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STATIC SEMANTICS FOR DYNAMIC DISCOURSE

One important development in semantics in the last twenty years, a development which has been very well chronicled in *Linguistics and Philosophy*, has involved the claim that semantics should be 'dynamic'. By this is meant that the meaning of a sentence should be thought of not so much in terms of its truth conditions as in terms of the 'potential to change truth conditions'. It is therefore timely, in this anniversary issue, for some critical reflections on the motivation for this change. Dynamic semantics begins with the fact that the utterance of a sentence is never in a vacuum, but is always in terms of a background set of assumed individuals, or assumed information, or an assumed time or location. Further, the utterance of the sentence has the power to change the background. The purpose of this article is not to advance any of the technical issues pursued in 'discourse representation theory' or 'dynamic Montague grammar' or whatever, but rather to question the need for any change in the basic aims of semantics. I will try to show that, while there are many semantic phenomena which have been insightfully addressed by those working in these and allied frameworks, they none of them need to be essentially linked with a 'dynamic' view of semantics.

[1] Thus Groenendijk and Stokhof (1991, p. 43): "The general starting point of the kind of semantics that DPL is an instance of, is that the meaning does not lie in its truth conditions, but rather in the way it changes (the representation of) the information of the interpreter". Hardt (1999, p. 187): "A major insight of dynamic semantics is that sentences have a systematic relation to context in two ways: not only are they evaluated with respect to the current context, but they also systematically change that context". And Chierchia (1992, p. 131): "the semantic contribution of a sentence is not just the presenting of a content, but also that of changing the information of the interpreter through that content". Also the first paragraph of Veltman (1996). Much in these passages is harmless, but the impression is given that traditional truth-conditional semantics does not already have this aim. In this paper I do not pretend to give anything like a full survey of the literature on these matters, since my aim is limited to considering whether there is a sense in which this work can be called 'dynamic' in a way which implies a change in the aims of semantics from the traditional truth-conditional model, as argued for in say Cresswell (1978). Where I do refer to the literature I have tried to concentrate on articles which have appeared in *Linguistics and Philosophy*. Most of these have extremely full reference lists which will give pointers to those who wish to follow up these matters.

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1. The Pragmatics of Discourse

There is a story told about Winston Churchill addressing the US congress just after the second world war, when Britain was in debt to the United States. The interchanges went (if I recall correctly[2]) something like this:

(1) CHURCHILL: I have not come to ask for money
(loud applause – long pause)

(2) CHURCHILL: for myself.
(short pause – then laughter)

Churchill, I understand, got relief from the debt that Britain owed to the United States. What then is the correct semantics for the interchange in (1) and (2)? I shall first set out an answer which I'll label the answer given by *static* semantics. On this answer meanings are assigned to *sentences*, and on this occasion there are two sentences involved

(3) I have not come to ask for money.

and

(4) I have not come to ask for money for myself.

Assume that meaning is about truth conditions, and assume a context in which 'I' is Churchill, the time is, say 1945, and it is the US congress which is being addressed. Then the meaning of (3) in this context is

(5) Churchill has not come in 1945 to ask the US congress for money.

[2] I no longer remember where I read this story, though no doubt public records would make it easy to verify. Even if it is not true it still makes my point.

In possible worlds semantics it is the set of possible worlds[3] in which Churchill is not asking the US Congress in 1945 to provide money. The meaning of (4) in the same context is the set of possible worlds in which Churchill is not asking the US Congress in 1945 to provide money for Churchill. Two sentences – two meanings. The question is what to make of the connection between the two sentences (3) and (4), and the utterances (1) and (2). The answer, according to static semantics, is straightforward. The US congress applauded after (1) because they interpreted (1) as an utterance of the sentence (3) and applauded on that basis. When Churchill, a master of timing, continued with (2) the congress realised that what Churchill had come to assert was (4). Realised, after a pause while they processed this fact, that they had been fooled, and appreciated Churchill's wit and timing. They also drew the inference that in fact he *had* come to ask for money, but admired his skill so that they were softened up to forgive the debt.

This account involves a *pragmatic* story. The question is whether (1)/(2) should determine (3) or (4) *semantically*. Look more closely at (5). The reason that a pragmatic account of how to obtain (5) from (3) is implausible is quite simple. It is a matter of *linguistic* knowledge that ***I*** in (3) leads to ***Churchill*** in (5), and so on. The case of (1)/(2) seems intuitively quite different. Here is an account of how the 'pragmatics' of (1)/(2) makes no reference to English. There is a sentence $\alpha\beta$, where α is an initial segment and β is the rest. There is a complex utterance u, which consists of an utterance of α followed by a pause followed by an utterance of β. During the pause the audience processes, and understands the truth conditions of α, and applauds the utterer. The continuation makes them realise that $\alpha\beta$ is the intended sentence, and they process that, and appreciate the performance. This is of course no more than the account I gave of the processing of (1)/(2), where (3) is α, and (4) is $\alpha\beta$. I repeat it here because it is a

[3] I am assuming here a possible-worlds version of truth-conditional semantics. It is of course vital to understand the truth-conditional view of semantics in its possible-worlds version as requiring meanings to be somewhat like what I once (Cresswell 1973, p. 112) called 'open propositions' – functions from contexts to sets of possible worlds. In that work a context of use was understood very generally as a property of utterances. Chapter 4 of Montague (1974) envisages 'pragmatics' as a generalization of logics like tense, modal and deontic logics, whose defining feature is that truth holds at an 'index' or 'point of reference' (*op cit*, p. 98). Montague writes "It is not necessary to consider them in their full Complexity". His point is that for tense logic the index can just be a time, for modal logic just a world, etc., but he clearly has in mind that the general framework of pragmatics should impose no restrictions on what they might be, and that a context of use is whatever it takes to determine truth conditions. Chapter 3 of Montague (1974) was originally published in 1968, but in the footnote on p. 95 Montague explains that it is based on a talk he gave in 1964, and states on p. 96 that the work was initiated in 1959.

dynamic account of the discourse. It acknowledges that the interpretation of the utterance of β does not treat it as an isolated phrase, but as the completion of $\alpha\beta$. The moral of course is that a dynamic interpretation of the *discourse* is perfectly compatible with a ‘static’ interpretation of α and $\alpha\beta$, and that the dynamic interpretation of the discourse is not part of semantics – at least for this example.

2. ANAPHORA

Perhaps the principal concern of dynamic semantics has been in the realm of pronouns and anaphora. Consider the following discourse:

(6) SPEAKER: A cat entered.
(pause)

(7) SPEAKER: It purred.

The discussion of (1)/(2) has shown that a pragmatic story is needed *before* you get to a sentence on which the semantics can work. The simplest way of forming a single sentence out of a discourse is by conjoining the separate sentences. In this case one could argue, in a manner parallel with (1)/(2), that (6)/(7) is to be analysed semantically by obtaining the truth conditions of the two sentences:

(8) A cat entered.

and

(9) A cat entered and it purred.

When (6) occurs the audience, like the US congress, thinks that what has occurred is an utterance of (8), and process it accordingly. After the pause and the occurrence of (7), the audience realises that the sentence (9) is intended, and processes it accordingly. This phenomenon seems exactly analogous to (1)/(2). If that is so then there would seem no more problem with the *semantics* of (6)/(7) than with (1)/(2). But matters are not quite so simple. In the first place (9) adds a new word ***and***, and ***and*** does not occur in (6)/(7). Juxtaposition of separate sentences need not always be interpreted conjunctively. To adapt an example from Groenendijk and Stokhof

(1991 p. 91), the following sequence of sentences can easily be interpreted as a conditional with the first sentence as antecedent:

(10) A client turns up. You treat him politely. You offer him a cup of coffee. You ask him to wait.

