical consideration for the first question. The information states represent the common ground between a set of participants. As such they contain the common ground experience of the participants, and in particular all the utterances of the conversation. The essential properties of these are preserved under OA. Under the natural assumption that time, place, speaker and hearer of an utterance are essential properties of an utterance, this will ensure that all the objects of the context of an utterance in the common ground experience are fixed within an OA-cell. Much the same holds for the objects of "joint attention" (Tomasello (1999), Clark (1996)). An episode of "joint attention" is an experienced event in the common ground and its object is an essential property of the event. It therefore should be fixed within an OA-cell as well. When the object of joint attention is only indirectly given in the common ground experience (let's say we talk about your niece who I do not know except through the conversation), it will be part of accepting the conversational contributions that the object exists and that the contributor initiating the episode of joint attention knows who she is talking about. Within an OA cell, the referent therefore seems as much a first class citizen as any other object.

This convinces me that any old discourse referent is fixed in the common ground by having been an object of joint attention in the common ground. Indeed references to old discourse referents are natural answers, even if the discourse referent has not been directly experienced by one participant. One may be more cautious however and only accept, e.g. the objects that are in the utterance situation, or the objects of joint attention that have been directly experienced. That does not matter since the weaker positions are also vulnerable to the circularity problem.

If I am right, question updates can themselves fix their referents. This means that the second time the same question is asked (with new constants), it is always answered. (The question update changes the information state so that OA becomes sensitive to the new discourse referents.) Notice that the same problem occurs when the original GS is accepted. There any rigid expression (John Smith, that book, you) fixes its referent. So any question like the ones in (27) is already answered.

(27) Who is John Smith?
Who is that?
Who are you?

And this is certainly to some extent as it should be. There is a sense in which the answer to these questions are known but it is the same sense in which the question is answered by the description that can be formed from it(Who sleeps? The sleepers.). (28)is however a natural conversation. A speaker asks a question and so expresses her ignorance. The other speaker answers it and the first speaker can conclude as indicated. It does not seem to matter that the visual experience of the first speaker already fixes the referent or that there are thousands of Kates or that there may be more than one friend of the second speaker whose name is Kate.

(28) Who is that?
I do not know who that is.
That is Kate, a friend of mine.
Oh, now I know who that is.

This can be resolved by providing for circular answers. Any question gives a concept of its Wh-markers, which will fix it. That concept or any concept which depends on it is never sufficient for knowing $q(dm, \varphi)$. If an information state only has that concept (or a concept depending on it) it does not answer the question.

The following is an attempt[5].

σ answers $q(x_1, \ldots, x_n, \varphi)$ iff $\sigma \models y_1 \wedge \ldots \wedge y_k$ and fixes them independently of φ
and $\sigma[q(x_1, \ldots, x_n, \varphi)] \models x_1 = y_1 \wedge \ldots \wedge x_k = y_k$

The notion of "fixed independently of φ" can be approximated by the following counterfactual.

If φ were false, $y_1, \ldots, y_n$ would still be fixed in σ.

A theory of arbitrary objects like Fine (1985) presumably offers ways of handling such dependencies in a more principled way. A simpler route is possible by following Dekker (2002) and Zeevat (1999) who argued that discourse referents are always associated with descriptions. This goes as follows: identify discourse markers with their associated descriptions and identify descriptions under logical equivalence. Now it is possible to define $i =_x j$ iff j gives an arbitrary interpretation to (the abstract description) x. y depends on x in i iff $\exists j(i =_x j \wedge jy \neq iy)$. It is now possible to define: y depends on x in σ by quantifying over $i \in \sigma$.

More in the spirit of the current approach is to use the counterfactual formulation. For this, it must be assumed that $q(dm, \varphi)$ is new to σ in the double sense that the discourse markers are new and that $\sigma[\neg q(dm, \varphi)] \neq \emptyset$. But that would rule out that σ has a positive answer to $q(dm, \varphi)$. What is possible is defining that A answers $q(x_1, \ldots, x_n, \varphi)$ with respect to σ.

A answers $q(x_1, \ldots, x_n, \varphi)$ on σ iff
$\sigma[\neg q(dm, \varphi)] \neq \emptyset$ and

[5] $y_1, \ldots, y_k$ are not necessarily already in σ: it suffices if they are definable, i.e. if the update with $y_1 \wedge \ldots \wedge y_k$ does not eliminate any complete class $i^{y_1, \ldots, y_k}$ from σ.

