The dynamics of topic and focus

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1 Background and Motivations

This article presents a dynamic account of topic and focus. A dynamic view on meanings as context change potentials (e.g. Stalnaker, Kamp, Heim, Groenendijk & Stokhof) will provide us with a substantial account of the dependence of focused answers on the *context* set up by their preceding questions. Questions pose conditions on the focal structure of their answers (Paul 1880) and can further restrict the domain of subsequent focusing operators like *only* (e.g. von Stechow 1990; von Fintel 1995; Jäger 1996). As an illustration of these two facts consider the following example:

(1) a. Who did John introduce to Sue?

b. Which gentlemen did John introduce to Sue?

c. John only introduced $[\text{Bill}]_{\text{F}}$ to Sue.

d. # John only introduced Bill to $[\text{Sue}]_{\text{F}}$.

After question (1a) or (1b), only an answer with the focal structure in (1c) is felicitous or *congruent*. The focal structure in (1d) is out. Consider now the meaning of the congruent answer (1c). After question (1a), (1c) means 'The only person John introduced to Sue is Bill'. After (1b), it can mean 'The only gentleman John introduced to Sue is Bill'.

Standard analyses of focus define congruence in terms of identity between the question meaning and the focal alternatives of the answer (e.g. von Stechow 1990; Roberts 1996), and identify the domain of focusing operators like *only* with the set of focal alternatives (e.g. Rooth 1985). In our example, the two distinct questions (1a) and (1b) pose the same conditions on the focal structures of their answers but can have different effects on the quantificational domain of subsequent *only*. These two facts constitute a problem for these standard theories unless they come equipped with a smart analysis of the *dynamics* of domain restriction which plays a role in these cases. The main goal of this article is to provide such an analysis.

Most existing dynamic analyses of questions have been developed in the tradition of the *partition theory* of Groenendijk and Stokhof 1984. In the partition theory, the meaning of a question is identified with the set of meanings of all its exhaustive answers. In a dynamic setting, questions partition information states, and answers eliminate blocks of these partitioned contexts (see Groenendijk 1999, but also Jäger 1996; Hulstijn 1997). These theories in which interrogatives and indicatives update a context, constitute a simple model of how information in discourse is organized by the question-answer relation (Carlson 1983; Roberts 1996). The notion of a partial or complete answer is specified in terms of entailment which is uniformly defined for indicative and interrogative sentences. Although logically very appealing, these theories are, empirically, not completely satisfactory. First of all, partitions seem to be too coarse-grained for a proper treatment of focus, and, thus, for an account of the facts in (1). Constituent answers are hard to tackle in these analyses as well. For example, Groenendijk cannot account for the different content expressed by answer (2c) after (2a) and after (2b), for the two questions, having the same set of complete answers, induce exactly the same partition.

(2) a. Who smokes?

b. Who doesn't smoke?

c. $[\text{John}]_{\text{F}}$.

Related difficulties also arise for theories in the Hamblin/Karttunen/Rooth tradition, e.g. problems with multiple foci (Krifka 1992) and alternative questions (von Stechow 1990; Krifka 2001). The standard treatment of alternatives as sets of (propositional) answers is not fined-grained enough and, as many people have argued, for a proper account we need the *abstracts* underlying the questions (see Ginzburg 1995; van Rooij 1997) and *direct access* to focus, i.e. structured meanings.

In a *structured meaning* account we have fitting analyses of questions and focus: questions denote abstracts, $\lambda\vec{x}\phi$, i.e. functions that when applied to the meaning of the possible constituent answers yield the meaning of the corresponding full sentential answers; and focus leads to a partition of the semantic value of an expression into a background part, also a function, and a focus part: $\langle\lambda\vec{x}\phi, \vec{a}\rangle$. Although structured meanings seem to supply us with the right level of fine-grainedness, this account does not assume interrogatives to belong to a uniform category or semantic type. Therefore, unlike the partition theory, structured meaning accounts lack an elegant analysis of embedding and coordination of questions, as in (3):

(3) Adam knows whether it's Mary's party, who will go and who invited whom.

In what follows we shall present an update semantics of questions and focus. Utilizing the close correspondence between information states in dynamic semantics – sets of world-assignment pairs – and structured propositions, the obtained analysis will combine the positive sides of partitions and structured meanings, solve the discussed difficulties and allow a number of further applications.

2 An update semantics of questions and focus

In this section we shall present an update semantics of questions and focus building on Gawron's (1996) dynamic model of domain restriction. In Gawron's analysis, the introduction of a quantificational operator was separated by the introduction of the quantificational domain. The latter was allowed to be fixed non-locally. The intuition was that domains of quantification are constructed by combining constraints that arise from different sources. These constraints were encoded in so called *environments* which mapped variables to sets of possible assignments encoding information about which values are possible for them. In this article, we propose to interpret the semantic contribution of interrogative sentences in term of extensions of these Gawronian environments. In our formalism, an environment is a sequence of sets of world-assignment pairs. We will take these sets to represent the *topics* under discussion in the current context. Interrogative sentences will be analyzed as setting up new topics, or expanding on previously introduced ones. From a topic in an environment we can easily recover the partition it would induce on the current information state. Therefore, we will be able to define all of the logical notions which are relevant for a theory of questions and answers. Since our topics are as fine-grained as abstracts, we will improve, though, on the partition theory with respect to phenomena like constituent answers or alternative questions. On the other hand, since interrogatives are associated with a uniform semantic type, we will also improve on the structured meaning account with respect to the embedding and coordination of questions. Finally, since, as in Gawron, topics encode domain restrictions, we will be able to account for the impact of questions on subsequent domains of alternatives and account for the 'gentlemen' example discussed in the introductory section of this article.

2.1 A closer look

Formulae are associated with context change potentials. A context s_e is a pair consisting of an information state s (a set of world-assignment pairs) and an environment e (a sequence of states). States encode what is known and what antecedents are available for future anaphora; environments encode information about what is merely under discussion. Contexts s_e can be depicted as in (4) where each box stands for an information state.

(4) $\langle s : \Box,\ e : \Box_1, \ldots, \Box_n \rangle$

For example, the empty box in (5a) stands for the state of minimal information, whereas the box in (5b) encodes the information that x is P.

(5) a. $\Box \ \mapsto \{(\emptyset, w) \mid w \in W\}$ (minimal information)

b. $\boxed{\text{x: P(x)}} \ \mapsto \{(g, w) \mid g(x) \in w(P)\}$ (x is P)

Questions Questions set up (or expand on previously introduced) topics. Interrogative sentences are formed by prefixing a question mark and a sequence of variables $x_1, ..., x_n = \vec{x}$ to a formula. The effect of updating with sentence $?\vec{x}\phi$ is that the last element in the output environment is a state that verifies ϕ.

