The Semantics of Dynamic Conjunction

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Abstract
In this paper we argue that a formal discourse- or dialogue-oriented theory of interpretation does not presuppose a dynamic notion of meaning. For the compositional interpretation of anaphorical or other rhetorical relations in discourse, a richer notion of *conjunction* may be needed, but not a *dynamic* notion of *meaning*. The dynamics of interpretation can be understood to reside in the (classical) combination of the contents of various sentences which are located at different positions in discourse. We also argue that by shifting the focus towards the interaction between meaning and context, the dynamics of merging information can be fruitfully studied from a perspective more general than a strictly linear one.

1 Introduction

In previous years it has been held that a non-compositional set up of a theory of interpretation is called for if we want to deal with a number of apparently semantic phenomena, such as singular intersentential anaphora, or 'donkey anaphora' (after Geach). However, it has been shown that this position, as such, is untenable.[1] An enriched notion of meaning, such as that of a relation modeling update of information about the values of variables, enables a straightforward compositional treatment of the type of anaphora involved. It is a well-established assumption nowadays that such a dynamic notion of meaning is key to the understanding of these and other types of phenomena in discourse.

According to the dynamic conception of meaning, (indicative) sentences are used to bring about changes in information states, and, consequently, conjunction can be understood as function or relation composition. Intuitively, this fleshes out the idea that the result of interpreting two consecutive sentences $S.\ S'$ equals that of interpreting S' in the state that results from interpreting S. The question that naturally arises is how this type of interpretation relates

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1. More implicitly in (Heim 1982), and most explicitly in (Groenendijk and Stokhof 1991).

to the classical notion of meaning, according to which (indicative) sentences are conceived of as conveying a certain amount of information.[2]

In the first part of this paper we answer this question for a system of dynamic semantics that models the interpretation of singular anaphoric relationships. We have chosen to investigate Groenendijk and Stokhof's *Dynamic Predicate Logic* (*DPL*), since it is a most elegant and widely known system. Our investigation focuses on the idea that meaning is something inherently *dynamic*, that it basically involves *changing* contexts. In the third section we show that *DPL*'s results concerning anaphoric relationships can be obtained without adopting such a dynamic notion of meaning.[3] We make our point in a constructive way: we state a system of static semantics *SPL* which covers all the *DPL*-results. All that can be properly called 'dynamic' in this system is its notion of conjunction.

Readers without an interest in these more or less quasi-philosophical and quasi-technical issues may skip the third section, and jump to the following sections where we start to develop a more general perspective on the dynamics of interpretation, or, rather on the dynamics of merging information. In section four we set out to explain the dynamic aspects of conjunction in *DPL* and *SPL* by explicitly relating the static meanings of different sentences in a discourse to the different times at which they are uttered or evaluated. It will be seen that dynamic conjunction can be understood as ordinary intersection of information contents which have been presented at different (temporal) locations.

Having located the dynamics of interpretation precisely there where pieces of information in a temporal order are combined, a more general perspective on the dynamic interaction between meaning and context becomes readily available. In section five we discuss some phenomena which seem to supply motivation for a less rigid and less linear view on interpretation in context, and for a more liberal and flexible approach.

2 Dynamic Predicate Logic

As our point of departure we take the system of *Dynamic Predicate Logic* (*DPL*), developed by Jeroen Groenendijk and Martin Stokhof (Groenendijk and Stokhof 1991).[4] The major challenge which systems like *DPL* seek to answer is that of providing for a compositional interpretation system which accounts for meaningful relationships between terms in different sentences or sentential clauses (singular anaphoric relationships, mainly).

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2. Suppose two (indicative) sentences S and S' are associated with certain (semantic) contents I and I', and that the interpretation of S and next S' in an information state σ leads to a state σ''. The principled question is how to combine the information I and I' into a content I'', such that the interpretation of I'' in σ leads to σ''? It will be clear that this question touches upon both the question of what kinds of entities these information contents are, and the question of what the required notion of combining information is.
3. A similar point was made at the ITALLC-conference by Jaroslav Peregrin and Hartley Slater; in this paper the point is actually proven.
4. Closely related work is presented by Irene Heim, Peter Staudacher, Jon Barwise, Henk Zeevat, and many many others, including myself.