One has to say here that the ***and*** in (9) is doing duty for an element which does not reach the surface in (6)/(7) – rather in the way that pronouns and indefinite phrases are often annotated with subscripts to indicate co-reference. No one supposes that these have a surface realisation, but they are needed for the purpose of semantic interpretation. But perhaps more important is the semantics of (9) itself. It is often held that there is an important syntactic difference between a sentence like (9) and

(11) A cat entered and purred.

It is claimed that while

(12) Every cat entered and purred.

is perfectly in order

(13) ?Every cat entered and it purred.[4]

is not. And the negative cases also seem to show a difference.

(14) No cat entered and purred.

is much happier than

(15) *No cat entered and it purred.

which, if interpretable at all, does not mean the same as (14). If this is right then the problem about (6)/(7) does not arise at the pragmatic level. Pragmatics takes you from (6)/(7) to (9), and from a discourse like

(16) SPEAKER: A cat entered.

(pause)

(17) SPEAKER: and purred.

[4] Heim (1983 p. 180) notes the oddness of 'Every soldier is armed. He will shoot.' See also Cresswell (1988, p. 167). I don't find it as bad as most linguists seem to, but I do agree that (12) is more natural than (13). ';' is often used in place of ***and*** for concatenation (see e.g., Muskens (1996, p. 150)). For more on concatenation see footnote 8 below.

to (10). The semantic problem is what to do with these sentences when you have got them. One way of representing the difference between (8) and (9) would be as

(18) $\exists x(\boldsymbol{cat}\ x \wedge \boldsymbol{entered}\ x)$

and

(19) $\exists x(\boldsymbol{cat}\ x \wedge \boldsymbol{entered}\ x \wedge \boldsymbol{purred}\ x)$

(I ignore tense here, and assume that these wff of regular predicate logic will be embedded in an intensional language in the usual way.) In (18) the quantifier $\exists$ ranges over the variables in two conjuncts, while in (19) its scope is extended to cover a third conjunct. Suppose, however, that it is claimed that, while (19) may provide a syntactically acceptable analysis of (10), the syntax of (9) as a paraphrase of (6)/(7) requires not (19) but

(20) $\exists x(\boldsymbol{cat}\ x \wedge \boldsymbol{entered}\ x) \wedge \boldsymbol{purred}\ x$

The problem then becomes how a quantifier can bind a variable which is not in its syntactic scope.

Among theories linked with a dynamic semantics are Heim 1983's 'file change semantics' and Kamp 1983's 'discourse representation theory'. Stripped of their metaphors in terms of a clerk updating files or a reader/hearer representing information in a 'discourse representation structure' or 'box', these theories claim that what appears to be an existential quantifier like ***a cat*** is really just a predicate, so that (6) is represented by

(21) $\boldsymbol{cat}\ x \wedge \boldsymbol{entered}\ x$

while (7) is represented by

(22) $\boldsymbol{purred}\ x$.

One then says that the discourse (in this case (6)/(7)) is *satisfied* iff there is some assignment to the variables, in this case x, which makes both (6) and (7) true. This in fact gives the same truth conditions as (19). If (6) is considered to be the whole discourse, then the discourse would be satisfied if (21) alone is satisfied by some assignment, which would give the truth conditions of (18). It is worth reflecting on the use of free variables in semantic representation. Consider the sentence

(23) Every boy brought a sister.

On at least one reading (23) entails that the sister is a sister of the boy in question. If this relativity is expressed explicitly you would get something like

(24) $\forall x(\textbf{\textit{boy}}\ x \supset \exists y(\textbf{\textit{sister}}\ yx \wedge \textbf{\textit{brought}}\ xy))$

where ***sister*** has an extra argument place to indicate that y is a sister of x. (24) does not contain any free variables but in

(25) That is the sister.

the representation, using explicit variables, might be something like

(26) $\textbf{\textit{sister}}\ xy$.

If (25) is interpreted as (26) the context would include an assignment μ to the variables, and (26) will be true in that context iff $\mu(x)$ is $\mu(y)$'s sister.

My concern is not whether explicit free variables are a good way to represent context dependence.[5] They may be or they may not. But they are a possible way to do so, and are equivalent to indexical ways. Our question is whether this can be called 'dynamic'? Well of course (26), like (21) and (22), does not have truth conditions in isolation, but only once values have been supplied for its free variables. In that sense the ordinary predicate calculus is dynamic. Perhaps what is meant is that there are a lot more hidden 'variables' in natural language that we may have supposed. That too is true, but it does not cause a revision of the aims of semantics. In short, phenomena that can be dealt with via assignments to the variables in a standard logical language do not give any support for thinking that semantics is not about the determination of truth conditions of sentences, and give no support to a semantics of discourse over and above a semantics of sentences.

[5] It is no part of this paper to take sides on whether context dependence should be represented by assignments to variables or should be provided by a semantical index. In Cresswell (1996) I tried to articulate the indexical approach and that view has been advocated by others for syntactical reasons. See especially Jacobsen (1999), Steedman (1988) and Szabolcsi (1987). Tense is an especially interesting case here. The indexical semantics suggested for ***and then*** mentioned at the end of the discussion of (79) below treats times as semantical indices, but at least one study of tense (Taylor 1977) treats the time index as a variable in the syntax. Montague (1974, p. 228), notes that assignments to free variables are a form of context dependence, though he assimilates them to demonstratives. Lewis (1972) speaks of an index as a 'coordinate' and on p. 175 explicitly includes an 'assignment coordinate' as one of the contextual coordinates.

3. Dynamic Predicate Logic and '*namely*' Variables

The theories developed by Kamp and Heim ask us to ignore the fact that indefinite noun phrases look like existential quantifiers.[6] What I want to do now is look at the approach based on the 'dynamic predicate logic' developed in Groenendijk and Stokhof (1991) in which the surface existential phrases are claimed to be genuine existential quantifiers, but in a non-standard logic. There is in English a certain use of the word 'namely'. Go back to (8). If the cat who entered is Bunthorne then one can say

(27) A cat (namely Bunthorne) entered.

That suggests understanding the sentence in the following way. An atomic sentence like

(28) It entered.

becomes

(29) It (namely Bunthorne) entered.

which can be expressed semi-formally as

(30) It = Bunthorne $\wedge$ it entered.

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[6] By treating what appear to be existential quantifiers, like the ones which appear in (58) and (59) below, simply as predicates, discourse representation theory leaves open the question of why they should appear to be quantifiers. Why should it happen that however you try to turn an indefinite existential phrase into a quantifier you cannot do so? (For some additional arguments that these phrases are quantifiers, see Chierchia (1992, p. 118f).) This has led some to advocate a quite different analysis of pronouns whereby say the 'it' in (7) goes proxy for a description like ***the cat who entered***. This is often called the *E-type* analysis (after Evans (1977)) and has been developed in Cooper (1979), Heim (1990), Neale (1991), Lappin and Francez (1994), and others. One version of this approach claims that expressions such as ***a cat*** are quantifiers evaluated in a very small domains, which are either supplied by the context or themselves subject to quantification. I have explored this option in Part II of Cresswell (1996), and it is not my purpose to consider it here, or take sides on just which of the available approaches to anaphora is the best one. Groenendijk and Stokhof on pp. 76–83 discuss the sense in which their theory is equivalent to discourse representation theory. There have been a number of descriptions of discourse representation theory in more standard logical languages. Three which have appeared in *Linguistics and Philosophy* are Zeevat (1989), Muskens (1996) (in a Montague-style intensional language), and Krifka (1996). In these articles the 'dynamic' aspect tends to drop out of the picture, and so, although the authors do not specifically address the question of the aims of semantics, their work may to some extent be said to be similar in spirit to the present paper; though of course they are concerned with questions of detail which go beyond anything I attempt. I have myself discussed discourse representation theory in Chapter 10 of Cresswell (1988).

