Weak Quantifiers and Information Structure[*]

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1. Introduction

In German, there is a systematic ambiguity in the interpretation of so called weak quantifiers[1], correlating to specific intonational patterns:

(1) a   Drei StudENten sind hungrig (existential)
     Three students are hungry
   b   DREI Studenten sind HUNGrig (partitive)

If the noun of the subject quantifier is stressed, the sentence gets an existential reading, which may be translated as *There are three students hungry*.

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[1]Basically, the strong-weak distinction is semantic in nature. I use the term "weak quantifier" here for those quantifiers which may get a existential reading.

If one assumes a modular design of grammar, there are two possibilities to account for this connection between stress pattern and meaning. One way would be to stipulate an interface between the phonology and the semantics module. As an alternative, one might say that there are only two interfaces (namely syntax/phonology and syntax/semantics) and the relevant information is dragged through syntax in one way or another. The latter version is obviously more restrictive. I therefore adopt this view. So let us examine the syntactic behaviour of weak determiners in German.

2. Syntax and Phonology

The distribution of weak determiners in German is nearly identical to that of adjectives. Both kinds of lexical items may occur in combination with the definite determiner.

(2) a   die kleinen Kinder
        the little children
    b   die drei Kinder
        the three children

So weak determiners are obviously not determiners in the syntactic sense of the word. As bare plurals and in adjective+noun constructions, nouns combined with a weak determiner may get a generic reading, a behaviour typical for adjunction structures.

(3)   Zehn Deutsche sind doppelt so dumm wie fünf Deutsche
        Ten Germans are twice as stupid as five Germans

There is a strong and a weak inflectional paradigm for adjectives in German, depending on the determiner of the entire DP.

(4) a   die kleinen Kinder
        the little$_{weak}$ children
    b   kleine Kinder
        little$_{strong}$ children

If weak determiners show overt inflection[2] (for example *viele* "many" or *wenige* "few"), they follow the same paradigm as adjectives.

(5) a   die vielen Kinder
        the many$_{weak}$ children
    b   viele Kinder
        many$_{strong}$ children

The remaining differences in the distribution of "common" adjectives and weak determiners (at most one weak determiner may occur in a string of prenominal adjuncts and it must precede the rest of the string) are most likely semantic in nature. I will not pursue this issue any further here.

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[2] The cardinal numbers do not inflect at all.

These observations lead to the conclusion that German weak determiners are syntactically adjectives, at least in one reading. Since bare AP+NP constructions involving common adjectives get an existential interpretation, (1a) should be analyzed as follows:

(6)   [$_{DP}$ Ø[$_{NP}$ [$_{AP}$ drei] [$_{NP}$ Studenten]]] sind hungrig

(I assume an empty indefinite plural determiner on independent grounds.) As I mentioned above, the difference between (1a) and (b) is represented in syntax. One way to account for this would be to assume a different syntactic structure for (1b).

But there is evidence against this view. Syntactically complex amount expressions, which combine with mass terms, show exactly the same pattern.

(7) a   Eine Menge GELD habe ich schon ausgegeben
         A   lot of money have I already spent
         'I have already spent a lot of money'
     b   Eine MENge Geld habe ich schon ausgegeben
         'A lot of the money I have already spent'

Whatever the syntactic structure of such DPs may be, they obviously do not parallel the subject DPs in (1) syntactically. This forces us to the conclusion, that the contrast in (1) and (7) is a property of amount expressions and not of a specific syntactic configuration. This apparently contradicts the claim that the relevant information is represented syntactically. But there is a way out.

The prosody of a sentence is determined by three kinds of information:

a) lexical information,
b) syntactic structure and
c) focus.

Stipulations about different lexical entries for the weak and the strong reading respectively should be excluded by Occam's Razor. The syntactic structure of both readings is identical, therefore the different intonation turns out to be a matter of focus. Since focus shows both prosodic and semantic effects, my argumentation from the beginning leads to the conclusion that focus is represented syntactically. As a minimal assumption, there is a syntactic feature [+F](ocus), which is freely assigned to some node at S-structure. This assignment is arguably restricted to heads and phrases and [+F] must not dominate [+F]. So (1a) and (b) may be distinguished by different locations of [+F].