A polar question like (6a), represented as in (6b), extends the environment with a state that entails that Mary smokes (e.g. (6c)).

(6) a. Does Mary smoke?

b. $?S(m)$

c. $\langle\Box\rangle[\![?S(m)]\!]\langle\Box, \boxed{\text{S(m)}}\rangle$

A constituent question like (7a) represented as (7b) extends the environment with a state which encodes the information that x is a smoker (e.g. (7c)). Intuitively we can think of (7b) as introducing the set of smokers as topic under label x.

(7) a. Who smokes?

b. $?xS(x)$

c. $\langle\Box\rangle[\![?xS(x)]\!]\langle\Box, \boxed{\text{x: S(x)}}\rangle$

Topics and sets of propositions From a topic in s_e we can uniquely derive the corresponding 'Hamblin' denotation[1] or Groenendijk and Stokhof's partition both expressed as a(n equivalence) relation over the current state s. As an illustration, consider the topics represented in (8b) and (9b) introduced by the questions (8a) and (9a). The partitions and 'Hamblin' denotations induced by these topics can be depicted as in (8c) and (9c), if we assume that j and m are the only individuals in the domain.

(8) a. $?xS(x)$

b. $\langle\Box, \boxed{\text{x: S(x)}}\rangle$

c. Hamblin:

$S(m)$
$S(j)$

G&S:

$\forall x \neg S(x)$
$\forall x(S(x) \leftrightarrow x = m)$
$\forall x(S(x) \leftrightarrow x = j)$
$\forall x(S(x) \leftrightarrow (x = j \vee x = m))$

(9) a. $?S(m)$

b. $\langle\Box, \boxed{\text{S(m)}}\rangle$

[1] We call the 'Hamblin' denotation of a question not the set of its congruent answers, but the set of its questioned propositions. Therefore we depart from the standard Hamblin-Karttunen approach where polar questions do not denote singleton sets. For the present notion, we do not have to assume that the denotation of polar questions is determined differently from the denotation of (multiple) wh-questions. Standard Hamblin denotations for polar questions can also be derived, but, in our view, are less interesting.

c. Hamblin: $\boxed{S(m)}$ G&S: $\begin{array}{|c|}\hline S(m) \\ \hline \neg S(m) \\ \hline \end{array}$

The state-environment pairs in (b) are more fine-grained than the G&S partitioned states in (c). E.g. (9) after (8) does not add anything to the partition (see (10c)), but it extends the environment in a non-trivial way (see (10b).

(10) a. $?xS(x) \wedge ?S(m)$

b. $\langle \square, \boxed{\text{x: S(x)}}, \boxed{\text{S(m)}} \rangle \quad \mapsto$

c.
$$\begin{array}{|c|}\hline \forall x \neg S(x) \\ \hline \forall x(S(x) \leftrightarrow x = m) \\ \hline \forall x(S(x) \leftrightarrow x = j) \\ \hline \forall x(S(x) \leftrightarrow (x = j \vee x = m)) \\ \hline \end{array} \sqcap \begin{array}{|c|}\hline S(m) \\ \hline \neg S(m) \\ \hline \end{array} = \begin{array}{|c|}\hline \forall x \neg S(x) \\ \hline \forall x(S(x) \leftrightarrow x = m) \\ \hline \forall x(S(x) \leftrightarrow x = j) \\ \hline \forall x(S(x) \leftrightarrow (x = j \vee x = m)) \\ \hline \end{array}$$

In what follows we shall exploit these two levels of fine-grainedness in a crucial way.

Entailment and support We define the logical notion of *entailment*, $\models$, in terms of the partitioned states (exactly as in Groenendijk 1998-99), and the more discourse oriented notion of *support*, $\models\!\!\!\approx$, in terms of the more fine-grained state-environment pairs. As for indicative sentences, support and entailment are the same notion. But, they crucially differ with respect to questions.

An interrogative is *entailed* in a context iff its update does not further partition the input state. An interrogative $?\vec{x}\psi$ is entailed after an indicative ϕ iff the indicative is a *complete answer* to $?\vec{x}\psi$. An interrogative $?\vec{x}\psi$ is entailed after another interrogative $?\vec{y}\phi$ iff any complete answer to $?\vec{y}\phi$ is a complete answer to $?\vec{x}\psi$. E.g.

(11) a. $\forall x(S(x) \leftrightarrow x = m) \models ?xS(x)$, but $S(m) \not\models ?xS(x)$

b. $?xS(x) \models ?S(m)$

On the other hand, an interrogative is *supported* in a context iff the topic it introduces is already entailed in the input context, either by the input state or by an old topic in the input environment. After an indicative ϕ, interrogative $?\vec{x}\psi$ is supported iff ϕ entails $\exists\vec{x}\psi$. After another interrogative $?\vec{y}\phi$, sentence $?\vec{x}\psi$ is supported iff $\exists\vec{y}\phi$ entails $\exists\vec{x}\psi$.

(12) a. $S(m) \models\!\!\!\approx ?xS(x)$

b. $?S(m) \models\!\!\!\approx ?xS(x)$, but $?xS(x) \not\models\!\!\!\approx ?S(m)$

Entailment seems to be relevant for *indirect* uses of interrogatives. The sentences (13a-b) are valid implications, but (13c) is not.

(13) a. If John knows that only Mary smokes, then John knows who smokes.

b. If John knows who smokes, then John knows whether Mary smokes.

c. If John knows that Mary smokes, then John knows who smokes.

The new notion of support is relevant for *direct* uses of questions in discourse. Question (14b), although entailed, is not supported after (14a) and indeed it is not a vacuous move: it introduces a *new* topic, it indicates a strategy to answer (14a) (see Roberts 1996).

(14) a. Who smokes?

b. Does Mary smoke?

As we will see, support will further play a crucial role for our characterization of focus and its pragmatic role.

Relevance In terms of entailment and support we define a generalization of Groenendijk's notion of *relevance* which also applies to questions. In doing so, we propose a formalization of Roberts's (1996) insight that a question is relevant iff it is part of a strategy to answer the immediate question under discussion.[2]

Groenendijk 1999 proposes the following characterization of the notion of a relevant (or pertinent, coherent) move in a discourse:

(16) A move is *relevant* iff it is (i) about the issue under discussion; (ii) non vacuous; and (iii) consistent.

Groenendijk's characterization of (i) in terms of *licensing*[3] and (ii) in terms of entailment prevents a correct application of this notion to questions. According to Groenendijk, questions are always licensed, and are informative iff they are not entailed. Therefore, we obtain the predictions in (17), which are highly counter-intuitive.