Using variables this becomes

(31) $x = y \wedge \textbf{\textit{entered}}\ x$.

The way Groenendijk and Stokhof (1991) present dynamic predicate logic involves interpreting a wff at a *pair* of assignments to its individual variables. Thus, where g and h are assignments to the variables, an atomic wff like ***entered*** x will be true with respect to the pair of assignments g and h iff first $g(x) = h(x)$ and second $g(x)$, and therefore $h(x)$, are in the set of individuals which is the interpretation of ***entered***, i.e., if this individual entered. What I have done in (31) is use ordinary predicate logic, with wff having an extra 'namely' variable, and replace g and h by a single assignment μ in such a way that $\mu(x) = g(x)$ and $\mu(y) = h(x)$. Then it is easy to see that ***entered*** x is true at $\langle g, h\rangle$ iff (31) is true at μ. (27) can be represented as

(32) $\exists x(x = y \wedge \textbf{\textit{cat}}\ x \wedge \textbf{\textit{entered}}\ x)$

in which y is a free variable, whose denotation in (27) is Bunthorne. Notice that (32) is equivalent to

(33) $\textbf{\textit{cat}}\ y \wedge \textbf{\textit{entered}}\ y$

which, except for the change of variable, is equivalent to (21). So that although it *appears* that (32) is existentially quantified, the appearance is deceptive. What we have discovered is a method whereby an apparent existential quantifier can be deprived of its quantificational effect, while remaining a syntactic part of the representing formula.[7] The translations which follow represent exactly the interpretation rules in Groenendijk and Stokhof (1991). (See the appendix.) A first shot at expressing (9) would seem to be

(34) $\exists y$ (a cat (namely y) entered and it (namely y) purred).

However, (34) will not do as it stands. The scope of $\exists$ in (9) ends after 'purred'. But (9) can easily be extended, as in

(35) A cat entered and it purred and it departed.

[7] This feature is similar to what is called 'existential disclosure' on p. 567f of Dekker (1993). Chierchia (1992, p. 143f) uses it to handle what Lewis (1975) calls 'adverbs of quantification', like ***usually*** in 'A farmer who owns a donkey usually beats it'.

What we need is a device which quantifies over the y position in (34) but somehow leaves y free. Bearing in mind that 'namely' is represented by identity in the underlying formal language the wff we require is

(36) $\exists z(\exists x(x = z \wedge \boldsymbol{cat}\ x \wedge \boldsymbol{entered}\ x) \wedge (z = y \wedge \boldsymbol{purred}\ z))$.

(36) replaces (20) as the representation of (9). The wff which represents (11) is

(37) $\exists x(x = y \wedge \boldsymbol{cat}\ x \wedge \boldsymbol{entered}\ x \wedge \boldsymbol{purred}\ x)$.

It is easy to see that (36) and (37) are equivalent, even though the scope of $\exists x$ in (36) ends after ***entered*** x, while in (37) it continues to the end of the sentence. Neither of these is equivalent to (19) because of the presence of the free y, which is of course needed as the variable available to link up with any further conjuncts which may be added. In fact both (36) and (37) are equivalent to

(38) $\boldsymbol{cat}\ y \wedge \boldsymbol{entered}\ y \wedge \boldsymbol{purred}\ y$.[8]

(36) and (37) do become equivalent to (19) if y is existentially quantified. So, if we call a discourse 'true' if all its members are satisfied by some assignment to the 'namely' variables, then (6)/(7) and (16)/(17) will each be a true discourse iff (19) is true.

4. NEGATION AND UNIVERSAL QUANTIFICATION

A significant fact is that 'namely' can be added only to certain quantifiers. It seems that it can be added to almost any kind of existential quantifier.

[8] One might try to treat a discourse as a set of sentences, and give a semantics to that set without prejudice to whether the set is to be interpreted conjunctively or in some other way. Where the set of sentences contains free variables, as say the set $\{\boldsymbol{cat}\ x \wedge \boldsymbol{entered}\ x, \boldsymbol{purred}\ x\}$, given an assignment μ, you can form the set of propositions $\{p, q\}$ where p is the value under μ of $\boldsymbol{cat}\ x \wedge \boldsymbol{entered}\ x$ and q is the value under μ of $\boldsymbol{purred}\ x$. But if these sentences are in the scope of a quantifier the situation is not so easy, since, for instance, it is unclear what it could mean for $\{\boldsymbol{cat}\ x \wedge \boldsymbol{entered}\ x, \boldsymbol{purred}\ x\}$ to hold *for some value of* x unless $\boldsymbol{cat}\ x \wedge \boldsymbol{entered}\ x \wedge \boldsymbol{purred}\ x$ is true for some value of x. The equivalence of (32) with (33), and of (36)/(37) with (38) might enable dynamic semantics to take advantage of the fact that, as shown in the discussion of (33) and (38), the 'quantifiers' lose their quantificational effect. Maybe there is a link here with the 'paratactic' account of indirect discourse in Davidson 1969. On Davidson's account, in a sentence like 'A woman said that she walked in to Devonport' the quantifier ***a woman*** would need to bind the pronoun ***she*** in a different sentence.

The case is quite different when dealing with negations or universal quantifiers. (15) is the negation of (12), and so it would seem that (15) can be represented as the negation of (37).

(39) $\sim \exists x(x = y \wedge \textit{\textbf{cat}}\ x \wedge \textit{\textbf{entered}}\ x \wedge \textit{\textbf{purred}}\ x)$

But (37) is equivalent to (38), and so (39) merely says that the contextually specified cat did not enter or purr. It is easy to see that something is wrong by using the namely test. For in suitable circumstances (12) could become

(40) A cat (namely Bunthorne) entered and purred.

But (14) could not become

(41) *No cat (namely Bunthorne) entered and purred.

Negation, it seems, should rule out any possible value for the 'namely' variable, and (39) should be replaced by

(42) $\sim \exists y \exists x(x = y \wedge \textit{\textbf{cat}}\ x \wedge \textit{\textbf{entered}}\ x \wedge \textit{\textbf{purred}}\ x)$

(42) is equivalent to

(43) $\sim \exists x(x\ \textit{\textbf{cat}}\ x \wedge \textit{\textbf{entered}}\ x \wedge \textit{\textbf{purred}}\ x)$

which is as it should be. We can now explain the oddness of (15). (15) is represented as

(44) $\exists z(\sim \exists y \exists x(x = y \wedge \textit{\textbf{cat}}\ x \wedge \textit{\textbf{entered}}\ x) \wedge (z = y \wedge \textit{\textbf{purred}}\ z))$

which is equivalent to

(45) $\sim \exists x(\textit{\textbf{cat}}\ x \wedge \textit{\textbf{purred}}\ x) \wedge \textit{\textbf{purred}}\ y.$

(45) has to mean that no cat entered, but the contextually specified object purred. Universal quantifiers also fail the namely test.