Let us examine what the focused constituents in (1) are. As an algorithm for the calculation of the position of focal stress, I use a modified version of the rules in Selkirk('84):

i)   If a [+F]-constituent dominates segmental material, it dominates one accented lexical item and every accented lexical item is dominated by [+F].
ii)   The accented item of a phrase is identical with the accented item of the most deeply embedded argument of the head of the phrase.

iii)   The accented item of a phrase is its head.

iii) only applies if ii) is not applicable. i)-iii) define a unique one-to-one mapping between occurrences of [+F] and pitch accents, provided that [+F] dominates segmental material at all (as we will see later, [+F] may be assigned to empty categories as well). Of course, this proposal is simplified in certain respects, but it will do for my purposes here.
i)-iii) immediately entail that in the DP

(8) $[_{DP} [_{NP} [_{AP} DREI] [_{NP} Kinder]]]$

with an accent on the adjective *drei* either A0 or AP must bear [+F]. Any other assignment of [+F] (including [+F] on a node dominating DP) yields an accent on the noun. Since AP is not branching, the question whether the head or the phrase is focused makes no difference here.

This leads us to the following focus-structures for (1):

(9) a   [+F Drei Studenten sind hungrig]
    b   [+F Drei] Studenten sind hungrig

However, the focus assignment in (9b) is not sufficient to get the partitive reading.

(10)   DREI Studenten sind hungrig
        THREE students are hungry

is interpreted as contrastive (for example *THREE students are hungry and not FOUR*).

(1b) differs from (10b) in that there is additional stress on the predicative adjective "hungrig". So we get the focus structure

(11) $[_{+F}$ Drei] Studenten sind $[_{+F}$ hungrig]

for (1b). This shows clearly that the partitive reading is not a property of the DP but of the entire sentence, a further argument against the assumption of different lexical entries.

But how shall we interpret (11)? As it stands, it is not sufficient for the partitive interpretation either, since one may interpret it as a multiple contrastive focus construction. The structure indicated in (11) would be something like

(12)   DREI Studenten$_i$ sind$_j$ HUNGrig (und nicht: VIER $\_\__i \_\__j$ beim ESsen)
        'THREE students are HUNGry (and not: FOUR   EAting)'

which may receive an existential interpretation. The gapping data (in brackets) show that the stress pattern is indeed a consequence of focus.

The crucial point which distinguishes (1b) and (12) is the fact in (1b) the first accent is realized as a L+H* and the second as H*+L tone (cf. Pierrehumbert/Hirschberg('90)). In (12), both accents are H*+L.

WEAK QUANTIFIERS AND INFORMATION STRUCTURE

What determines whether a given focus is realized as a falling or a rising accent? To answer this question, I adopt a proposal by Krifka('92) who claims that a sentence is partitioned in a first step into a topic part and a comment part. Both parts contain a focus part (which may be an improper part) and a background part (possibly empty). "Comment" and "background" are purely descriptive notions here, names for the material in the respective domain which does not belong to topic or focus respectively. Topic is syntactically represented as a feature [+T], similar to focus. The assignment of these features is governed by the following principles:

a)   At least one constituent (head or phrase) bears the feature [+T].
b)   [+T] must not dominate [+T].
c)   Every [+T]-constituent contains a [+F] and c-commands another [+F].
d)   [+F] must not dominate [+F].

For the sake of simplicity, I identify "comment" with the c-command-domain of the deepest topic. Most likely, this works crosslinguistically only at LF, but in German S-structure and LF are more or less identical as far as topic is concerned.

An immediate consequence of these rules is that the entire focus domain (topic or comment respectively) may be focused as a whole, which is a reconstruction of the pretheoretic notion of "neutral stress".

For the prosodic interpretation of [+T] we need two additional rules besides i)-iii):

iv)   The [+F] contained in [+T] are mapped to an L+H* pitch accent.
v)   The [+F] c-commanded by all [+T] are mapped to an H*+L pitch accent.