(17) a. Who smokes?

b. Well, does Mary smoke? (not relevant)

c. Well, does Mary work? (relevant)

Question (b) is not relevant after (a) because, since it is entailed, it is not informative. Question (c) is relevant because licensed, not entailed and consistent. Intuitively though, both questions are non-vacuous moves after (a), but only (b)

[2]Eventually our characterization of the notion of a strategy of inquiries should take into account the *average informativity* of the possible answers, or borrowing a term from information theory, the *entropy* of the related questions (see van Rooij 2003). This would allow us to distinguish sub-question (b) from (c) in example (15). The former is intuitively part of a much more efficient strategy to answer (a).

(15) a. Who ate what?

b. What did Fred eat?

c. Did Fred and Mary eat the beans?

[3]Groenendijk's licensing turns out to be equivalent to Lewis's (1988) notion of aboutness.

is about (a), since, intuitively, it suggests a strategy to answer (a). Entailment does not seem to be the right notion to characterize non-vacuous questions, and Groenendijk's licensing should be modified to capture aboutness of questions, and not only of assertions.

We propose to define vacuity in terms of support rather than entailment and to generalize Groenendijk's notion of licensing as follows. An interrogative sentence $?\vec{x}\phi$ is licensed in a context iff $?\vec{x}\phi$ is entailed in the context. An indicative ϕ is licensed in a context iff $?\phi$ is entailed in the context. Intuitively, a sentence is licensed iff it exclusively addresses the question under discussion Q either by giving a partial answer to Q (as in Groenendijk) or by introducing a question the answers of which are partial answers to Q, i.e. an entailed question.

The obtained notion of relevance gives us the correct predictions in (18).

(18) a. Who smokes?

b. Well, does Mary smoke? (relevant)

c. Mary smokes. (relevant)

d. Well, does Mary work? (not relevant)

Sub-question (18b) is licensed, but not supported (although entailed) after (18a), therefore it is relevant, as well as sentence (18c). Question (18d) is not relevant because it is not licensed.

Topics and quantification A further crucial characteristic of topics in this framework is that they encode domain restrictions (as in Gawron 1996). An update with a quantified sentence $\exists x\phi$ only modifies the state parameter, but crucially depends on the environment parameter, in particular on the last topic in which the quantified variable is defined, $e(x)$, which encodes all restrictions previously placed on x.

(19) a. $?xS(x) \wedge \exists xP(x)$

b. $\langle\Box\rangle[\![?xS(x)]\!]\langle\Box, \boxed{\text{x: S(x)}}\rangle[\![\exists xP(x)]\!]\ \langle\boxed{\text{x: S(x)} \wedge \text{P(x)}}, \boxed{\text{x: S(x)}}\rangle$

The valid entailments in (20) illustrate a crucial feature of our formalism. Questions can restrict subsequent quantification if coindexed.

(20) a. $?\vec{x}\phi_1 \wedge \ldots \wedge ?\vec{x}\phi_n \wedge \exists\vec{x}\psi \ \models\ \exists\vec{x}((\phi_1 \wedge \ldots \wedge \phi_n) \wedge \psi)$

b. $?\vec{x}\phi_1 \wedge \ldots \wedge ?\vec{x}\phi_n \wedge \forall\vec{x}\psi \ \models\ \forall\vec{x}((\phi_1 \wedge \ldots \wedge \phi_n) \rightarrow \psi)$

Presupposition Topics can be also presupposed. Presupposition (denoted by Beaver's partial operator ∂) expresses conditions on the input context which must be satisfied for the sentence to be defined (Stalnaker, Heim, Beaver). An update with a presupposition $\partial\phi$ is defined in s_e iff s_e supports ϕ. Please notice that presupposition is defined in terms of support rather than entailment. This means that a presupposed topic like $\partial[?xI(a,x)]$ is defined after $?I(a,b)$, but not after $?xyI(y,x)$. This notion of presupposition will play a crucial role for our treatment of focus.

Focus Focus indicates the presence of a topic in the context. More specifically, as in the structured meaning approach, focus leads to a 'partition' of the sentence into: (1) a presupposed topic (background); and (ii) an existential sentence (focus).[4]

A sentence like (21a) represented as (21b) presupposes that the set S of smokers is under discussion and asserts that Mary is part of it.

(21) a. $[\text{Mary}]_{\text{F}}$ smokes.

b. $\partial[?xS(x)] \wedge \exists x(x = m)$

c. $\langle \Box, \boxed{\text{x: S(x)}} \rangle\ [\![\partial[?xS(x)] \wedge \exists x(x = m)]\!] \langle \boxed{\text{x: S(x)} \wedge \text{x=m}}, \boxed{\text{x: S(x)}} \rangle$

This analysis covers focus in questions as well as illustrated in (22). Question (22a) represented in (22b) again presupposes that the set of smokers is under discussion, and asks whether Mary is among them.

(22) a. Does $[\text{Mary}]_{\text{F}}$ smoke?

b. $?(\partial[?xS(x)] \wedge \exists x(x = m))$

c. $\langle \Box, \boxed{\text{x: S(x)}} \rangle [\![?(\partial[?xS(x)] \wedge \exists x(x = m))]\!] \langle \Box, \boxed{\text{x: S(x)}}, \boxed{\text{x: S(x)} \wedge \text{x=m}} \rangle$

Note that from the representations in (21b) and (22b) we can recover the ordinary meanings of the sentences.

(23) a. $?xS(x), \partial[?xS(x)] \wedge \exists x(x = m) \models S(m)$

b. $?xS(x), ?(\partial[?xS(x)] \wedge \exists x(x = m)) \models ?S(m)$

In the following sections, we will discuss a number of applications of this formalism. Section 3 deals with questions and answers. Section 4 with focus and its pragmatic and semantic role.

3 Questions and answers

In this part, we will show how the formalism presented in the previous section allows us to solve a number of problems arising for standard analyses of questions and answers. The finegrainedness of our notion of a topic will be used for a treatment of constituent answers and alternative questions which improves on proposition set analyses of questions and answers (section 3.1 and 3.2). Section 3.3 deals with embedding and coordination of questions showing how the problems typical of a structured meaning account are avoided in the present framework. Finally, section 3.4 concludes this part with an analysis of which-interrogatives.

[4]Focused sentences often receives an exhaustive interpretation (see Zeevat 1994). An interesting question is whether exhaustivity should be part of the meaning of focus or not (see Kiss's (1998) distinction between identificational (exhaustive) and information (non-exhaustive) focus in Hungarian). On the present analysis, we define a non-exhaustive notion of focus, assuming that exhaustive meanings can be derived by other pragmatic means (e.g. Schulz and van Rooij 2004). An exhaustive notion of focus, however, would not be hard to define in this framework (by means, for example, of the $only_x$ operator introduced in section 4.1).