σ fixes $y_1, \ldots, y_k$ and
$\sigma[q(x_1, \ldots, x_n, \varphi)][A] \models x_1 = y_1 \wedge \ldots \wedge x_k = y_k$

σ can then be said to answer $q(dm, \varphi)$ iff it can be decomposed into a τ and A such that $\tau[q(dm, \varphi)][A] = \sigma$ and A answers $q(dm, \varphi)$ on τ.

It is probably correct to say that a ban on circularity still does not give an absolute criterion for knowing a Wh-question. There are ways of idenfication that have priority over others. The goals of the speaker that asks the question also may rule out certain answers as uncooperative. But a non-circular notion is progress and is needed to keep our field respectable. It cannot be that semantics has discovered that there is no criterion for knowing the answer to a Wh-question. The conflict with common sense is just too blatant.

I have little to say about embedded questions, which formed the discovery ground of the GS theory.

The analysis of an information state answering a question does the job. Presumably somebody who knows a question $q(dm, \varphi)$ has an information state K_i at every carrier i of σ that can be split into τ and A such that $K_i = \tau[q(dm, \varphi)][A]$ and A answers $q(dm, \varphi)$ on τ.

It follows that:

$\forall i \in \sigma \; K_i$ answers $q(dm, \varphi)$ on every τ such that $\sigma = \tau[q(dm, \varphi)]$

In the earlier version of this paper Zeevat (1994), I saw some future in the idea that $q(dm, \varphi)$ assigns the unique exhaustive value to dm in $i \in \sigma$ and that it would be possible to constrain the members of K_i to assign the same value, presumably by demanding that they agree with i with respect to all constants x such that ix is defined and by having the same ontology. This would come down to saying that $K_i \subseteq OA_i$.

But this is not defensible for a knowledge operator, since it would imply that it is within our power to know the haecceities of objects. Also in knowledge, the subject can know concepts which happen to pick out the objects in i but will pick out different objects in other epistemic alternatives.

A relaxed version of asking for the same object in different alternatives is to demand that the concept pick out the same object in every two epistemic alternatives that are modal alternatives of each other. This also implies that ix is denotation of x in all modal and epistemic alternatives of i. But an update that just eliminates the epistemic alternatives in which dm is not exhaustive with respect to φ does not guarantee that all. If the question is *who sleeps*, then —unless the subject knows who sleeps— *who* will denote whoever sleeps in an epistemic alternative j. This can be repaired.

Let $OA(i, j, X)$ iff $\exists k \; (OA(i, k) \wedge i =_X j)$ and $i \models K(X)$ iff $\forall j \in K_i \; \forall k \in K_i \; (OA(k, j, X) \Rightarrow \forall x \in X \; ix = jx)$. It is now possible to redefine knowledge update as:

$\sigma[K\varphi] = \{i \in \sigma : i \models K(X) \wedge K_i \models \varphi\}$

This forces discourse referents of φ to be fixed in K_i and is sometimes too strong.

(29) John knows that somebody stole his watch.

(29) has a reading as indicated, but also a reading where John does not know who stole it. This reading can be obtained by closing of the φ by means of a double negation. An interpretion of a that-clause must mark which of the discourse markers are outside the scope of the double negation. In this view, *de dicto* is the special case and indirect questions and *de re* propositions are treated uniformly.

"Wondering who" can be approximated as the desire to "know who" that presupposes that "know who" is false.

While this may be correct or not, "knowing who" is just as vulnerable to circularity as σ answering $q(dm, \varphi)$, and circularity is not solved in this way.

So my final analysis of x knows $q(dm, \varphi)$ must be that there is a p such that x knows p and p answers $q(dm, \varphi)$ on σ. x wonders $q(dm, \varphi)$ would be something like "$\forall p(p$ is true and answers $q(dm, \varphi)$ on $\sigma \Rightarrow x$ wants to know p". x decides $q(dm, \varphi)$ iff "it will be that case that x will bring about some p and p answers $q(dm, \varphi)$ on σ". These do not have the elegant uniformity that can be achieved in GS between questions and non-questions. But that does not seem in reach here.

4 Topic and Focus

The idea that topic and focus are related to exhaustivity goes back to Szabolcsi (1981). In her theory, a focused constituent is reinterpreted by applying an exhaustivity operator to it. Here I achieve the same by letting it supply the answer to the question resulting from omitting it in the sentence and replacing it by a suitable Wh-element. This same theory is also defended -but without the exhaustification- in van Kuppevelt (1991), who extends the theory with a connection to the theory of discourse: any sentence should be viewed as an answer to an explicit or implicit question.