Now we are ready to give the necessary and sufficient structure for the partitive reading.

(13)   [$_{+T}$ [$_{+F}$ Drei] Studenten] sind [$_{+F}$ hungrig]

It is easy to see that this is the only way to get the observed intonation. As for additional evidence, one may look at Japanese data, where topic constituents are marked with a particle *wa*, while non-topic subjects are marked with the nominative particle *ga*.

(14) a soto   de kodomo **ga**   san- nin asonde iru
        outside lok children nom 3   class   playing are
        'There are three children playing outside'
     b san- nin no kodomo **wa** soto   de asonde iru
        3   class attr children top outside lok playing are
        'Three of the children are playing outside'
  (data from Löbner '90)

To sum up, the partitive reading of a weak quantifier arises if and only if the quantifier is a topic and the determiner bears a narrow focus. This generalization presumably holds for any language where such ambiguity is observed.

The single pitch accent in (1a) is realized as H*+L. So the question arises whether there is

any topic in this sentence at all. Semantic considerations lead me to the assumption that in so called thetic sentences without any overtly realized topic, referential time should count as topic. Syntactically, [+T] is assigned to some empty temporal adverb in SpecTP, which must be simultaneously bear [+F] to fulfill the wellformedness conditions for the distribution of [+T] and [+F]. So at least at LF we get the following possible information structures for (1a):

(15)   [$_{+T}$ [$_{+F}$ *referential time*]] [$_{+F}$ Drei Studenten sind hungrig]

3. Semantics

It is obvious that some contextual information is necessary to account for the semantic impact of information structure. Instead of extending traditional semantic frameworks with more or less arbitrary tools for the treatment of context information, it is reasonable to use a dynamic setup, where context is the basic notion of semantic analysis. Generally, in Dynamic Semantics the meaning of a sentence is seen as an update function, which maps an input epistemic state (or, equivalently, an input context) to an output state. An epistemic state is (or represents) partial knowledge about the world. In the first place, a context contains only information about a subset of the individuals in the domain of the model. This partial domain is sometimes called "Universe of Discourse". In the second place, the knowledge about the properties of and the relation among this individuals is partial too.   Following Groenendijk et al.('94), complete knowledge about a given context domain is called a "possibility". To account for the partiality of this kind of information, a context is a **set of possibilities** which share their domain .

Sentences are interpreted as **updates** or functions over contexts. An update may either introduce new discourse referents into the context domain or it may eliminate possibilities and therefore increase the knowledge about the domain. In recent dynamic theories like DRT or Dynamic Predicate Logic, it is assumed that indefinites introduce new elements ("discourse referents") into the context domain, while definites or pronouns pick up referents already present in the input context. On the other hand, the intuitive content of the notion "topic" is that the interpretation of the respective constituent ranges over objects familiar in the context. This leads us to the expectation that the topic/comment dichotomy can be reduced to the notion of (in-)definiteness (or vice versa) in some way or another. But this assumption is not supported by the facts. Both definite and indefinite DPs may occur in either the topic part or the comment part of a sentence.

(16) a [$_{topic}$ The PRINTer] [$_{comment}$ is out of WORK]
       b   [$_{comment}$ The PRINter is out of work]
(17) a [$_{topic}$ THREE children] [$_{comment}$ are in the GARden]
       b   [$_{comment}$ Three CHILDren are in the garden]

In (16) the subject is definite, in (17) indefinite. The a-examples are categorical (subject = topic), the b-examples thetic. Each of the four possible combinations are fully acceptable. But the indefinite *three children* in (17)a does introduce some entity into the discourse.

(18) a THREE children$_i$ are in the GARden. They$_i$ are happy.
      b   *They$_i$ are happy. THREE children$_i$ are in the GARden.