(46) *Every cat (namely Bunthorne) entered.

Sentences with universal quantifiers not only fail the namely test in respect of the quantificational phrase in which they occur. They also fail it in respect of indefinites within the scope of the universal quantifier:

(47) *Every cat caught a mouse (namely Squeaky).[9]

The predicate 'caught a mouse' does not of itself fail the namely test since

(48) x caught a mouse (namely Squeaky)

is a perfectly acceptable predicate. With y for 'Squeaky' (48) would have the form

(49) $\exists z(\boldsymbol{caught}\ xz \wedge z = y \wedge \boldsymbol{mouse}\ z)$.

This means that

(50) Every cat caught a mouse.

cannot be formalised as

(51) $\forall x(\boldsymbol{cat}\ x \supset \exists z\ (\boldsymbol{caught}\ xz \wedge z = y \wedge \boldsymbol{mouse}\ z))$.

(51) says that every cat caught the same contextually specified mouse. To get the right interpretation the y position must be existentially quantified, so that a universal quantifier must existentially bind the namely variables free within its scope. Thus (50) is represented as

(52) $\forall x \exists y(\boldsymbol{cat}\ x \supset \exists z(\boldsymbol{caught}\ xz \wedge z = y \wedge \boldsymbol{mouse}\ z))$

which is equivalent to

(53) $\forall x(\boldsymbol{cat}\ x \supset \exists z(\boldsymbol{mouse}\ z \wedge \boldsymbol{caught}\ xz))$.[10]

My purpose in these last two sections has not been to adjudicate between the use of double assignments, as in Groenendijk and Stokhof, and 'namely' variables, but simply to point out that the translation scheme shows that there is no *empirical* difference between the two approaches. And since the use of free variables does not constitute a departure from the standard truth-conditional account of meanings, then neither do the empirically equivalent dynamic theories of semantics.

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[9] At least on the 'narrow scope' reading of ***a mouse***. And of course it is only deviant when a proper name follows ***namely***. There is nothing wrong with the famous: Every Englishman reveres a woman (namely his mother).

[10] In (53) there is no free 'namely' variable, and if we tried to interpret (13) by analogy with (36) all we would get would be a sentence equivalent to

(1) $\forall x(\boldsymbol{cat}\ x \supset \boldsymbol{entered}\ x) \wedge \boldsymbol{purred}\ y$.

(1) has to mean that every cat entered and some contextually specified object purred.

5. DONKEY SENTENCES

The semantic rules that Groenendijk and Stokhof provide for dynamic implication (see the Appendix) entail that

(54) If a cat entered it caught a mouse.

translates into the namely language as

(55) $\forall z(\exists x_1(x_1 = z \wedge \boldsymbol{cat}\ x_1 \wedge \boldsymbol{entered}\ x_1) \supset \exists y \exists x_2(\boldsymbol{caught}\ z x_2 \wedge x_2 = y \wedge \boldsymbol{mouse}\ x_2))$.[11]

(55) is easily seen to be equivalent to

(56) $\forall x_1((\boldsymbol{cat}\ x_1 \wedge \boldsymbol{entered}\ x_1) \supset \exists x_1 \exists x_2(\boldsymbol{mouse}\ x_2 \wedge \boldsymbol{caught}\ x_2))$.

This enables an account of what, following Geach, are called 'donkey sentences':

(57) If a farmer owns a donkey he beats it.

It is not hard to see that the universal interpretation still arises when the phrases are made as explicitly 'existential' as possible:

(58) If at least one farmer owns at least one donkey he beats it.

[11] This treatment of ***if*** makes it impossible for an indefinite phrase in an implication to be the anaphoric antecedent of a pronoun occurring after the whole sentences. Barker (1997) suggests that this feature causes trouble for such discourses as

> If a donkey is Andalusian it has a good disposition.
> If it likes farmers it is usually perfectly placid.

Obviously whatever repair (if any) is available to Groenendijk and Stokhof is also available to the 'namely' translations. Roberts (1989) discusses cases where a modalized second sentence can pick up anaphoric reference to an indefinite phrase in a prior conditional thus (p. 683):

> If John bought a book, he'll be home reading it by now.
> It'll be a murder mystery.

is quite acceptable, but would not be with 'it's' replacing 'it'll'. Roberts is discussing these matters in the context of discourse representation theory, but on any account the mechanism needed is a way of making the second sentence part of the consequent of the initial conditional.

(59) If there is even so much as a single farmer who owns even so much as a single donkey he beats it.

The existential phrases in (58) and (59) pass the namely test.[13] You can easily say

(60) At least one farmer (namely Pedro) owns at least one donkey (namely Grosvenor).

The translation of (57) is

(61) $\forall z_3 \forall z_4(\exists x_1 \exists z_1(x_1 = z_1 \wedge \boldsymbol{farmer}\; x_1 \wedge \exists x_2 \exists z_2(\boldsymbol{donkey}\; x_2 \wedge x_2 = z_2 \wedge z_1 = z_3 \wedge z_2 = z_4 \wedge \boldsymbol{owns}\; z_1 z_2)) \supset \exists y_1 \exists y_2(z_3 = y_1 \wedge z_4 = y_2 \wedge \boldsymbol{beats}\; z_3 z_4))$.

(61) is equivalent to

(62) $\forall x_1 \forall x_2((\boldsymbol{farmer}\; x_1 \wedge \boldsymbol{donkey}\; x_2 \wedge \boldsymbol{owns}\; x_1 x_2) \supset \boldsymbol{beats}\; x_1 x_2)$.

The universal interpretation for both farmers and donkeys provided by (62) (i.e., the reading in which it is claimed that a farmer who owns many donkeys beats them all, often called the ‘strong’ reading) is usually held to be correct for many instances of (57), though, see for instance Chierchia (1992, p. 116) for a less clear example. There are however other sentences

[13] Although I do not discuss definite descriptions in this paper it is not difficult to see that they too pass the ‘namely’ test. The following example is loosely based on Lewis (1979, p. 348f):

(1) The cat is chasing the cat.

The point is that ‘the cat’ refers to whichever cat is most ‘salient’, and that salience can change as the sentence progresses, so that (1) speaks of two different cats. With ‘namely’ in place (1) becomes

(2) The cat (namely Bruce) is chasing the cat (namely Albert).

(2) is perfectly acceptable. Definite noun phrases like ***the cat*** can be used to pick up on an already introduced individual. Thus

(3) If there is a cat (namely y) who entered then the cat (namely y) purred.

Dekker (1996, p. 217), extends dynamic predicate logic by incorporating restrictions which do not permit an indefinite phrase to pick up on a discourse individual already in play. This would require certain restrictions on the namely variable.

which seem clearly to have a 'weak' reading. The most famous are those based on Schubert and Pelletier (1989). Consider

(63) Every motorist who has a coin puts it in the parking meter.