3.1 Constituent answers

On the present account, a constituent answer is expressed as an existential sentence, the domain of which is crucially restricted by the preceding question (cf. Dekker 2002).

Term answers like *John* are represented as in (24f).

(24) a. Who smokes? b. $?xS(x)$

c. Who doesn't smoke? d. $?x\neg S(x)$

e. $[\text{John}]_\text{F}$. f. $\exists x(x = j)$

Given these representations, we correctly predict that after (24a), *John* means 'John smokes'; after (24c), instead, it means 'John does not smoke'.

(25) a. $?xS(x), \exists x(x = j) \models S(j)$

b. $?x\neg S(x), \exists x(x = j) \models \neg S(j)$

This analysis can be extended to *yes-no* answers. *Yes* and *no* are represented as in (26d):

(26) a. Does Mary smoke? b. $?S(m)$

c. $[\text{Yes}]_\text{F}/[\text{No}]_\text{F}$. d. $\exists\top/\neg\exists\top$

Given these representations we correctly predict that after (26a), *yes* means 'Mary smokes'; and *no* means 'Mary does not smoke'.

(27) a. $?S(m), \exists\top \models S(m)$

b. $?S(m), \neg\exists\top \models \neg S(m)$

3.2 Alternative questions

Proposition set theories of questions in both the G&S and Hamblin/Karttunen traditions have been shown to have problems in accounting for alternative readings of disjunctive questions (see von Stechow 1990; Krifka 2001). In this section, we would like to show that our analysis is fine-grained enough to express the contrast between polar and alternative question readings, and to account for the disambiguating role of focus in these cases.

Question (28) is ambiguous between a polar question reading (expected answers: *yes*/*no*) and an alternative question reading (expected answers: *tea*/*coffe*).

(28) Do you want coffee or tea?

Intonation seems to play a disambiguating role. In alternative questions, the alternatives are stressed.

(29) Do you want COFFEE or TEA? a. #Yes / #No. b. Coffee / Tea.

If we assume for (28) the focal structure in (30a) and for (29) the focal structure in (31a), the contrast between polar and alternative readings follows directly from our analysis of focus.

(30) a. [Do you want coffee or tea]$_F$? (polar reading)

b. $?(W(c) \vee W(t))$

c. Yes / No.

d. $\exists\top$ / $\neg\exists\top$

e. topic: | W(c)∨W(t) | $\mapsto$ f. Hamblin: | You want coffee or tea |

(31) a. Do you want [coffee]$_F$ or [tea]$_F$? (alternative reading)

b. $?(\partial[?xW(x)] \wedge \exists x(x = c \vee x = t))$

c. Coffee / Tea.

d. $\exists x(x = c)$ / $\exists x(x = t)$

e. topic: | x: W(x)∧(x=c ∨ x=t) | $\mapsto$ f. Hamblin: | You want coffee | / | You want tea |

The formulae (30b) and (31b) set up different topics, therefore they (i) express different question meanings (compare the Hamblin denotation in (f) induced by the introduced topic in (e)); and (ii) allow different constituent answers.

3.3 Embedding and coordination of questions

In the introduction we pointed out that although the fine-grainedness of the structured meaning analysis of questions is needed to account for constituent answers and alternative questions, it is problematic too. By assuming that different types of interrogatives have denotations of different categories, the structured meaning account has problems with the coordination and embedding of questions. This problem disappears once one assumes a propositional set theory as those proposed by Hamblin, Karttunen or Groenendijk & Stokhof. According to these latter theories, polar and (multiple) *wh*-questions all have denotations of the same category, and all these questions can thus be coordinated under *know* and *wonder* as in (32):

(32) Adam *knows/wonders* whether it's Mary's party, who is invited, and who will kiss whom.

Only Groenendijk & Stokhof's analysis, however, correctly predicts that indicatives can also be freely coordinated under *know* with interrogatives:

(33) Adam knows that it's Mary birthday and who is invited to come.

Moreover, by thinking of the denotation of a question as an equivalence relation, the inclusion relation accounts for *entailment* not only in case of declaratives, but also for interrogatives. Our approach shares with Groenendijk & Stokhof these desirable consequences. First, coordination between indicatives and interrogatives of any 'type' is unproblematic: a context s_e can also be updated with ϕ if ϕ contains both an indicative and an interrogative. This updated context gives rise to a structured state: the partition $P(s_e[\phi])$. As shown in the appendix, entailment can be defined in terms of subsistence between such structured states. Taking $K_a(i)$ to denote the epistemically accessible worlds to Adam in possibility i, and ignoring anaphoric dependencies and presuppositions, we can simply assume that the state-environment pair with respect to which the embedded clause should be interpreted in possibility $i = \langle g, w \rangle$ is $K_a^*(i) = \{\langle h, w \rangle : h = g \wedge v \in K_a(w)\}_{e_0}$, where e_0 is the 'empty' environment which makes $P(K_a^*(i)) = \{\langle j, j' \rangle : j, j' \in K_a^*(i)\}$. Now we can define the update of context s_e with sentence '$know(a, \phi)$' as follows:

(34) $s_e[know(a, \phi)] \quad = \quad \{i \in s : K_a^*(i) \text{ entails } \phi\}_e$

This has the result that sentence (33), for instance, is predicted to be true in possibility $i = \langle g, w \rangle$ iff (i) Adam knows that it's Mary's birthday, and (ii) Adam knows that d is invited to come if and only if d is actually invited in w, for every d.[5]

Groenendijk & Stokhof account for the fact that *to wonder*, in distinction with *to know*, cannot embed indicatives by assuming that the former verb is *intensional* and not *extensional*. We won't make use of this assumption, however. Instead, we will assume that a sentence of the form '$wonder(a, \phi)$' can only be true in i if (i) $K_a^*(i)$ does not entail ϕ, but (ii) ϕ does not eliminate any possibility of $K_a^*(i)$. This has the result that ϕ cannot be an indicative, because that would either eliminate possibilities, or else be entailed by $K_a^*(i)$.

3.4 *Which*-questions

To end this section we briefly present an analysis of *which*-interrogatives, which will also play a role later on.

We assume that a *which*-phrase gives rise to the presupposition that the set over which it ranges is already given as a *topic*. Questions (35a) and (36a) are represented as in (35b) and (36b).