On the one hand, the referents of *three children* belong to the entities familiar in the context. On the other hand, you cannot refer to them by means of a pronominal anaphor before they are explicitly mentioned by a indefinite DP (cf.(18b)). So in some sense indefinite topics merely **activate** old discourse referents instead of introducing them. The introduction of d(iscourse)-referents is done by indefinites which belong to the comment as does the subject in (17b). Therefore we have to distinguish between two nested contextual domains:

(a) the context domain as a whole, which is the resource domain for the interpretation of topics and, so I suspect, the domain for adverbial quantification (in Groenendijk et al.('94) the elements of this domain are called "pegs") and

(b) the domain of **active** d-referents, which is the resource domain for the interpretation of anaphors (ordinary variables in the system described so far).

Every variable is mapped to a peg, but there may be inactive pegs which are the value of no variable.

Following Vallduví('92), I assume that information structure does not affect truth conditions. The notion of truth is not crucial in dynamic semantics, but there is a kind of counterpart. Remember that the interpretation of a sentence is an update function. This function is a **partial** function from the set of contexts **into** the same set. This means that there are nontrivial restrictions on the domain and the range of an update. The input restrictions are comparable to the traditional notion of "presupposition", the output restrictions correspond to truth conditions. Therefore the Predicate Logic translations of (17a) and (b)

(19) a top[$\exists$x.*children*(x) $\land$ *card*(x) = 3] $\land$ $\exists$t.*present*(t) $\land$ *in_the_garden*(x,t)[3]
      b   top[$\exists$t.*present*(t)] $\land$ $\exists$x.*children*(x) $\land$ *card*(x) = 3 $\land$ *in_the_garden*(x,t)

have the same output conditions, which are represented in the **Context Representation Structure** (CRS) in (20) (the technical details are left to the appendix).
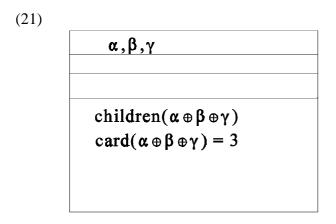
(20)

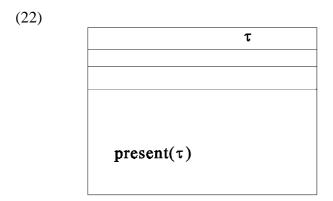| α, β, γ	τ
x	t
x --> $\alpha \oplus \beta \oplus \gamma$, t --> τ	
children($\alpha \oplus \beta \oplus \gamma$) card($\alpha \oplus \beta \oplus \gamma$) = 3 present($\tau$) in_the_garden($\alpha \oplus \beta \oplus \gamma,\tau$)	

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[3]The operator "top" is the semantic counterpart of the syntactic feature [+T]. The definition is given in the appendix. I ignore focus at this point.

The Greek letters in the first line represent the pegs. The second line contains the variables and the third the mapping from variables to pegs. The body of the box contains conditions on the interpretation of the pegs which any of the possibilities in a context must fullfill.

The topic-operator requires that the material in its scope neither introduces new pegs nor new conditions. The only new entities permitted are variables. Therfore in (19a) both the pegs α, β and γ and the condition that they represent three children must be part of the input information. According to this, the minimal input for (19a) is at least as in (21).

(21)

α, β, γ
$\text{children}(\alpha \oplus \beta \oplus \gamma)$ $\text{card}(\alpha \oplus \beta \oplus \gamma) = 3$

The pegs α, β and γ are inactive her and connot be picked up by an anaphor. In (19b), the referential time is topic and therefore already present in the input:

(22)

τ
$\text{present}(\tau)$

The CRS in (20) represents the result of updating either (21) with (19a) or (22) with (19b).