(63) pretty clearly only claims that the motorist puts at least one coin into the meter, and so the Groenendijk and Stokhof account would make the wrong prediction. There appears to be dispute in the literature about which reading is primary, and much work is designed to show why one is to be preferred. This controversy indicates that both readings should be available. An analysis of the weak reading is given in Chierchia (1992) in a formal language using what are now known as *generalized Quantifiers*.[14] This means treating ***every*** as a two-place variable-binding operator, where $(\boldsymbol{every}\ x)(\alpha, \beta)$ is true iff every value of x which makes α true also makes β true. Chierchia then uses the fact that

(64) $(\boldsymbol{every}\ x)(\alpha, \beta)$

is equivalent to

(65) $(\boldsymbol{every}\ x)(\alpha, \alpha \wedge \beta)$[15]

to analyse the weak reading of (63) as

(66) Every motorist who has a coin is a motorist who has a coin and puts it into the parking meter.

The problem with (66) is how the phrase 'motorist who has a coin' can have the same meaning both times if the quantifier ***a coin*** on its second occurrence binds 'it'. Chierchia solves the problem by taking the ***and*** in (66) to be a dynamic ***and***. In terms of the 'namely' analysis, with ***deposits*** for ***puts into the meter***, (66) becomes

(67) $(\boldsymbol{every}\ x_1)(\exists y_1 \exists y_2(\boldsymbol{motorist}\ x_1 \wedge x_1 = y_1 \wedge \exists x_2 \exists z(\boldsymbol{coin}\ x_2 \wedge x_2 = z \wedge z = y_2 \wedge \boldsymbol{has}\ x_1 z)), \exists y_1 \exists y_2 \exists z_1 \exists z_2(\boldsymbol{motorist}\ x_1 \wedge x_1 = z_1 \wedge \exists x_2 \exists z(\boldsymbol{coin}\ x_2 \wedge x_2 = z \wedge z = z_2 \wedge \boldsymbol{has}\ x_1 z) \wedge z_1 = y_1 \wedge z_2 = y_2 \wedge \boldsymbol{deposits}\ z_1 z_2))$

[14] It has been known for a long time that ordinary language quantifiers like ***every*** are two-place quantifiers. (See for instance, Cresswell (1973, p. 135.)) Since Barwise and Cooper (1981) it has become customary to call these *generalized quantifiers*. Chierchia is working within a Montague framework in which the variable-binding is done by a λ-operator.

[15] Barwise and Cooper (1981, p. 179) claim that all quantifiers satisfy this equivalence. Generalized quantifiers are important in the study of words like ***most***, which cannot be expressed by an ordinary quantifier and a connective. I have nothing to add in this paper to the extensive literature on such quantifiers or on such adverbs as ***usually***, since they do not change any of the points made here about dynamic semantics.

(67) is equivalent to:

(68) $(\textbf{\textit{every}}\ x_1)((\textbf{\textit{motorist}}\ x_1 \wedge \exists x_2(\textbf{\textit{coin}}\ x_2 \wedge \textbf{\textit{has}}\ x_1x_2)), (\textbf{\textit{motorist}}\ x_1 \wedge \exists x_2(\textbf{\textit{coin}}\ x_2 \wedge \textbf{\textit{has}}\ x_1x_2) \wedge \textbf{\textit{deposits}}\ x_1x_2))$.

In the case of (67) the point to note is that the repeated phrase 'motorist who has a coin' can be represented by the wff

(69) $(\textbf{\textit{motorist}}\ x_1 \wedge x_1 = y_1 \wedge \exists x_2 \exists z(\textbf{\textit{coin}}\ x_2 \wedge x_2 = z \wedge z = y_2 \wedge \textbf{\textit{has}}\ x_1 z))$.

So one can introduce a two-place 'dynamic' quantifier $(\textbf{\textit{every}}^d\ x_1, y_1, y_2$, in such a way that

(70) $(\textbf{\textit{every}}^d\ x_1, y_1, y_2)(\textbf{\textit{motorist}}\ x_1 \wedge x_1 = y_1 \wedge \exists x_2 \exists z(\textbf{\textit{coin}}\ x_2 \wedge x_2 = z \wedge z = y_2 \wedge \textbf{\textit{has}}\ x_1 z), \textbf{\textit{deposits}}\ y_1 y_2)$

is specified to have the same meaning as (67).[16] This could not be done if 'motorist who has a coin' were represented simply as

[16] The way Chierchia puts it on p. 141 is: "Thus a lexically governed transformation on logical forms has been turned into a semantical constraint on lexical meaning". Chierchia's own procedure involves translation into Montague's intensional logic, which makes extensive use of explicit variable-binding, and, whether or not explicit variables are used, something is required to indicate just what the quantifier must apply to. Thus, for instance, in (24) the x variable in ***sister*** indicates that the initial quantifier is to apply to it, and there is no reason to build this into the meaning of ***every***. One of the things I found in Cresswell (1996) in trying to articulate a variable-free semantic theory was that there are times when syntactical devices are needed to indicate just how the binding should go, and one could argue that this sort of information is precisely what is supplied in the different ways of interpreting donkey sentences. (I'm not sure whether the authors mentioned in footnote 5 have experienced the same problem. In some cases it can be solved by building binding instructions into the syntactic rules.) Kanazawa (1994, p. 138), attributes to earlier work by Chierchia the formalization of strong readings with generalized quantifiers using

(1) $(\textbf{\textit{every}}\ x)(\alpha, \alpha \supset \beta)$

(but with dynamic implication) in place of (65). With (1) the strong interpretation of (57) becomes

(2) $(\textbf{\textit{every}}\ x_1)(\exists y_1 \exists y_2(\textbf{\textit{farmer}}\ x_1 \wedge x_1 = y_1 \wedge \exists x_2 \exists z(\textbf{\textit{donkey}}\ x_2 \wedge x_2 = z \wedge z = y_2 \wedge \textbf{\textit{owns}}\ x_1 z)), \exists y_1 \exists y_2(x_1 = y_1 \wedge x_2 = y_2 \wedge \forall z_1 \forall z_2\ (\textbf{\textit{farmer}}\ x_1 \wedge x_1 = z_1 \wedge \exists x_2 \exists z\ (\textbf{\textit{donkey}}\ x_2 \wedge x_2 = z \wedge z = z_2 \wedge \textbf{\textit{owns}}\ x_1 z) \supset \exists y_1 \exists y_2(z_1 = y_1 \wedge z_2 = y_2 \wedge \textbf{\textit{beats}}\ z_1 z_2)))$

which is equivalent to:

(3) $(\textbf{\textit{every}}\ x_1)((\textbf{\textit{farmer}}\ x_1 \wedge \exists x_2\ (\textbf{\textit{donkey}}\ x_2 \wedge \textbf{\textit{owns}}\ x_1 x_2)), \forall x_2((\textbf{\textit{farmer}}\ x_1 \wedge \textbf{\textit{donkey}}\ x_2 \wedge \textbf{\textit{owns}}\ x_1 x_2) \supset \textbf{\textit{beats}}\ x_1 x_2)))$

(71) $\boldsymbol{motorist}\ x_1 \wedge \exists x_2(\boldsymbol{coin}\ x_2 \wedge \boldsymbol{has}\ x_1 x_2)$

because the x_2 attaching to ***coin*** in (71) is not required to be identical in value with any variable free in (71). Phenomena from anaphora may well show that the meanings of determiners involve functions with argument places over and above those used in standard logic; and if that is what is meant by calling semantics 'dynamic' then I certainly endorse it. But, as I have been constantly stressing throughout this paper, that fact simply shows that truth-conditional semantics is more complicated than we thought. If does not show that we were mistaken in thinking that semantics is about the determination of truth conditions.