(35) a. Which men are bachelors?

b. $\partial[?xM(x)] \wedge ?xB(x)$

(36) a. Which bachelors are men?

b. $\partial[?xB(x)] \wedge ?xM(x)$

[5] Of course, to account for focus in the embedded clause, we might assume a more interesting interaction between $K_a(i)$ and the environment of the 'main' context.

Question (35) presupposes that the set of men is under discussion and it asks which of them are bachelors. Question (36) presupposes that the set of bachelors is under discussion and it asks which of them are men. In distinction with Groenendijk & Stokhof's (1984) treatment, according to which (35) and (36) are equivalent, this analysis allows us to capture the contrast between these two questions. Although (35b) and (36b) determine the same partition, under the assumption that in all worlds all bachelors are men, (36b) is vacuous whenever defined. In distinction with (35b), which is not a trivial question.

4 Pragmatic and semantic role of focus

In this section we turn to a number of applications of the presented analysis of focus. Section 4.1 distinguishes between focus and topic sensitivity and sketches a way of implementing this distinction in the present framework. Section 4.2 defines a notion of discourse congruence to capture which focal structures are felicitous in which contexts. Finally, section 4.3 discusses how the present theory can be extended to an analysis of contrastive topics.

4.1 Focus and topic sensitivity: *only* and *always*

Sentences such as (37a) and (37b) are commonly analyzed as involving a dependency between the position of focus and the interpretation of *focus sensitive expressions* like *only*. In a situation where Kim serves Pat and Sandy Courvoisier, and serves nobody anything else, (37a) is true while (37b) is false. An expression is focus sensitive if its interpretation involves essential reference to the information structure of the sentence containing it.

(37) a. Kim only serves Sandy $[\text{Courvoisier}]_{\text{F}}$.

b. Kim only serves $[\text{Sandy}]_{\text{F}}$ Courvoisier.

Analysts (e.g. Rooth 1985) typically refer to a single mechanism, so–called *association with focus*, to explain the meaning difference between (37a) and (37b).

However, focus sensitive expressions do not constitute a uniform class (see Beaver and Clark 2003). In this section, we focus on the expressions *only* and *always*, and summarize evidence suggesting that sentences involving these two expressions seem to gain their interpretation in different ways. From this evidence, we argue that some focus sensitive expressions (e.g. *only*) are directly sensitive to focus, whereas others (e.g. *always*) are not. We then sketch an analysis of these two types of focus sensitive expressions in the framework presented in this paper.

The first piece of evidence comes from the interaction of focus sensitive expressions and reduced pronouns. *Only* and its cross-linguistic counterparts systematically fail to associate with reduced pronouns such as '*im* 'him'; see

Hoeksema and Zwarts (1991:67) and Bayer (1999:59). In contrast, *always* and its cross–linguistic counterparts can.

Consider the context below. (38), with *always*, is a felicitous response, whereas (39), with *only*, is not. (39) cannot mean 'I only discussed Fred and no one else with Sandy'.

> **Context**: You had many discussions with Sandy, but what I want to know is the extent to which you talked about Fred. Of all the times you talked with Sandy, how often was Fred the person you talked about?

(38) I $[\text{always}]_F$ discussed'im with Sandy
Can mean: "Whenever I discussed someone with Sandy, I discussed Fred."

(39) # I $[\text{only}]_F$ discussed'im with Sandy
Cannot mean: "I only discussed Fred (and no one else) with Sandy."

We find the same split between *always* and *only* in extraction contexts, as illustrated by (40a) and (40b) (see Krifka 1992, 234). (40a), with *always*, can mean 'We should thank the man such that, if Mary took someone to the movies, it was him', where *always* apparently associates with a gap in the *wh*–relative. In contrast, with *only*, (40b) cannot mean 'We should thank the man such that Mary took only HIM to the movies'. The extraction of the focus associate of *only* is impossible, but the extraction of the focus of *always* is possible.

(40) a. We should thank the man whom Mary always took ___ to the movies.

b. We should thank the man whom Mary only took ___ to the movies.

This data from reduction and extraction suggests that *only* has compulsory association with focus in its syntactic scope. In contrast, reduction or extraction of material does not affect the interpretation of *always*. Similar patterns emerge cross–linguistically (see Beaver and Clark 2002b). Other phenomena not discussed here that give further evidence of the split between *always* and *only* include negative polarity items and ellipsis.[6] A formal framework which treated focus sensitive expressions as a homogeneous class would fail to capture these differences. In the remainder of this section, we sketch how the framework discussed in this paper accounts for the distribution of focus sensitive expressions. In particular, our analysis hinges on the claim that the focus sensitivity of *only* is derived from a grammatical mechanism, whereas the interpretation of *always* is determined by the discourse topic.

Adverbs of quantification such as *always* are analyzed here as in the Lewis–Heim–Kamp tradition, schematized in (41). They form tripartite structures where *if/when*–clauses, if present, provide the restriction. In contexts in which an *if/when*–clause is not present, the discourse topic determines what is actually

[6] For discussion, see Beaver and Clark 2002a, Beaver and Clark 2002b, Beaver and Clark 2003.

quantified over by the adverb.

(41) $\text{Quantifier}_{\text{topics}}(\text{Restriction})(\text{Scope})$

An utterance of the sentence in (42), with focus on *Bill*, would be felicitous in a context in which the topic $?xI(j,x,s)$ 'Who does John introduce to Sue?' has already been introduced. The sentence in (42) is represented as in (43). Since the sentence in (42) is defined only in contexts in which the topic $?xI(j,x,s)$ has been introduced, the context makes salient an interpretation in which the variable quantified over by *always* is x and, consequently, the domain of quantification of *always* is restricted to individuals John introduces to Sue. However, there could be other contexts in which (42) is felicitous. The crucial component of our analysis is that the restrictor of *always* is contextually identified, rather than being tied to the position of focus.

(42) John always introduces $[\text{Bill}]_{\text{F}}$ to Sue.

(43) $\text{always}(\emptyset)(\partial[?xI(j,x,s)] \wedge \exists x(x=b))$

We treat the focus sensitive expression *only* as an indexed sentential operator $\textit{only}_{\text{x}_1,\ldots,\text{x}_n}$, where $\text{x}_1, \ldots, \text{x}_\text{n}$ are focus variables. The interpretation of $\textit{only}_{\text{x}}$ involves a universal quantification over the focused variable x which is automatically restricted by the presupposition expressed by focus. This analysis predicts that *only* obligatorily associates with focus. In contrast, in the analysis sketched above *always* is predicted to only optionally associate with focus.

The sentence in (44) receives the analysis in (45). As in standard analyses of (un)selective binding, only_{x} changes the quantification force of the quantifier binding x from existential to universal.[7] Given the presupposition triggered by focus in (44), the universal quantification is automatically restricted to individuals John introduced to Sue. In a neutral context, (44) means 'The only person John introduced to Sue is Bill'.