This much about the semantic import of topic. Now we have to take focus into account. It is widely accepted that focus generates a set of alternatives to the "ordinary" interpretation of the sentence. These alternatives are created by replacing the interpretation of the focused constituent with a item which is (i) in some sense comparable to the replaced material and (ii) salient in the context. I do not want to discuss, what comparability actually is. Besides identity of the logical type, I think sortal identity is required too. Alternatives to the focus of the topic in (17a), the cardinal adjective *three*, are arguably other cardinal modifiers. If the focus is bound, the focus sensitive operator determines the semantic/pragmatic import of these alternatives. If the focus is free as in our examples, the alternatives are used by pragmatic felicity conditions, which presumably depend on the illocutionary role of the utterance (cf. Krifka('92)). By uttering an

assertive sentence, the speaker forces the hearer to believe that the alternatives are presumably false, as it is illustrated in the following examples:

(23)   The BUTler is the murderer ⇝ The gardener is not the murderer
(24)   John drives a PORsche ⇝ John does not drive a Mercedes

Since the present semantic framework is a monotonic one, this kind of defeasible inference is not expressible. Instead of "presumably false" I therefore use the weaker notion of "possibly false", which says that updating with the negation of a given update does not lead to a contradiction. Obviously the excluded alternatives should be possible in the input state of the hearer; otherwise this restriction is trivially met. Another point is that we do not know what alternatives are salient in an actual context. But I think it is legitimate to assume that there is at least one alternative which is affected by the felicity conditions. Otherwise focusing would be useless. Therefore I propose the following felicitiy conditions for assertive sentences:

If the update α is the interpretation of an assertive sentence and ϕ the interpretation of a focused constituent of that sentence, than α is a felicitous update in a context ct iff there is at least one alternative $\alpha[\phi'/\phi]$ to α such that ϕ' is comparable to ϕ and salient in ct and
i) $ct \vDash \Diamond \alpha[\phi'/\phi]$
ii) $ct[\alpha] \vDash \Diamond \neg \alpha[\phi'/\phi]$ [4]

Now let us turn to our example (17a), which is repeated here.

(25) a $[_{topic}$ THREE children] $[_{comment}$ are in the GARden]
      b $top[\exists x.children(x) \wedge card(x) = 3] \wedge \exists t.present(t) \wedge in\_the\_garden(x,t)$
      c $top[\exists x.children(x) \wedge card(x) = n] \wedge \exists t.present(t) \wedge in\_the\_garden(x,t)$

The interpretation of (25a) is (25b). Since the cardinal adjective *three* is in focus, there must be some natural number n such that (25c) fullfills the mentioned felicity conditions. The second one requires that the output context (20) fullfills the requirement that

(26) $(20) \vDash \Diamond \neg top[\exists x.children(x) \wedge card(x) = n] \wedge \exists t.present(t) \wedge in\_the\_garden(x,t)$

Suppose that n is smaller than or equals 3. In (20) it is **known** that there are three children playing in the garden. Therefore (25c) is not a possible update in (20) and (26) cannot be fullfilled. This leads to the conclusion that n must be greater than 3.

The first condition says that (25c) is a possible update in the input. (21), the minimal input for (25b), as it stands does not meet that requirement, since there must be n pegs in the input which are known to be children, and n is greater than 3. Therefore we have to extend (21) with a fourth child-peg to make it a felicitous input.

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[4] $\alpha[\phi'/\phi]$ is the update we get by replacing ϕ in α by ϕ'. $ct[\alpha]$ is the output context reached after updating ct with α.

(27) a   b

α,β,γ,δ
$children(\alpha \oplus \beta \oplus \gamma \oplus \delta)$ $card(\alpha \oplus \beta \oplus \gamma) = 3$

α,β,γ	δ	τ
x		t
$x \longrightarrow \alpha \oplus \beta \oplus \gamma$, $t \longrightarrow \tau$		
$children(\alpha \oplus \beta \oplus \gamma \oplus \delta)$ $card(\alpha \oplus \beta \oplus \gamma) = 3$ $present(\tau)$ $in\_the\_garden(\alpha \oplus \beta \oplus \gamma, \tau)$ $\Diamond \neg in\_the\_garden(\delta, \tau)$		

(25a) is only felicitous in a context which is an extension of (27a). The resulting context is an extension of (27b). It can easily be seen that (27a) represents exactly the presupposition which (25a) intuitively has.

Things work similar in (17b), which is repeated as (28).