How do we find out about the question? A popular view suggested by work on operators like *only* and *even* (Rooth (1992)) and on subjunctives (Kasper (1992) is that it derives from a binary division coded into the form of the utterance by a variety of devices in different languages: syntactic position, case-marking, intonation etc. Others (e.g. Vallduvi (1992)) assume a tripartite structure, by distinguishing within the topic, a contrastive topic and a link.

I want to suggest that it is not necessary to assume a formal division and that indeed a formal division is hard to maintain. Kasper (1992) convincingly shows that in many cases, we must divide the semantical content of a word into a presupposition and an asserted part in order to obtain a sensible construction of the meaning of the subjunctive sentences. He equally convincingly argues that this division cannot be made once and for all in the lexicon: different contexts lead to different divisions. It follows that these divisions cannot be formally marked by any device unless we assume syntax beneath the word level, intonational patterns that select part of a word meaning, lexical marking of focus, or similar unconvincing stratagems. What we are left with for the interpretation of the formal devices are just constraints: in particular constraints that tell us what cannot be topic, e.g. the NP marked by *wa* in Japanese must be in the topic of the sentence, post-Wackernagel material cannot appear (with the exception of verbal material) entirely in a topic, focus-intonation similarly indicates that some of its material must stay out of the topic. Binary (or ternary) divisions are easy to mark in natural languages (compare quantification, subordination). So the variety of means of expression indicates that we are not dealing with a binary division. The fact that ternary divisions have been proposed also points in this direction[6].

The current context suggests a simple solution. The update formula for the sentence as a whole is computed. This formula allows a set of abstractions, corresponding to the questions that the sentence could possibly answer. Certain of these questions are ruled out by topic or focus marking. Other questions are already answered by the information state. The remaining questions together form the topic or topics of the sentence. So the informational contribution of the sentence is obtained by asserting the sentence (its representation with slots unified with Wh-elements in the topics) in an information state to which we have added the topic questions.

This predicts a series of exhaustification effects, which indeed we find in many cases. Sometimes however it appears as if there is a unique question. These are the cases like (30)where strong intonational marking suggests a single question "who does John like".

(30) John likes MARY

Even then, the reconstruction into a question and an answer to the question can be performed in a number of ways, depending on the Wh-element chosen. (31) lists some possibilities.

(31) a. Who does John like? Mary.
b. Which girl does John like? Mary.
c. Which of Jane and Mary does John like? Mary.

It is the information state that determines which one is chosen. If it is known that John likes a girl, or that he likes one of Jane and Mary, the last two questions are the topics that apply. If nothing is known about the answer to (31a) , that will be (part of) the topic.

The variation in possible topics increases if larger foci are considered, as in (32) which may answer a question about John's emotional attitudes towards girls, John's liking of people in general, etc.

(32) John [LIKES MARY]

The assignment of a focus to a sentence is not unique, and even when it is unique, it does not give rise to a unique question.

Suppose we know has John has a farm and we are wondering about his life-stock. The assertion (33)

[6]Scepticism abounds in phonetic circles about the claims that are made for intonational marking. But also with respect to syntactic and morphological marking more scepticism is needed, if one looks at recent work on Japanese and Korean. And it is as clear as it should in German and Dutch? Rather than giving up these claims, it seems that a far better case can be made now against a simple formal distinction than in 1993. Lack of time and space prevents me from doing so.

(33) John has 5 sheep.

is then naturally interpreted as answering a series of questions (34) where the (b) and (c) answers are responsible for the implicatures that John has no goats or cows and that he does not have 6 or 12 sheep. There is no other theory of topic and focus that has an explanation of these effects. They are a serious problem for the theory of Rooth and other theories that have a binary or ternary division.

(34) a. Does John have life-stock?
b. What life-stock does he have?
c. How many X does he have?

A serious problem for this approach is that it needs to explain *only*. In the standard analysis, *only* applies to a focus. But in our approach, the focus already has an exhaustive interpretation. Adding *only* to a sentence with a given focus would be semantically superfluous. This is illustrated in (35).

(35) Who does Mary love? She loves only John.
Mary likes only BEANS.

In both examples, *only* seems superfluous. In (35a) because of the exhaustivity of answers, in (35b) because of the exhaustivity of foci. If we do not assume that we are completely on the wrong track, an explanation must be available for these occurrences of *only*. There are two possibilities. One is that *only* here functions as a mirative pragmatic marker indicating that the answer goes against the expectations of the interlocutor: he or she would expect that Mary loves more people or likes more vegetables. This would place *only* on a par with *even* which reverses such expectations. Another explanation could come from the underspecification involved in determining the precise topic: *only* could enlarge the extension of the restriction on the Wh-phrase in the topic (maybe from the contextually given set of alternatives that would otherwise be picked up to the full range of the possibilities) and thereby strengthen the exhaustivity. In both cases, *only* would have a role that is much less semantical than has generally been assumed[7].