(44) John only introduced $[\text{Bill}]_{\text{F}}$ to Sue.

(45) $\text{only}_{\text{x}}(\partial[?xI(j,x,s)] \wedge \exists x(x=b)) \models \forall y(I(j,y,s) \leftrightarrow y=b)$

The domain of *only* can be further restricted by a preceding question. After the question in (46a), the response in (46c) means 'The only gentleman John introduced to Sue is Bill', as in (47).

(46) a. Which gentleman did John introduce to Sue?

b. $\partial[?xG(x)] \wedge ?xI(j,x,s))$

c. John only introduced $[\text{Bill}]_{\text{F}}$ to Sue.

d. $\text{only}_{\text{x}}(\partial[?xI(j,x,s)] \wedge \exists x(x=b))$

(47) $?xG(x)$, $?xI(j,x,s)$, (46d) $\models \forall y((G(y) \wedge I(j,y,s)) \leftrightarrow y=b)$

[7] More precisely, *only* is analyzed as a selective or asymmetric quantifier; see Dekker 1993. See the appendix.

4.2 Discourse congruence

In this section we show how our dynamic analysis enables us to give an interesting characterization of the notion of discourse congruence which covers contextual restrictions while avoiding problems of over- and under-focus, and which uniformly applies to answers, denials, questions and questions strategies.

In our proposal a sentence ϕ is *congruent* after ψ iff (i) the presupposition of ϕ is defined after ψ, and (ii) no more material is in focus than needed to satisfy (i).

Our conditions (i) and (ii) are closely related to Schwarzschild's (1999) *givenness* and *avoid focus* constraints. As Schwarzschild's *givenness*, condition (i) is a formalization of the traditional idea that non-focused material must be old. In distinction with Schwarzschild, however, our analysis of givenness is of a rather *global* nature: the existential closure of the non-focused parts of a whole clause has to be 'given' in the context, not the individual words themselves.[8] Condition (ii) corresponds to Schwarzschild's optimality theoretic constraint to avoid unnecessary focus: in our framework it will prevent us from placing more material in focus than is strictly necessary to allow the context to support the focal presupposition of the sentence.

Focus presupposes a question, and presupposition is defined in term of support. Therefore in order to understand condition (i) it is important to recall after which sentences a question is supported. As noted above, and explained more formally in the appendix, a question $?\vec{x}\psi$ is supported after an indicative ϕ or an interrogative $?\vec{x}\phi$ iff ϕ or $\exists\vec{x}\phi$ entails $\exists\vec{x}\psi$. By this notion of support, we can account for the intuition that a sentence is congruent if it *either* 'matches' the question the sentence addresses (example (48)), *or* it stands in *contrast* with an earlier made assertion (example (49)).

(48) a. Who voted for Mary? $?xV(x,m)$

b. $[\text{John}]_{\text{F}}$ voted for Mary. $\partial[?xV(x,m)] \wedge \exists x(x=j)$

(49) a. Bill voted for Mary. $V(b,m)$

b. No, $[\text{John}]_{\text{F}}$ voted for Mary. $\partial[?xV(x,m)] \wedge \exists x(x=j)$

Sentences (48b) and (49b) are congruent after (48a) or (49a), because they are minimally focused to be defined after the respective antecedents. In the same contexts, the alternative focus structures in (50) are predicted to be infelicitous.

(50) a. # John voted for $[\text{Mary}]_{\text{F}}$. $\partial[?xV(j,x)] \wedge \exists x(x=m)$

b. # $[\text{John}]_{\text{F}}$ voted for $[\text{Mary}]_{\text{F}}$. $\partial[?xyV(x,y)] \wedge \exists x(x=j) \wedge \exists y(y=m)$

[8] Our analysis also has nothing to say about embedded F-marking and de-accenting. For an account of the latter phenomenon see Aloni, Butler and Hindsill's contribution to this volume.

Sentence (50a) is undefined after (48a) or (49a), and, therefore, violates condition (i). Sentence (50b) instead violates condition (ii). Had *John* not been in focus there, then the presupposition of the sentence would already be supported after (48a) or (49a).

Just like Roberts 1996, our notion of congruence applies to questions and question strategies as well. Also in these cases, *under*focused questions will be undefined and *over*focused ones will violate our minimality constraint.

Finally, our dynamic analysis also immediately predicts correctly for sequences in which contextual restrictions play a crucial role. Since question (51) supports question (48a), in our analysis the two questions pose the same condition on the focal structure of their answers.

(51) Which Democrats voted for Mary? $\partial[?xD(x)] \wedge ?xV(x,m)$

4.3 Contrastive Topics

In the literature, there exist two popular views on what a sentence is *about*. According to a tradition starting with Paul 1880, the topic of a sentence is the *question* the sentence is addressing. According to another tradition going back at least to Goodman 1961, the topic of a sentence is the *referent* the sentence is about. In more recent analyses along the second tradition, e.g. Reinhart 1981 and Vallduví 1992, this referent need not be a particular real entity, but is thought of rather as a *discourse referent*. By representing questions *as* discourse referents in an environment, we suggest that these two views are two sides of the same coin.

What a sentence is about is linguistically *marked*, in English, by the use of accent. Jackendoff 1972 distinguishes between A and B accent. The rising A accent marks *dependent* focus, while the falling B accent marks *independent* focus.

(52) (Who ate what? What about Fred?) Fred_B ate the beans_A.

According to our analysis, focus presupposes a topic: it indicates that it addresses a certain question. Because two foci are used, (52) presupposes at least the multiple *wh*-question (53a) as in Roberts 1996. However, as in Büring 1999, we will also assume that (52) presupposes (53b).

(53) a. Who ate what? $?xy\ A(x,y)$

b. What did Fred eat? $?y\ A(f,y)$

According to Roberts 1996, the two questions form part of a questioning *strategy*. Our notion of *relevance* between questions shows that the question (53b) can be part of a strategy to answer (53a), but not the other way around. Thus, we can determine that the presupposition and assertion of (52) should be represented as follows:

(54) a. Fred_B ate the beans_A.

b. $\partial[?xyA(x,y)] \wedge \partial[?yA(f,y)] \wedge \exists y[y=b]$ or equivalently

c. $\partial[?xyA(x,y)] \wedge \partial[?x(x=f)] \wedge \exists y[y=b]$

The ordinary meaning of the sentence is entailed: (54c) $\models A(f,b)$.