(28) a [$_{+T}$ [$_{+F}$ *referential time*]][$_{comment}$Three CHILDren are in the garden]
   b   top[$\exists t.present(t)$] $\wedge$ $\exists x.children(x) \wedge card(x) = 3 \wedge in\_the\_garden(x,t)$
   c top[$\exists t'.tense(t')$] $\wedge$ $\exists x.children(x) \wedge card(x) = 3 \wedge in\_the\_garden(x,t')$

As I mentioned above, I suppose that referential time is the topic of thetic sentences. Since tense, as a non-branching node in syntax, bears the focus feature as a whole, alternatives to it may be any temporal specification, as indicated in (28c). According to the first felicity condition, (28c) must be a possible update in every context where (28a) is felicitous. Therefore some temporal peg besides the actual referential time τ must be available in the input context such that it is possible that there are three children in the garden at that time too. In the context obtained after processing (28a), it must be possible that there are no three children in the garden at that time. In particular, it must be possible that the three children under discussion are not in the garden at the alternative time.

(29) a   b

	τ	υ
present(τ), tense(υ)		

α,β,γ	τ	υ
x	t	
x --> $\alpha \oplus \beta \oplus \gamma$, t --> τ		
children($\alpha \oplus \beta \oplus \gamma \oplus \delta$) card($\alpha \oplus \beta \oplus \gamma$) = 3 present($\tau$), tense($\upsilon$) in_the_garden($\alpha \oplus \beta \oplus \gamma$,$\tau$) $\diamond \neg$in_the_garden($\alpha \oplus \beta \oplus \gamma$,$\upsilon$)		

So (28a) maps a context which fullfills the conditions in (29a) into a context which fullfills the conditions in (29b). The nontrivial point in (29) is that a thetic sentence like (28a) must be at least potentially temporally contingent. This implies that the existential reading of weak quantifiers (and thetic sentences in general) disallow individual level predicates in the sense of Kratzer('89) and Diesing('92). Let us take an example.

(30)   a*[$_{+T}$ [$_{+F}$ *referential time*]][$_{comment}$Two STUdents are intelligent]
     b   [$_{+T}$[$_{+F}$TWO] students] [$_{comment}$ are inTELligent]

(31) a   b

α,β		τ	υ
x		t	
x --> $\alpha \oplus \beta \oplus \gamma$, t --> τ			
students($\alpha \oplus \beta$) card($\alpha \oplus \beta$) = 2 present(τ), tense(υ) intelligent($\alpha \oplus \beta$,τ) $\diamond \neg$intelligent($\alpha \oplus \beta$,υ)			

α,β	γ	τ
x		t
x --> $\alpha \oplus \beta$, t --> τ		
students($\alpha \oplus \beta$) card($\alpha \oplus \beta$) = 2 present(τ) intelligent($\alpha \oplus \beta$,τ) $\diamond \neg$intelligent(γ,τ)		

(31a), the output of (30a), is obviously not consistent. If you know that α and β are intelligent at time τ, you know that they are intelligent at any time. Therefore it is **not** possible that they are not intelligent at time υ. This predicts correctly that (30a) is ungrammatical if you take *intelligent* as a individual level predicate. On the other hand, there is nothing wrong with (31b), the output of (30b). Hence the partitive reading is possible with either stage level or individual level predicates.

4. Conclusion

To conclude, the prosodic patterns of existential vs. partitive weak quantifiers in German indicate a different information structure. The interaction of topic and focus constrains the domain of information states a sentence can be felicitously updated to. Semantically, both readings of weak quantifiers are uniformly existential. The different interpretations arise because of the different pragmatic import of information structure. Therefore, neither different lexical entries nor *ad hoc* stipulations about the syntactic structure are necessary to explain the relevant facts.

Since the information which is required to interpret information structure is heavily context dependent, it is reasonable to use a dynamic framwork, where the notion of context is central and not an additional complication as in traditional (static) semantics. To deal with the intuitive old/new dichotomy which characterizes both the definite/indefinite and the topic/comment distinction, I decided - following Groenendijk et al.('94) - to assume two nested contextual domains. The first one is the domain of discourse referents in general (pegs) which restricts the interpretation of topics. As a subset, there are active referents (variables), that anaphors may refer to. This division of labour allows to characterize the partitive weak quantifiers as "indefinite topics" without running into a *contradictio in adjecto*.