5 Plurals

That the framework of generalised quantifiers is fruitful for analysing plural determiners has been proven by a constant stream of publications. For a recent overview see Westerstahl (1995). My aim in this subsection is to provide an alternative not for those insights but for the view that full generalised quantifiers in natural language semantics is the only way to go. NL quantifiers are simpler. What I propose is close to early DRT. Without exhaustivity, it is not correct.

[7]This would be true, if there was not "only if", especially if one agrees with the logical tradition that "John will come, only if Mary comes" does not entail that "John will come, if Mary comes". No matter how much focus intonation one puts on an if-clause, it will not get rid of that entailment, inserting *only* is the only way. I have no solution.

In the simple theory, plural NPs are a special kind of definites and indefinites, introducing discourse markers for sets, generally of cardinality ≥ 2. The NP puts various constraints on these sets: the noun and its modifiers providing a superset, the determiner information about the cardinality and definiteness. More surprisingly, some determiners also rule on the mode of application of the set to the predicates of which the NP is an argument.

The most important constraint is that the set always belongs to the extension of the noun. The noun sometimes has an anaphoric role referring back to an earlier plural referent included in the noun extension. In these cases, the denotation of the NP-referent must belong to this subset of the extension. In other cases, it is the noun extension itself that supplies the superset.

The denotation also meets some conditions deriving from the determiner. These conditions constrain the set or the relation between the set and the noun denotation. Some determiners rely on contextual information for specifying the constraint: the vague determiners (many, few, etc.)[8].

A last type of constraint that the determiner can impose concerns the binding of the argument place occupied by the NP. Certain determiners lexically prefer a distributive interpretation (*many, every*). This is not the only source of distributivity, some argument positions of verbs disallow collective interpretations and so force distributive interpretations.

Finally, certain determiners are negations of indefinite determiners. The negation stops them from being indefinites. Examples are *no* and *few.* And I have nothing to say about generics, bare NPs or the *pars pro toto* readings of definite plurals, as in *The Greeks invented Euclidean geometry.*

Certain predicates and relations obey special constraints. Some one-place predicates (e.g. nouns) are strictly distributive, i.e. they obey (36). Here and below I will use $x \in y$ as an abbreviation for $x \subseteq y \wedge \#x = 1$.

(36) $\forall x \in y\ Px \leftrightarrow Py$

Others also allow collective readings.

The situation with many-place predicates is more complicated. In this paper, I will only consider the ∀∃∀∃-postulate (37), here formulated for a 2-place predicate (it can be generalised to more places)

(37) $\forall v \in x\ \exists w \in y\ Rvw \wedge \forall v \in y\ \exists w \in x\ Rwv \rightarrow Rxy$

Other postulates are obtained by applying distributivity for one-place predicates in turn to more argument places. Sometimes this is a lexical property, other times collective readings are also allowed.

An example of such a derived postulate for 2-place relations is (38). This relation allows distributivity over both coordinates.

[8] Like *only* and *even* it is possible to see these determiners as markers of surprise in a particular direction: the number is surprising because less was expected, the number is surprising because more was expected, etc.

(38) $\forall v \in x\ \forall w \in y\ Rvw \leftrightarrow Rxy$

5.1 Some constraints

Let x be the discourse referent of the NP, $NOUN$ be the extension of the noun (or the contextually determined restriction of that extension). The determiners *all, every, each* and *the* provide the constraint (39),

(39) $x = NOUN$

when they are absent, the constraint (40) applies.

(40) $x \subset NOUN$

Using proper subset here is essential as will become clear later. The simplest explanation for having subset is that definiteness corresponds to identity with the noun denotation and indefiniteness with being a proper subset of the noun denotation[9].

A number of determiners provide cardinality constraints. Some of these are stated in the following table. The variable n is a number value provided by the context.