What Jackendoff called A and B accent is called *focal* and *topical* accent respectively by Büring 1999. Büring proposes that a sentence like (52) not only has a focal-value, but also a *topic-value*. The former corresponds with our question (53b), but the latter is not a question, but rather a *set* of questions: for each relevant individual d the question what d ate. To account for the intuition that (52) is only a *partial* answer to question (53a), he states an extra *disputability* condition. If we denote the topic-value of A by $[[A]]^t$, the condition says that if in A a topical accent is used, at least one question in $[[A]]^t$ must still be open. This disputability condition, however, gives rise to the so-called *last answer problem.*

(55) a. Who ate what?

b. Mary$_B$ ate sprouts$_A$, and

c. Fred$_B$ ate the beans$_A$.

After (55b) is given, answer (55c) might resolve the whole question (55a), which is in conflict with Büring's disputability condition. We have taken over Roberts' (1996) suggestion that 'topic'-accent indicates, or presupposes, the use of a certain questioning strategy: (52) presupposes both (53a) and (53b), and congruence demands that the former must have been asked before the latter. But note that from our relevance condition we can still *derive* Büring's disputability in case (52) is used out of context without making use of non-ordinary semantic values. The reason is that the assertion presupposes questions (53a) and (53b), and that our relevance condition on questions demands that (53b) can only be part of a strategy to answer (53a) in case there is at least one individual different from Fred whose eating behavior is still in question.

Büring 1999 makes crucial use of his disputability condition to explain why sentence (56a) only has a $\neg\forall$ reading, i.e., that (56a) cannot mean (56b):

(56) a. All$_B$ politicians are not$_A$ corrupt.

b. $\forall x[Pol(x) \rightarrow \neg Crpt(x)]$

However, this much follows already from our assumption that sentences with independent and dependent focus presuppose two questions, and the general condition that question Q' cannot be part of a strategy to answer Q if they denote the same partition. Notice that it follows from our reasoning above that (56a) presupposes either $\partial[?xPol(x)] \wedge ?xCrpt(x)$ and (57a), or $\partial[?xPol(x)] \wedge ?xCrpt(x)$ and (57b):

(57) a.

$\forall x[Pol(x) \rightarrow Crpt(x)]$
$\neg\forall x[Pol(x) \rightarrow Crpt(x)]$

b.

$\forall x[Pol(x) \rightarrow Crpt(x)]$
$\forall x[Pol(x) \rightarrow \neg Crpt(x)]$

Now suppose that (56a) actually presupposed (57b). Assuming that the presupposition of a question is the union of its possible answers, it follows that (56a) must presuppose that *either* all politicians are corrupt, *or* no politician is corrupt. Assuming that question Q' can only be part of a strategy to resolve 'goal'-question Q if Q' and Q do not denote the same partition, we demand that partition (57b) is not the same partition as the one denoted by $\partial[?xPol(x)] \wedge ?xCrpt(x)$. This means that there must be at least more than one politician, and that it is *not* presupposed that either all politicians are corrupt, or that none of them is corrupt. So, our conditions demand that the partition due to $\partial[?xPol(x)] \wedge ?xCrpt(x)$ denotes a cell where some but not all politicians are corrupt. But this is inconsistent with the presupposition of (57b), which rules out the possibility that (56a) presupposes (57b). The sequence consisting of $\partial[?xPol(x)] \wedge ?xCrpt(x)$ and (57a), on the other hand, is predicted to be appropriate, and will thus be chosen. But this means that (56a) can be given only as answer to (57a), and thus can receive the $\neg\forall$ reading only.

5 Conclusion

We have analyzed within dynamic semantics how questions can restrict the domain of quantificational sentences used later in a discourse. We have done this by extending Gawron's (1996) dynamic analysis of domain restriction with an explicit treatment of questions and focus. Our analysis of questions incorporates Groenendijk's logic of interrogation, but improves on it by introducing (basically) the abstracts underlying the questions to the discourse. In this way we were able to account for constituent answers, alternative questions and (multiple) focus while maintaining an uniform category for interrogative sentences. We have further modeled the distinction, put forward in Beaver and Clark 2003, between focus and topic sensitivity. Focus sensitivity derives from a grammatical mechanism, whereas the interpretation of topic sensitive operators is a purely pragmatic matter.

Appendix

Formal Definitions

The vocabulary of our language is like that of standard first-order predicate logic with identity, but with a polyadic existential quantifier $\exists x_1, \ldots, x_n$, and with the addition of a sentential operator only$_{x_1,..,x_n}$, a presupposition operator ∂ and a question operator $?x_1, \ldots, x_n$. We do not have compound interrogatives or quantification into questions, but we have presupposed questions and can form sequences of questions (and assertions). As for the semantics, formulae are associated with context change potentials. A context s_e is a pair consisting of an environment e and an information state s. An information state consists of a set of world-assignment pairs. An environments is a sequence of information states. If $c = s_e$ is a context, then $S(c) = s$ and $E(c) = e$.

Elements of a state are called *possibilities*, given a possibility $i = \langle w, g \rangle$, we write $i(\alpha)$ to refer to the denotation of α with respect to g_i and w_i. As in Dekker 1993, possibilities are ordered by an extension relation $\prec$: j *extends* i, $i \prec j$ iff $w_i = w_j$ & $g_i \subseteq g_j$. This extension relation carries over to an ordering relation between information states: s is a *substate* of t, $s \prec t$ iff $\forall i \in s: \; i \prec t$, where $i \prec t$ iff $\exists j \in t : i \prec j$.

Now we can give a recursive definition of the context-change potential of the formulae of the language. The basic formulae are defined as expected: they can only influence the state parameter s and eliminate possibilities in s in which the formulae are false:

1. $s_e[Pt_1, ..., t_n] = \{i \in s \mid \langle i(t_1), ..., i(t_n) \rangle \in i(P)\}_e$

In the interpretation rule of *negation*, we make crucial use of the ordering relation $\prec$. Just like atomic formulae, negation influences only the state parameter:

2. $s_e[\neg\phi] = \{i \in s \mid i \not\prec S(s_e[\phi])\}_e$

Conjunction is defined as standard in dynamic semantics as sequential update:

3. $s_e[\phi \wedge \psi] = s_e[\phi]\,[\psi]$

Until now the environments played virtually no role. They are crucial, however, for the semantic analysis of *quantified* sentences. The update of context s_e with an existential sentence $\exists x_1, ..., x_n \phi$ is defined in terms of the merge of two information states. The *merging* of information state s with information state s', $s \wedge s'$, is defined as the 'least upper bound' of s and s' (see again Dekker 1993):

$$s \wedge s' = \{i \mid \exists j \in s : \; \exists j' \in s' : \; dom(i) = dom(j) \cup dom(j') \; \& \; j \prec i \; \& \; j' \prec i\}$$