The Felicity Conditions for the interpretation of focus do not only account for the partitive reading of weak quantifiers, they predict (together with the plausible assumption that referential time is the topic of thetic sentences) that individual level predicates are excluded in thetic sentences. As I showed in Jäger('92), this is the key generalization to account for the stage/individual level contrasts observed by Kratzer and Diesing without *ad hoc* stipulations about argument structure or syntax.

5. Appendix: Dynamic Modal Predicate Logic with Referent System and Plural

Syntax

The Syntax of DMPL is the syntax of Modal Predicate Logic with an additional propositional Operator "**top**" and an one-place functor "card".

Model for DMPL

$\mathcal{M} = \langle U, W, \mathcal{F} \rangle$

U, the universe of the model, is some denumerable infinite set.

W is the nonempty set of possible worlds.

The Interpretation Function $\mathcal{F}$ maps the constants of DMPL to intensions in the usual way. Besides this, there is an derived interpretation function $^*\mathcal{F}$, which shifts the extension of a constant from individuals to sets:

For all $w \in W$:

$^*\mathcal{F}(c,w) \doteq \{ ^*\mathcal{F}(c,w) \}$ iff c is an individual constant and

$^*\mathcal{F}(P,w) \doteq \{ \langle \alpha_1,...,\alpha_n \rangle | \forall x_1,...,x_n[x_1 \in \alpha_1,...,x_n \in \alpha_n \rightarrow \langle x_1,...,x_n \rangle \in \mathcal{F}(P,w)] \}$ iff P is an n-ary predicate constant.

Possibilities

$\langle v,n,r,g,w\rangle$ is a possibility iff
v is a finite set of variables of DMPL,
n is a natural number[5] such that $|v| < 2^n$,
r is a total function from v into nonempty subsets of n,
g is a total one-to-one function from n into U,
$w \in W$.

$\langle v,n,r,g,w\rangle \le \langle v',n',r',g'w\rangle$ iff
$\qquad v \subseteq v' \wedge n \le n' \wedge r \subseteq r' \wedge g \subseteq g'$.

Contexts

ct is a context iff ct is a set of possibilities and there is a set of variables v such that:
$\forall i[i \in ct \rightarrow \exists n,r,g,w: i = \langle v,n,r,g,w\rangle]$

This ensures that all possibilities in a context share the variables defined.

$ct \le ct'$ iff $\forall i[i \in ct' \rightarrow \exists j : j \in ct \wedge j \le i]$

Semantics of DMPL

Following the usual convention, I write $ct[\varphi]$ instead of $[\varphi](ct)$.
Some further abbreviations:

a) $\langle v,n,r,g,w\rangle(\alpha) \doteq$ ${}^*\mathscr{F}(\alpha,w)$ iff α is a constant,
$\qquad\qquad\qquad\qquad \{g(x)|\ x \in r(\alpha)\}$ iff $\alpha \in v$,
$\qquad\qquad\qquad\qquad \{g(x)|\ x \in \alpha\}$ iff $\alpha \subset n$,
$\qquad\qquad\qquad\qquad$ undefined elsewhere.