$\#x = 3$	three
$\#x > \#(NOUN \setminus x)$	most
$\#x \geq 2$	some
$\#x \geq 2$	a few
$\#x < 3$	less than three
$\#x > 5$	more than 5
$\#x \geq n$	many

This deals with most meanings of determiners. The negative ones can just be defined in terms of the positive ones:

(42) no:= not a
no:= not some
few:= not many

[9]The proper cardinals are compatible with definiteness and indefiniteness ("three books" vs "the three books"), the others are either definite or indefinite. While indefiniteness leads to a new discourse marker (otherwise the noun would already denote the subset), discourse markers for definites can be old and new. An important argument for this view is that one cannot use "a N" in situations where "N" is known to have a singleton denotation, even if the object is new to the discourse.

(41) *A first child born in the 22nd century

So uniqueness is marked by definite markers and the (mostly non-universal) counterexamples to the inverse principle that definite marking means uniqueness must be explained by assuming other triggers for definite markers.

Every, many, most and *each* bind the predicate in a special way: they demand that each of the members of the discourse referent meets the condition of the predicate. In (43) I provide an update definition for distributivity. There is also a definition for fullness (intended for the semantics of *all*). These definitions are the same but for the fact that fullness continues to work for collective readings and mass interpretations of the constants.

(43) distributivity: $\sigma[dist(x, \varphi)] = \{i \in \sigma : \forall j\ j =_x i \wedge jx \in ix \rightarrow j \in \sigma[\varphi]\}$
fullness: $\sigma[full(x, \varphi)] = \{i \in \sigma : \forall j\ j =_x i \wedge jx \subseteq ix \rightarrow j \in \sigma[\varphi]\}$

In (43) distributivity is defined by quantifying over x-variants j of i that assign members of ix to x, for fullness, quantification is over all parts of ix.

Below a combination of the constraints is provided, combining with the verb *to run*.

A boy runs.	$x \wedge x \subset BOY \wedge \#x = 1 \wedge run(x)$
Some boys run.	$x \wedge x \subset BOY \wedge \#x \geq 2 \wedge run(x)$
The boy runs.	$x \wedge BOY = x \wedge \#x = 1 \wedge run(x)$
The boys run.	$x \wedge BOY = x \wedge \#x \geq 2 \wedge run(x)$
All boys run.	$x \wedge BOY = x \wedge \#x \geq 2 \wedge full(x, run(x))$
Every boy runs.	$x \wedge BOY = x \wedge dist(x, run(x))$
Three boys run.	$x \wedge BOY = x \wedge \#x = 3 \wedge run(x)$
Few boys run.	$\neg(x \wedge x \subset BOY \wedge \#x > n \wedge dist(x, run(x)))$
Many boys run.	$x \wedge x \subset BOY \wedge \#x > n \wedge dist(x, run(x))$
Most boys run.	$x \wedge x \subset BOY \wedge \#x > \#(BOY \setminus x) \wedge dist(x, run(x))$

This gives the simple naive approach. It is inadequate as it stands because it is not able to deal with lexically exhaustive quantifiers like "precisely 2" or readings of quantifiers like 2 in which they carry an exhaustive interpretation.

Suppose there are five sleeping boys. Then both (44)

(44) Less then four boys sleep
$x \wedge boy(x) \wedge \#x < 4 \wedge sleep(x)$

and (45) are true under a standard DRT-interpretation: just take a smaller subset of the sleeping boys.

(45) Precisely 2 boys sleep
$x \wedge boy(x) \wedge \#x = 2 \wedge sleep(x)$

Another example that comes out wrong is the cumulative reading of (46).

(46) 4 boys danced with 5 girls

(46) is true (due to our ∀∃∀∃-meaning postulate) when the cumulative interpretation is true (the total number of boys who danced with girls is 4 and the total number of girls they danced with is 5). Unfortunately it also is true if five boys danced with six girls (in the cumulative reading), i.e. when it is intuitively false.

5.2 Adding Exhaustivity

Hans Kamp (p.c.) found an analysis of the problem of cumulative quantification that avoids Scha's unappealing solution of multiple NP insertion. What I present here is still very close to Kamp's idea, which can be recapitulated in the following three steps, applying to the example (47).

(47) 200 Dutch firms own 600 American computers.

from Scha (1981).

(48) 1. interpret the relation by the ∀∃∀∃ meaning postulate)
2. apply the "naive" approach to obtain a DRS
3. exhaustify the resulting DRS

My one change is to do the exhaustification beforehand by updating with (49). This is assuming that (49) is a topic addressed by the sentence. (The question can be glossed as: How many Dutch firms own how many American computers.)

(49) $q(n \wedge m \wedge x \wedge y \wedge \#x = n \wedge \#y = m \wedge \neg\neg(dutch\_firm(x) \wedge american\_computer(y) \wedge own(x,y)))$

After this update we then add (50) with next to the shared constants, the unifications $n = 60$ and $m = 300$.