If we define random assignment, $s[x]$, as $\{\langle w, g[x/d] \rangle : \; \langle w, g \rangle \in s \; \& \; d \in D\}$, we can define the update of s_e with an existential sentence in terms of this merge-operator as follows. Assume $x_1, ..., x_n = \vec{x}$ are not defined in s.[9]

4. $s_e[\exists\vec{x}\phi] = (S((s[x_1], ..., [x_n])_e[\phi]) \; \wedge e(\vec{x}))_e$

where $e(x_1, ..., x_n)$ is the last state in e in which the variables $x_1, ..., x_n$ are defined. More formally, if $e = \langle e_1, ..., e_m \rangle$, then (i) $e(x_1, ..., x_n) = e_m$, if $n = 0$; (ii) $e(x_1, ..., x_n) = e_i$ in e, such that $x_1, ..., x_n \in dom(e_i)$ and $\forall e_j[x_1, ..., x_n \in dom(e_j) \rightarrow j \leq i]$, otherwise.

[9] As in Heim 1982, variables cannot be reset. So, in addition to formulae containing free variables, quantified sentences are partial updates as well. Since this issue is not directly relevant to the issues discussed in this article, we have passed over it in what proceeds.

Quantificational sentences make use of the environment, but have no influence on these environments themselves. Only *questions* have. The effect of updating context s_e with question $?\vec{x}\phi$ is that the last element in the new environment is a set of possibilities that verify ϕ. If $e = \langle e_1, ..., e_n \rangle$ and $e' = \langle e'_1, ..., e'_m \rangle$ are environments, then $e + e' = \langle e_1, ..., e_n, e'_1, ..., e'_m \rangle$.

5. $s_e[?\vec{x}\phi] = s_{e'}$ where $e' = e + S(s_e[\exists\vec{x}\phi])$.

An update with a quantifier or a question will depend on the last introduced state in the current environment in which the quantified variables are defined. Yes-no questions and answers will depend on the last introduced state.

Finally, we define the operator $\text{only}_{\vec{x}}$ which is analyzed as an asymmetric adverb of quantification. Let $j \prec_{\vec{x}} i$ iff $j \prec i$ and $dom(g_i) = dom(g_j) \cup \{\vec{x}\}$. Let ϕ be of the form $\partial[?\vec{x}\psi_1] \wedge \exists\vec{x}\psi_2$

6. $s_e[\text{only}_{\vec{x}}(\phi)] = \{j \in s \mid \{i \mid j \prec_{\vec{x}} i \;\&\; i \prec S(s_e[\exists\vec{x}\psi_1])\} \subseteq \{i \mid i \prec S(s_e[\phi])\}\}_e$

Disjunction, implication and universal quantifier are defined as standard in terms of conjunction, negation and the existential quantifier.

Topic and sets of propositions From a topic e_k of domain $x_1, ..., x_n = \vec{x}$ in a context s_e we can derive the corresponding 'Hamblin' denotation, $H_k^{s_e}$, or G&S partition, $P_k^{s_e}$, both expressed as a(n equivalence) relation over s.

Definition 1 [Hamblin denotation]

$$H_k^{s_e} = \{\langle i, j \rangle \mid i, j \in s \;\&\; \exists\vec{d} \in D^n : i[\vec{x}/\vec{d}] \prec (s \wedge e_k) \;\&\; j[\vec{x}/\vec{d}] \prec (s \wedge e_k)\}$$

Definition 2 [G&S partition]

$$P_k^{s_e} = \{\langle i, j \rangle \mid i, j \in s \;\&\; \forall\vec{d} \in D^n : i[\vec{x}/\vec{d}] \prec (s \wedge e_k) \;\leftrightarrow\; j[\vec{x}/\vec{d}] \prec (s \wedge e_k)\}$$

Entailment and Support Building on Groenendijk 1998, we define *entailment* in term of subsistence between structured states. By $P(s_e)$ we will denote the partition induced on s by all the topics in e. Let $L(e)$ be the length of e, i.e. if $e = \langle e_1, ..., e_m \rangle$, then $L(e) = m$.

Definition 3 $P(s_e) = \bigcap_{k \in L(e)}(P_k^{s_e})$

Partitions $P(s_e)$ assigned to contexts s_e are equivalent to the structured states σ defined in Groenendijk 1998. We denote by ι the pair $\langle i, j \rangle$ of world-assignment pairs elements of such a structured state. Groenendijk defines *subsistence* between *structured states* in terms of the notion of $\prec$ between world-assignment pairs defined above. A pair $\langle i, j \rangle$ subsists in $\langle i', j' \rangle$, $\langle i, j \rangle \prec \langle i', j' \rangle$ iff $i \prec i' \;\&\; j \prec j'$. This relation between pairs of possibilities carries over to a relation between structured states: $\sigma \prec \sigma'$ iff $\forall\iota \in \sigma : \iota \prec \sigma'$, where $\iota \prec \sigma'$ iff $\exists\iota' \in \sigma' : \iota \prec \iota'$.

We can now define entailment. We denote by `min` the context of *minimal* information $\{(\emptyset, w) \mid w \in W\}_\emptyset$.[10]

Definition 4 [Entailment]

(i) $s_e \models \phi$ iff $P(s_e) \prec P(s_e[\phi])$

(ii) $\phi_1, \ldots \phi_n \models \psi$ iff $\mathtt{min}[\phi_1]...[\phi_n] \models \psi$

Support is defined in terms of *subsistence* between *contexts*, rather than partitioned states. A context s_e subsists in context t_f, $s_e \prec t_f$ iff $s \prec t$ and $e + s \prec f + t$, where an environment e subsists in f, $e \prec f$, iff $\forall f_j \in f : \exists e_i \in e : e_i \prec f_j$. We can now define support.

Definition 5 [Support]

(i) $s_e \approx\!\!\!\!\mid\; \phi$ iff $s_e \prec s_e[\phi]$

(ii) $\phi_1, ..., \phi_n \approx\!\!\!\!\mid\; \psi$ iff min $[\phi_1]...[\phi_n] \approx\!\!\!\!\mid\; \psi$

In terms of support, we define Beaver's (1995) presupposition operator.

Definition 6 [Presupposition]

$$s_e[\partial\phi] = s'_{e'} \quad \text{iff} \quad s_e[\phi] = s'_{e'} \;\&\; s_e \approx\!\!\!\!\mid\; \phi, \text{ undefined otherwise.}$$

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[10] In this semantics, we need the notion of a minimal context. Quantifying over all possible states would lead to a different notion of entailment.

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