b) $\langle v,n,r,g,w\rangle[x] \doteq \{\langle v_x,n+m,r[x/m],g',w\rangle|\ m \in \mathbb{N} \wedge g' \in g_m\}$
c) $v_x \doteq v \cup \{x\}$
d) $r[x/m] \doteq \lambda y.\iota z[x \ne y \rightarrow z = r(y) \wedge x = y \rightarrow z = (n+m)\backslash n]$
e) $g_m \doteq \{g \cup \{\langle n,d_1\rangle,...,\langle n+m-1,d_m\rangle\}|\ d_1,..d_m \in U\}$
f) $ct[x] \doteq \bigcup_{i \in ct} i[x]$
g) $ct'\backslash ct \doteq \{i|\ j \in ct' \wedge k \in ct \wedge k \le j \wedge i \in j\backslash k\}$ iff $ct \le ct'$, undefined elsewhere.
h) $\langle v',m,s,h,w\rangle\backslash\langle v,n,r,g,w\rangle \doteq \{\langle v',n,r',g,w\rangle|\ \forall x[x \in v \rightarrow r'(x) = r(x) \wedge$
$\qquad\qquad\qquad\qquad\qquad\qquad x \in v'\backslash v \rightarrow r'(x) \subset n \wedge$
$\qquad\qquad\qquad\qquad\qquad\qquad \{g(y)|\ y \in r'(x)\} = \{h(y)|\ y \in s(x)\}]\}$

i) $\qquad ct[P(\alpha_1,...,\alpha_m)] = \{i \in ct|\ \langle i(\alpha_1),...,i(\alpha_m)\rangle \in i(P)\}$

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[5]A natural number is set-theoretically defined as the set of natural numbers smaller than n. 0 is defined as the empty set.

ii) $ct[\phi \wedge \psi] = ct[\phi][\psi]$
iii) $ct[card(\alpha) = n] = \{i\in ct|\ |i(\alpha)| = n\}$
iv) $ct[\neg\phi] = \{i\in ct|\ \neg\exists j: j\in ct[\phi] \wedge i\leq j\}$
v) $ct[\phi\vee\phi] = ct[\neg(\neg\phi\wedge\neg\psi)]$
vi) $ct[\phi\rightarrow\psi] = ct[\neg(\phi\wedge\neg\psi)]$
vii) $ct[\exists x\phi] = ct[x][\phi]$
viii) $ct[\forall x\phi] = ct[\neg\exists x\neg\phi]$
iv) $ct[\Diamond\phi] = \{i \in ct|\ ct[\phi] \neq \varnothing\}$
x) $ct[\Box\phi] = ct[\neg\Diamond\neg\phi]$
xi) $ct[\textbf{top}\phi] = (ct[\Box\phi][\phi])\backslash ct$

Context Representation Structures
A **CRS** is a 4-tupel $\langle V,P,R,Con\rangle$ such that:
- V is a finite set of DMPL variables,
- P is a finite set of peg-variables (written as Greek letters),
- R is a one-to-one function from V into $\oplus P$ (the closure of P under $\oplus$)
- Con is a set of CRS-conditions.

$x \in \oplus \textbf{P}$ iff
- $x \in P$ or
- $x = y\oplus z$ and $y,z \in \oplus P$

An **Atomic CRS-condition** is a pair of an n-ary DMPL-predicate and an n-tupel of elements of $\oplus P$.
An **Modal CRS-condition** is a sequence of "$\Diamond$" and a atomic CR-condition.
A **CRS-condition** is either an atomic or a modal CR-condition.

The **$\oplus$-closure** of a function f from P into n is the function $\oplus f$ from $\oplus P$ into 2^n such that for all $x,y\in \oplus P$:
- $\oplus f(x) = \{f(x)\}$ iff $x \in P$,
- $\oplus f(x\oplus y) = \oplus f(x) \cup \oplus f(y)$.

A context ct **supports** an atomic CRS-condition $P(x_1,...,x_m)$ under f iff :
     $\forall i\in ct: \langle(i(\oplus f(x_1)),...,i(\oplus f(x_m))\rangle \in i(P)$.
A context ct **supports** a modal CRS-condition $\Diamond P(x_1,...,x_m)$ under f iff :
     $\exists i\in ct: \langle(i(\oplus f(x_1)),...,i(\oplus f(x_m))\rangle \in i(P)$.

A CRS $\langle V,P,R,Con\rangle$ **represents** a context ct iff for all $\langle v,n,r,g,w\rangle \in ct$:
a) $V \subseteq v$,
b)   there is a one-to-one function f from P into n such that $\forall x[x\in V \rightarrow r(x) = \oplus f(R(x))]$,
c)   ct supports every element of Con under f.

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7. References

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