(50) $x \wedge y \wedge \#x = 60 \wedge \#y = 300 \wedge dutch\_firm(x) \wedge american\_computer(y) \wedge own(x,y)$

Similarly for the other quantifiers. If they are in focus, they classify an exhaustively interpreted discourse referent. I will treat these exhaustivity effects under the heading of scalar implicatures.

6 Scalar Implicatures

Scalar implicatures is another area in which exhaustification does provide a direct explanation, independently of pragmatic maxims. If we analyse (51) as indicated,

(51) John has four sheep.
$x \wedge have(j,x)) \wedge \#x = 4 \wedge sheep(x))$

against the background of the question (52) it cannot be that there are more than 4 sheep that John owns. If there are, we can form another set of 4 sheep owned by John who are not contained in the set chosen as value for x.

(52) $q(n \wedge \neg\neg(\#x = n \wedge x \wedge have(j, x) \wedge sheep(x))) \wedge n = 4$

In this way, exhaustification explains all of the implicatures of the form (53) for n a number greater than 4.

(53) John does not have n sheep

In applying exhaustification to other cases of scalar implicature however, things turn out to be more complicated than in this numerical case. Indeed, some of the cases discussed below could be regarded as arguments against the reduction of scalar implicatures to exhaustification, since special assumptions are often needed.

The first group of examples are formed by monotone increasing determiners like *some, most, at least three etc.* that seem compatible with the application of *all*. If $A(det\ N)$ holds with *det* one of the mentioned determiners and A a simple context that does not bring the *det N* configuration into the scope of a quantifier or a negation, there is a scalar implicature that *not A(all N)*. An example is (54).

(54) statement: Most sheep died.
implicature: Not all sheep died.

Now given an analysis of the determiners in question, exemplified in (55),

(55) $x \wedge sheep(x) \wedge die(x) \wedge \#(SHEEP \setminus x) < \#x$

it is possible to assign the set of all sheep to the discourse marker introduced by the NP. The condition $x \subset SHEEP$ introduced by the indefiniteness of *most* will prevent this for exhaustive values for x. This gives a semantic analysis of *some* that would work out on (56) as follows:

(56) Most sheep died.
$x \wedge x \subset SHEEP \wedge \#x > \#(SHEEP \setminus x) \wedge die(x)$

Exhaustification for x does not work if all sheep died. There is no value that simultaneously satisfies $q(x \wedge \neg\neg(sheep(x) \wedge die(x)))$ and (56) .

A similar analysis applies to the other determiners.

(57) Two sheep died.
$x \wedge x \subset SHEEP \wedge \#x = 2 \wedge die(x)$
At least three sheep died.
$x \wedge x \subset SHEEP \wedge \#x \geq 3 \wedge die(x)$

At most three sheep died.
$x \wedge x \subset SHEEP \wedge \#x < 4 \wedge die(x)$

Notice that under the conditions that $SHEEP$ is plural, and has more than 3 members, if it holds (perforce exhaustively) that all sheep died, it still follows (non-exhaustively) that *some*, *most* and *at least three* sheep died. In our theory, it follows that the questions in (58) must be answered in the positive, though the affirmative sentences can not be used with the NP or determiner in focus.

(58) Did some sheep die?
Did most sheep die?
Did at least three sheep die?

So the normal entailments[10] come out correctly and it even holds that in the restricted sense that answers to the corresponding questions must be answered positively, these quantifiers remain monotone increasing.

Sometimes, it is better to interpret scalar implicatures as part of another phenomenon. A case in point is the scalar implicature around *or* in (59).

(59) John has sheep or John has goats.

(59) seems to exclude that John has animals of both kinds. Following the method of before, one introduces a variable that can be classified by *or* and *and* (in a mutually exclusive way) and introduce a suitable partial ordering on the values of that variable, as in (60),

(60) $z \wedge connection(z, sheep, goats) \wedge or(z)$

The values of z are the domain of connectives ordered by implication.

To be precise:

f is a connective if $f \in 2^{2\times 2}$,
$f \leq g$ iff $\forall x\ g(x) \leq f(x)$,
$or(z)$ iff $z = \{<<0,0>,0>,<<1,0>,1>,<<0,1>,1>,<<1,1>,1>\}$ and
$connection(z, p, q)$ iff $z(<p,q>) = 1$.

If John has both sheep and goats, disjunction is a proper value for z, but not an exhaustive one. Conjunction is however exhaustive. *Or* itself can never be exhaustive, since whenever it holds, there is a stronger connective (*and*, *left and not right* or *right and not left*) that wins out over *or*. So the explanation fails, basically because there is no motivation here for an analogy to the subset requirement for "some".