6. Dynamic Conjunction

The other area which has been thought to lead to dynamic semantics is presupposition. There is an account of discourse given by Robert Stalnaker.[17] Stalnaker's idea is this. At any point in a discourse there are a number of propositions that one 'presupposes' in the sense of assuming them to be the case. Under the kind of idealisation that Stalnaker is assuming, at a given point in the discourse there is a set p of possible worlds, and the participants are assuming that any world not in p is ineligible for consideration. p is often called the 'common ground'. For instance we may all believe that Alice was in the room five minutes ago. If I say

(72) Alice is not in the room.

all my hearers may conclude

(73) Alice left the room in the last five minutes.

Now (73) does not follow from (72), but it *does* follow from (72) together with the proposition that Alice was in the room five minutes ago. This

(3) gives the reading that every farmer with donkeys beats them all – i.e., (3) gives the strong reading. Kanazawa is concerned to defend the strong readings, for which Chierchia (pp. 153–163) suggests an E-type analysis (see footnote 6). Chierchia (p. 159) suggests that "E-type pronouns are interpreted as variables ranging over functions". Among these are the pronouns in 'paycheck' sentences, of the kind ascribed in Partee (1978) to Karttunen (1969), which seem to involve non-first-order variable-binding. (I offer an analysis in a rather different framework on pp. 197–200 of Cresswell (1996).)

[17] See for instance, Stalnaker (1979). On p. 321, Stalnaker uses 'context set' for 'common ground'. The account of how the assertion of a sentence reduces the context set is given on p. 323. Stalnaker's purpose in that article is to investigate the possibility of using the notion of a context set to describe various kinds of speech act.

proposition may never have been stated, or it may have been introduced because at some earlier point in the discourse someone did state that Alice was in the room. Suppose that p is the set of worlds that are presupposed at a point in a discourse, and that a sentence α is then uttered. Suppose that the meaning of α is just the proposition (set of worlds) q. After the utterance of α the participants might add q to the presupposition of the discourse, so that it now becomes $p \cap q$. In this way the meaning of α might be thought of as the potential to change the presupposition from p to $p \cap q$.

It should be clear that however illuminating this way of putting things is it does not lead to any new *semantics*, because the updating of presuppositions by successive utterances assumes that the meaning of each sentence is just a set of possible worlds – or world-time pairs to take account of tensed languages.[18] An example of what is claimed to be a genuinely dynamic operator is the word ***maybe***.[19] Assume that ***maybe*** is used in a context in such a way that ***maybe*** α is true iff α is not ruled out by the common ground. Assume that the meaning of a sentence in a language in which presupposition is taken into account is a set of pairs $\langle w, p\rangle$ in which w is a world-time pair and p is a set of world-time pairs. We can express the meaning of ***maybe*** as follows:

(74) ***maybe*** α is true at $\langle w, p\rangle$ iff there is at least one world w' in p such that α is true at $\langle w', p\rangle$

---

[18] Or maybe even indices of a more general kind to take care of words like ***I*** as discussed above. Though there is a quite serious problem here. Suppose, as in the example about to be discussed, that a participant in the discourse, say Basil, believes, at 4.05 p.m. that Alice was in the room five minutes before. Must Basil believe that Alice was in the room at 4.00 p.m.? Only if Basil realises that it *is* now 4.05 p.m. That suggests that the content of Basil's belief is not the set of worlds in which Alice is in the room at 4.00 p.m., but the set of world-time pairs $\langle w, t\rangle$ in which Alice is in the room five minutes before t. But *that* belief need not stay constant as the discourse progresses. For, given that Basil is conscious of the passage of time, then at 4.10 p.m. Basil presumably believes that Alice was in the room *ten* minutes ago, not five minutes ago. So Stalnaker's insight might not be quite so clear as it at first seems.

[19] This particular example has been adapted from Veltman (1996, p. 223) (see also the discussion in Muskens et al. (1997, p. 595)) but the issues it raises go to the heart of dynamic semantics. It is of course a controversial question whether in fact there is such a thing as semantic presupposition. For my own part I have seen little in the technical work on this which answers the criticisms levelled in Chapter 4 of Lycan (1984) (extending Boër and Lycan (1976)), though p. 180 of Cresswell (1973) offers a semantic analysis of *the* involving presupposition. But the question for the present paper is solely whether a semantics which adds common ground to the index is 'dynamic'. A critical discussion of the presupposition theory alluded to here is found in Geurts (1996).

which is to say that p does not rule α out. The importance of operators like ***maybe*** is in their connection with what is perhaps the most crucial operator in dynamic semantics – conjunction. We have already seen that phenomena involving separate sentences may be replicated in a single conjunctive sentence. But as the analysis of (9) in terms of (36) shows ***and*** is not always straightforward classical conjunction. Consider the two 'discourses':

(75) Maybe it's raining .... It's not raining.

and

(76) It's not raining .... Maybe it is raining.

The claim is that discourse (75) is perfectly in order. When the first sentence is uttered nothing is assumed except that rain has not already been ruled out. Then the utterance of the second sentence excludes this possibility. (76) by contrast turns out to be contradictory, or at least infelicitous. For the utterance of its first sentence requires that the context be 'updated' by ruling out worlds in which it rains, and then the second sentence cannot be true. In place of (75) and (76) consider the following:

(77) Maybe it's raining, but it's not raining.

and

(78) It's not raining, but maybe it is raining.

First suppose that ***but*** is classical conjunction. Then both (77) and (78) are perfectly acceptable, since they will be true at $\langle w, p\rangle$ iff ***it's raining*** is false at $\langle w, p\rangle$ but true at $\langle w', p\rangle$. Dynamic semantics involves a non-standard conjunction. I shall use $\wedge_d$ for this:

(79) $\alpha \wedge_d \beta$ is true at $\langle w, p\rangle$ iff α is true at $\langle w, p\rangle$ and β is true at $\langle w, q\rangle$

where, for any world w', $w' \in q$ iff $w' \in p$ and $\langle w', p\rangle \in V(\alpha)$. (79) may seem strange but it reflects what has been said about (75)/(76). When the first conjunct α is uttered the presuppositional context is just p, but the utterance of α, according to the Stalnaker principle, *changes* the context, so that by the time the second conjunct is to be evaluated the context has changed to contain only those worlds in p where α is true. Despite its appearance this 'dynamic' way of viewing (79) does not in any way involve a new attitude to semantics. Although there is a sense in which the semantics for $\wedge_d$ might be thought to 'change the context' – that is only in the sense that in order to evaluate $\alpha \wedge_d \beta$ at a context $\langle w, p\rangle$ you need to evaluate β at another context $\langle w, q\rangle$. That is no different from ordinary tense and modal operators, where the truth of say $M\alpha$ at w depends on the truth of α at some other w'. In the case of a two-place operator the index for one argument of the operator may be different from that required for the other. Thus α ***and then*** β is true at t iff α is true at some earlier t' and β is true at t.[20]

With $\wedge_d$ explicating ***but*** (78) is contradictory but (77) is not. However the facts might not be so clear as the defenders of these semantic accounts might think.[21] Here is a scenario in which an obviously contradictory sentence can be uttered in such a way as to convey non-contradictory information:

(80) (Alice is addressing Basil.)
ALICE: It's raining

(aside to Celia so that Basil cannot hear)

ALICE: but it's not raining.

(80) seems no more problematic than (75)/(76), for all that

(81) It's raining but it's not raining.