The approach is however not very natural to begin with. First, the addition of an extra variable is not warranted by anaphoric phenomena (the connection cannot be picked up by an

[10] Entailment intuitions can be reconstructed in two ways: (a) given that we know the premises can we answer *Yes* to the yes-no-question formed from the conclusion or (b) given that we know the premise can we sincerely and correctly assert the conclusion. For many examples in standard logic only the first interpretation can be maintained.

anaphoric process). Second, the scalar implicature can equally well be derived in another way. The falsity of the conjunction is inferable if the disjunction gives two still possible distinct answers to the same question. That happens to be the most normal use of disjunctions. Exhaustivity is a crucial part of that inference, since the disjuncts may be compatible while their interpretation as an exhaustive answer to the same question is not.

Anaphora occurs with scalar implicatures like the ones in (61).

(61) John's sheep is rather heavy.
implicature: John's sheep is not extremely heavy.

The example can be continued with (62) which seems to pick up the degree of heaviness of John's sheep for applying it to Bill's sheep.

(62) Bill's sheep is just as heavy.

In this way (62) is analysed as (63) and acquires the implicature in the usual way.

(63) $q(w \wedge weight(w, s)) \wedge rather\_heavy(w)$

Here w can be thought of as a positive real, $weight(w, x)$ applies whenever weighing x gives a greater value than w[11], and *rather heavy* applies to an interval of weights distinct from that to which *extremely heavy* applies. Thus we maintain the entailment from *extremely heavy* to *rather heavy*, while obtaining a scalar implicature if exhaustification applies.

Scalar implicatures can be cancelled, as is fitting for implicatures.

(64) Does Leif have three chairs?
Yes, Leif has three chairs.

Following Kadmon (1990), the answer does not implicate that Leif has precisely three chairs. It may be that three chairs are needed for seating some extra guests, but that Leif owns six chairs in total.

Other means of cancelling the implicatures are connected with explicit cancellation and so-called twiddly intonation.

(65) a. Leif has three chairs, allright, but he may have more.
b. Leif has three -even six- chairs.
c. Leif has thReE chairs.

As exhaustification is connected with the topic-focus division in the sentence, it follows that all kinds of cancellation must be related to means of influencing this division. An explicit question changes the division: if possible, the topic will coincide with the question. The

[11] I weigh one kilo, non-exhaustively, but not 100 kilos. Similarly, I am one foot tall, but not seven.

explicit question thereby cancels the exhaustivity of the answer. Provisions also form a restriction on the topic-focus division. Constructing the topic as: *How many chairs does Leif own?*, i.e. making *three* the focus, for (65b) is contradicted by the interjection. Thereby, only the weaker question *Does Leif have three chairs?* can be the topic, with a treatment of the rejected topic included in the interjection. In (65a) , the proviso similarly forces a weaker topic. Finally in (65c) , the phenomenon of twiddly intonation is characteristic of topic resetting and should make it impossible to make *three* focus.

It is not the sentence as such that forms an exception to exhaustification. Cancellation can be limited to part of the sentence, while other quantifiers remain exhaustive. Compare (66).

(66) 3 boys kissed most—maybe all— girls.

One phenomenon that may be reduced to scalar implicatures, in our reconstruction, are the Evans-effects. Evans (1977) observes that there is a crucial difference between saying (67):

(67) John has sheep. Bill shaves them.

versus (68).

(68) John has sheep, that Bill shaves.

In the first, but not in the second case, Bill shaves all of John's sheep.

In the case of the single sentence, the focus can only include the whole NP, not the NP without the relative clause (this would only be possible if the relative clause were non-restrictive). In the other case, we assume that the discourse referent of the NP *sheep* receives an exhaustive interpretation by being in focus.

An obvious advantage of this treatment of scalar implicatures is that it is independent of the lexical inventory of a language. If a language has a maximal cardinal, it still has its scalar implicatures in this treatment. It has also a conceptual advantage. The decision to insert any new specification in an assertion, involves an answer on the part of the speaker to a question with respect to the dimension of the specification and suggests that the speaker is able to answer the question. New specifications therefore naturally add topical questions to the context of the assertion and are naturally interpreted as distinct answers to those topical questions. My view of scalar implicatures directly follows from sentence planning, while the classical view (Horn (1972), Gazdar (1979)) requires a further Gricean explanation.