[20] I have no problem with calling this feature 'dynamic', except that the impression is often given that this goes beyond Montague's work. (E.g., the passage from Hardt (1999, p. 187), quoted above immediately follows the sentence: "Since Montague a primary focus of semantics has been to describe a compositional method for constructing the logical representation of a sentence meaning, and then evaluating that representation with respect to a given context".) The remarks in footnote 3 above about Montague's early work should make clear that an index involving a presupposition does not reflect a new attitude to semantics. The meaning of a sentence α in what Veltman (1996) calls an 'update semantics' is a function $[\alpha]$ which takes an 'information state' σ into another information state $\sigma[\alpha]$. (Veltman points out on p. 221 that functional notation would normally require that this be written $[\alpha](\sigma)$, but that $\sigma[\alpha]$ is more convenient.) For comparative purposes we may consider an information state as a set p of world-time pairs. The meaning of a discourse consisting of two sentences, α and β in that order, in the initial information state p, can then be represented as $p[\alpha][\beta]$. There is a close connection between this view of a discourse and $\wedge_d$. For, where W is the set of all world-time pairs, let $|\alpha|_p = \{w \in W\colon \alpha \text{ is true at } \langle w, p\rangle\}$ and (following Stalnaker's view of discourse) let $p[\alpha] = p \cap |\alpha|_p$. Then $w \in p[\alpha][\beta]$ iff $w \in p$ and $\alpha \wedge_d \beta$ is true at $\langle w, p\rangle$.

[21] There are also problems about embedding. While it's unclear whether ***maybe*** can be embedded at all, the meaning of ***M(it's not raining*** $\wedge_d$ ***maybe it is raining***) according to the semantics given by (79) would depend on whether the modal operator changes the common ground, since there is no contradiction in saying that from the point of view of the present context it is definitely not raining in the relevant accessible world, but that the context of that world does not rule out rain in that world.

expresses a contradiction. (81) is equally contradictory whether ***but*** is represented by $\wedge_d$ or classical conjunction. Once more it is not clear just which sentence a discourse should lead to. But even if there is a case for incorporating a 'presupposition' into the semantics by way of an additional index to account for a word like ***maybe*** understood in accordance with (74), that is simply one more case of the kind of context-dependence which is already known to be ubiquitous in ordinary truth-conditional semantics for natural language.

7. CONCLUSION

In this paper I have argued that phenomena which lead to the view that semantics should be about the potential to change truth conditions show no more than the extent to which natural language meanings are context dependent, and must be represented as functions from context to truth conditions. In the particular case of anaphora I have shown how to represent one very influential dynamic approach in ordinary predicate logic, where the context works by supplying values to free variables. None of this need or should be construed as in any way detracting from the value of work in dynamic semantics.[22] My sole concern is to maintain that it leaves the basic aims of truth-conditional semantics exactly as they always were.

APPENDIX: TRANSLATION INTO THE 'NAMELY' LANGUAGE

This appendix makes precise the translation method used in Sections 3 and 4. I shall follow Groenendijk and Stokhof (1991, p. 54), except for some minor terminological changes. It will avoid confusion if I use different symbols for the dynamic operators. I shall use $\neg$, &, $\vee^d$, $\rightarrow$, $\exists^d$ and $\forall^d$ in place of $\sim$, $\wedge$, $\vee$, $\supset$, $\exists$ and $\forall$, which I will reserve for the classical operators. I shall assume that an interpretation is a pair $\langle D, V\rangle$ where D is a domain (of 'individuals') and V is a function assigning a set of n-tuples from D to each n-place predicate P of a language $\mathcal{L}$ of first-order predicate logic (though without individual constants). In standard predicate logic a wff is interpreted with respect to an assignment μ to the variables, and we

[22] In particular the purpose of this paper is neither to endorse nor criticise any of the theories discussed here as against their rivals. I must also stress that the claims of the paper are perfectly compatible with the fact that insights from a dynamic construal of semantics may provide clues to solving many semantic problems – indeed if the 'namely' account has anything to recommend it, it is important to point out that I only came to it as a result of trying to understand dynamic predicate logic.

may write $\models_\mu \alpha$ to mean that α is true (in the particular interpretation) with respect to the values that μ assigns to its free variables. For dynamic predicate logic a wff is evaluated at a *pair* of assignments. Groenendijk and Stokhof use $[\![\ ]\!]$ to indicate both the basic interpretation of all the constants, and also the set of pairs of assignments to the variables of $\mathcal{L}$ for which a wff is true. To facilitate comparison with ordinary predicate logic, where Groenendijk and Stokhof would write $\langle g, h\rangle \in [\![\alpha]\!]$ for wff α and assignments g and h to the variables, I will write $\models_{gh} \alpha$ with '$\Dashv$' to mean 'not $\models$'. I call assignments g and h x-alternatives if they coincide on all variables except (possibly) x (Groenendijk and Stokhof use '$g[x]h$'). Where g, h, j and k are all assignments to the variables of $\mathcal{L}$, the dynamic truth rules for complex wff may be expressed as

[P^d] $\models_{gh} Px_1 \ldots x_n$ iff $g = h$, and $\langle g(x_1), \ldots, g(x_n)\rangle \in V(P)$.

[$\neg^d$] $\models_{gh} \neg\alpha$ iff $g = h$ and $\Dashv_{gj}\alpha$ for all j.

[$\&^d$] $\models_{gh} \alpha \,\&\, \beta$ iff there is some j such that $\models_{gj} \alpha$ and $\models_{jh} \beta$.

[$\vee^d$] $\models_{gh} \alpha \vee^d \beta$ iff $g = h$ and $\models_{hj} \alpha$ or $\models_{hj} \beta$ for some j.

[$\rightarrow^d$] $\models_{gh} \alpha \rightarrow \beta$ iff $g = h$ and for all j, if $\models_{gj} \alpha$ then $\models_{jk} \beta$ for some k.

[$\exists^d$] $\models_{gh} \exists^d x\alpha$ iff there is an x-alternative j of g such that $\models_{jh} \alpha$.

[$\forall^d$] $\models_{gh} \forall^d x\alpha$ iff $g = h$ and for every x-alternative j of g there is some k such that $\models_{jk} \alpha$.

A variable x may be said to *occur*^{d} in α if it occurs in atomic wff in α or in $\exists^d x$ in α. An occurrence^d of x can be called *free*^{d} in α if it is not in the scope of any $\forall^d x$ in α. It is a consequence that if $\models_{gh} \alpha$ and x is not free^d in α then $g(x) = h(x)$. $\models_{gh}$ is explained dynamically by saying that α can be thought of as a computer program which, when given g as input, gives h as output. Although this may be a helpful metaphor I try to make the precise meaning of $\models_{gh}$ clear by showing how to translate wff of dynamic predicate logic into ordinary classical first-order logic. Let $\mathcal{L}$ be a language of dynamic predicate logic. Where X is the set of variables in $\mathcal{L}$ let Y and Z be two disjoint sets of variables distinct from X and indexed so that for x_i in X, y_i will denote the corresponding variable in Y, and z_i the corresponding variable in Z. I shall usually speak of the members of X as the xs, the members of Y as the ys, and the members of Z the zs, and when I write x_i I shall understand x_i to be in X, and so on. Let $\mathcal{L}^+$ be the classical first-order language whose predicates are those of $\mathcal{L}$, and whose variables are those in X, Y or Z. Since $\mathcal{L}$ and $\mathcal{L}^+$ contain the same predicates an interpretation $\langle D, V\rangle$ can equally be an interpretation to $\mathcal{L}$ and $\mathcal{L}^+$. I shall use both g, h etc. and μ, ρ etc. as assignments to the variables, but when I write $\models_{gh} \alpha$, for α in $\mathcal{L}$, I shall mean that α is true with respect to gh (in the given interpretation) when interpreted dynamically and when I write $\models_\mu$ α, for α in $\mathcal{L}^+$, I shall mean that α is true with respect to μ when interpreted classically. The notation $\alpha[z_1/x_1, \dots, z_n/x_n]$ will be interpreted to denote a bound alphabetic variant of α in which no z_i quantifiers occur and in which each free occurrence of x_i has been replaced by a free occurrence of z_i. This notation will only be used when wff are interpreted classically, and so the use of bound alphabetic variants will be legitimate. (Bound alphabetic variants are not of course equivalent as a rule at all pairs of assignments in dynamic predicate logic.[23]) I now show how to translate each wff α and $\mathcal{L}$ into a wff $\tau(\alpha)$ of $\mathcal{L}^+$. For atomic wff:

$$\tau(Px_1 \dots x_n) \text{ is } x_1 = y_1 \wedge \cdots \wedge x_n = y_n \wedge Px_1 \dots x_n$$

For complex wff the inductive definition of $\tau(\alpha)$ is as follows:

> $\tau(\neg\alpha)$ is $x_1 = y_1 \wedge \cdots \wedge x_n = y_n \wedge \forall y_1 \dots \forall y_n \sim \tau(\alpha)$, where $x_1, \dots, x_n$ are the variables which are free^d in α.
>
> $\tau(\alpha\&\beta)$ is $\exists z_1 \dots \exists z_n(\tau(\alpha)[z_1/y_1, \dots, z_n/y_n] \wedge \tau(\beta)[z_1/x_1, \dots, z_n/x_n])$, where $x_1, \dots, x_n$ are all the free^d variables *common* to α and β.
>
> $\tau(\alpha \vee^d \beta)$ is $x_1 = y_1 \wedge \cdots \wedge x_n = y_n \wedge (\exists y_1 \dots \exists y_n \tau(\alpha) \vee \exists y_1 \dots \exists y_n \tau(\beta))$, where $x_1, \dots, x_n$ are the variables which are free^d in $\alpha \vee^d \beta$.

[23] It may be that talk of free and bound occurrences of variables in dynamic predicate logic is misleading, since one of its principal features is that a quantifier can 'bind' a variable not in its scope. In classical predicate logic if two assignments μ and ρ coincide on all the variables free in a wff α, then $\models_\mu \alpha$ iff $\models_\rho \alpha$. In particular wff with no free variables coincide in truth value in a given interpretation with respect to *every* assignment. In dynamic logic this is not so. That is why I have used free^d when speaking of a wff of dynamic logic. $\models_{gh} \exists^d x_1 Px_1$ iff there is an x_1-alternative j of g such that $\models_{jh} Px_1$, and this latter will hold iff $j = h$ and $j(x_1) \in V(P)$. So $\models_{gh} \exists^d x_1 Px_1$ iff $h(x_1) \in V(P)$. But $\models_{gh} \exists^d x_2 Px_2$ iff there is an x_2-alternative k of g such that $\models_{kh} Px_2$, and this latter will hold iff $k = h$ and $(x_2) \in V(P)$. So $\models_{gh} \exists^d x_2 Px_2$ iff $h(x_2) \in V(P)$. Since nothing prevents $h(x_1) \in V(P)$ and $h(x_2) \notin V(P)$ then these two wff need not always be satisfied by the same assignments. Groenendijk and Stokhof have a careful discussion of this on pp. 58–61. On p. 61 they have a partial result that if g and h agree on all the variables free in a wff α, then $\models_{gh} \alpha$ for some j iff $\models_{hj}$ for some j. In terms of the translations it is only $\forall^d x$ which binds both x and the namely variables. $\exists^d x$ binds only x, $\neg$, $\vee^d$ and $\rightarrow$ bind only the namely variables, and & binds neither.

$\tau(\alpha \to \beta)$ is $x_1 = y_1 \wedge \cdots \wedge x_n = y_n \wedge \forall z_1 \ldots \forall z_n(\tau(\alpha)[z_1/y_1, \ldots, z_n/y_n] \supset \exists y_1 \ldots \exists y_n \tau(\beta)[z_/x_1, \ldots, z_n/x_n])$, where $x_1, \ldots, x_n$ are the variables which are free^d in $\alpha \to \beta$.

$\tau(\exists^d x\alpha)$ is $\exists x \tau(\alpha)$

$\tau(\forall^d x\alpha)$ is $x_1 = y_1 \wedge \cdots \wedge x_n = y_n \wedge \forall x \exists y_1 \ldots \exists y_n \tau(\alpha)$, where $x_1, \ldots, x_n$ are the variables which are free^d in $\forall^d x\alpha$.[24]

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[24] Using these translations it is clear that

(1) $\exists^d x Px \,\&\, Qx$

and

(2) $\exists^d x(Px \,\&\, Qx)$

are equivalent, since (1) becomes

(3) $\exists z(\exists x(x = z \wedge Px) \wedge (z = y \wedge Qz))$

and (2) becomes

(4) $\exists x \exists z((x = z \wedge Px) \wedge (z = y \wedge Qz))$.

(3) and (4) are equivalent, and if y is existentially quantified (4) becomes

(5) $\exists y \exists x \exists z((x = z \wedge Px) \wedge (z = y \wedge Qz))$

which is equivalent to

(6) $\exists x(Px \wedge Qx)$.

Groenendijk and Stokhof describe a wff α as simply *true* for an assignment g if $\models_{gh} \alpha$ for some assignment h, and point out on p. 73 that in that sense of truth every wff of dynamic predicate logic is equivalent to a wff of ordinary predicate logic. Such an equivalence is to be expected since the problem of wff like (1) is not a problem about their final semantic representation, but a problem of how to get the meaning of (6) with an existential quantifier which appears to bind a variable not in its scope. (6) does not enable the unique recovery of a wff of dynamic predicate logic, since it is equally what you get from (1) and (2). To be sure (1) and (2) are equivalent when interpreted dynamically, and each of them is true at g for some h iff (6) is true classically, but the equivalence is only partial. The equivalence of (1) with (3), and of (2) with (4) is a complete equivalence in that (3) and (4), although classically equivalent, differ syntactically in ways which correspond with the ways in which (1) and (2) differ syntactically.

Note that the only variables in α are the xs, and the only variables free in $\tau(\alpha)$ are the xs and the ys, never the zs. Let $\langle D, V\rangle$ be an interpretation to the (common) predicates of $\mathcal{L}$ and $\mathcal{L}^+$.

THEOREM 1. Where α is any wff of $\mathcal{L}$ and g and h are any assignments to the variables of $\mathcal{L}$ such that $g(x) = h(x)$ for any $x \in X$ which is not free^d in α, and μ is any assignment to the variables of $\mathcal{L}^+$ such that $\mu(x_i) = g(x_i)$ and $\mu(y_i) = h(x_i)$ for every $x_i \in X$ free^d in α, then $\models_{gh} \alpha$ iff $\models_\mu \tau(\alpha)$.

The proof is by a somewhat tedious and uninteresting induction on the construction of α in $\mathcal{L}$. ■

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