7 Conclusion

The current paper[12] is a reworking of Zeevat (1994), especially of the heavily flawed section on answering questions. It started a long time ago as an attempt to develop a DRT/dynamic

[12]There are too many people who commented on earlier versions of this paper to thank them each individually. Special thanks go to Hans Kamp for convincing me that it is possible to make sense of cumulative readings with simple means, to Werner Saurer for pointing out to me that exhaustivity also can go in the other direction and to Alastair Butler for taking some of these ideas further.

semantics account of questions and answers. I think it does that successfully. It brings some more uniformity: semantic and pragmatic questions become the same, exhaustivity can be treated in one go instead of in two goes, since the question-answer relation can be treated dynamically. It is also uniform over definite and indefinite answers.

The approaches of Jäger (1997) and Groenendijk (1999) for developing an account of questions and answers in order to formalise the intuition that assertions are relevant because they answer common ground questions are limited because their models are not epistemic. One can however do the same here by demanding that a relevant assertion eliminate at least one cell in every question induced partition of a cell of the OA-partition of the information state. The set of open questions of an information state can be naturally defined as the set of sequences of discourse referents such that $\sigma \models q(< x_1, \ldots, x_n\}, \varphi)$ while σ does not answer $q(< x_1, \ldots, x_n\}, \varphi)$. This set can be represented by a single question. There is also no need for a separate QUD (Ginzburg (1995)) since open questions are recoverable and Wh-constants are like other discourse markers. (They would therefore participate in any mechanism that tries to keep track of the activation level of discourse referents.)

The later aim of this paper was to analyse exhaustivity and to provide a uniform treatment of the areas where it seems to play an important role: questions, answers, focus, quantifiers, scalar implicatures and Evans effects. It does that and other phenomena have been reduced to it, especially in Butler (2002). I regard the demonstration of the possibility of having one single approach to all these phenomena as the real contribution of the paper. Any approach that loses this unity is a step backwards. As Butler demonstrates, it is not necessary to stick to the framework of Update Semantics or to my particular formalisation.

For the analysis of questions and exhaustivity, there is a serious competitor. It is to apply Gricean reasoning on the fact that the speaker said A and not B[13]. If questions are sets of distinct propositional answers (as Hamblin (1976) had it, unfortunately without making distinctness an explicit demand), a similar uniform approach can be developed, which continues to work where this account has to give up: where it becomes implausible to have variables with values and where one is dealing with contrast rather than with focus. It is even possible to see the development in this paper as the special case where distinctness can be understood as different values for the same variable. The Gricean reasoning is simple: it is the inference that the other answers were not selected because they are either entailed or false. I have recently tried to work this out a bit in Zeevat (2004). If I am right there, what I am doing here is not incorrect, but it is dealing with a special case under some idealisations.

The current approach to scalars together with update semantics approaches to clausal implicatures makes it necessary to reinterpret the phenomenon of conversational implicatures. There is a class that is directly connected with basic interpretation (clausals and scalars) and that can be captured by a -discourse- grammar. Typical of this class is that does not require sophisticated and conscious reasoning. On the other hand, there can be no grammatical alternative for the implicatures generated by flouting maxims, where typically reasoning is required about goals of the speaker and alternatives for reaching the communicative goals.

[13]Most Gricean reasoning can be brought in this form. The speaker said that Black Bart caused the sheriff to die, not that he killed him. The speaker said that the candidate was good at cycling, not in his job. The speaker said something obviously false, not what he really thought. The speaker saw John with a woman, not with his wife. Implicatures arise in matching what the speaker could be expected to say and with what she said in fact.

Notice that Grice's original aim to maintain a simple logic and explain special effects by an additional mechanism is very much the methodological principle here. The mechanisms involved in clausal and quantity implicatures are simpler than the reasoning about communicative behaviour proposed by Grice.

The use of definite descriptions as an alternative for the DRT-analysis for various discourse phenomena finds important support in the Evans-phenomena. With a mechanism like the one proposed here, the difference between such an approach and DRT largely disappear: topic questions assign descriptions also to indefinite discourse markers. The fact that, for adequate analyses of the plural, it seems imperative to use the full generalised quantifier structure as proposed by Montague (rather than bundles of simple semantic features) pleads against the general spirit of the analyses proposed in early DRT for the singular NPs. These arguments no longer hold in a setting like the current one. NL quantification becomes simpler and less ambiguous as a result. Also the development of plural NPs in language evolution becomes easier to understand. But I have not dealt with plural anaphora, as in van der Berg (1996) or Nouwen (2003) and that is a crucial test.

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