General set-up In the system of *DPL*, this enterprise boils down to that of giving an interpretation for the language of first order predicate logic, in which syntactically free variables, may get bound, semantically, by preceding (coindexed) existential quantifiers. The *DPL*-valid equivalence in (1) then can be taken to model the intuitive extensional equivalence of (2) and (3), the first of which displays an anaphoric relationship:

(1) $(\exists x(Fx \wedge Gx) \wedge Hx) \Leftrightarrow \exists x((Fx \wedge Gx) \wedge Hx)$
(2) A letter has arrived for you. It is lying on the table in the hall.
(3) A letter which has arrived for you is lying on the table in the hall.

Indefinite noun phrases and pronouns are decorated with indices, or variables, and, in the dynamic process of interpretation, it is monitored what their possible values are. Since the possible values of such indefinite noun phrases are 'remembered', they are available as possible values of anaphorically related pronouns later in the discourse. Thus, relations of coreference holding between indefinite antecedents and anaphoric pronouns, can be cashed out (dynamic) semantically.

Let us consider one example:

(4) Mary borrowed [a copy of *Naming and Necessity*]$_x$ from [a professor in linguistics]$_z$. (The pages were covered with comments and exclamation marks.) [He]$_z$ must have studied [it]$_x$ intensively.

Suppose that this example is 'read' in some context g, which may be any assignment of individuals to variables. Interpreting the first sentence with respect to g may yield a new context k. Using obvious abbreviations, this can be indicated in the following way:

(5) g $[\![$Mary borrowed [a *cnn*]$_x$ from [a *pl*]$_z$.$]\!]$ k

If there is such a context k, as in (5), then it will hold in that context k that x is a copy of *nn* which Mary borrowed from z, a professor in linguistics. Actually, assignment k assigns such individuals to x and z in that case. In such a context the second sentence can be interpreted next, which may yield context h as a possible output:

(6) k $[\![$[He]$_z$ must have studied [it]$_x$ intensively.$]\!]$ h

If (6) holds, h is equal to k and we find, in k, not only that individual x is a copy of *nn* which Mary borrowed from professor in linguistics (z), but also that z studied x intensively.

Formal details The language of *DPL* is that of ordinary first order predicate logic, but for the present purposes we can stick to a fragment without individual constants and identity. The language is built around a set of variables F, and sets of n-ary relational constants R. The language includes atomic formulas $Rx_1, \ldots, x_n$, negation $\neg$, existential quantification $\exists x$, and conjunction $\wedge$. In most systems of dynamic semantics existential quantifiers can be conceived of as atomic formulas, and existentially quantified formulas $\exists x\phi$ as conjunctions $\exists x \wedge \phi$. Universal quantification $\forall x$, implication $\rightarrow$, and disjunction $\vee$ can be defined in terms of $\exists x$, $\neg$ and $\wedge$.

A model $M = \langle D, E \rangle$ for this language consists of a domain of individuals D, and an interpretation function E which maps n-ary relational constants to n-ary relations between individuals. (Reference to models is suppressed in most of this paper.) The formulas of this system are interpreted as relations between variable assignments, subsets of H^2, where $H = D^F$ is the set of variable assignments. Each pair $\langle g, h \rangle$ in the interpretation $[\![\phi]\!]$ of a formula ϕ must be understood as presenting a possible 'input' assignment g, with respect to which the formula may produce assignment h as a possible output. If such a pair $\langle g, h \rangle$ is an element of $[\![\phi]\!]$ it is also written as $g[\![\phi]\!]h$.

Interpretation in *DPL* is specified as follows:

(7) $g[\![Rx_1 \ldots x_n]\!]h$ iff $g = h$ & $\langle g(x_1), \ldots, g(x_n) \rangle \in E(R)$
$g[\![\neg\phi]\!]h$ iff $g = h$ & for no h: $g[\![\phi]\!]h$
$g[\![\exists x]\!]h$ iff there is a $d \in D$: $g[x/d] = h$
$g[\![\phi \wedge \psi]\!]h$ iff there is a $k \in H$: $g[\![\phi]\!]k[\![\psi]\!]h$

Atomic formulas are interpreted as 'tests', pairs $\langle g, g \rangle$ of assignments g with respect to which the atoms are true in a standard sense. A possible input for a negated formula $\neg\phi$ is any assignment g with respect to which ϕ cannot be successfully interpreted; input and output are the same in that case. An existential quantifier $\exists x$ does no more than 'resetting' the current value of x to an arbitrary value. Since conjunction is interpreted as relation composition, the possible values of such a variable can be monitored, and further constrained.

It is relatively easy to verify that the formulas $(\exists x\phi \wedge \psi)$ and $\exists x(\phi \wedge \psi)$ have the same interpretation in *DPL*. For $(\exists x\phi \wedge \psi)$ is short for $((\exists x \wedge \phi) \wedge \psi)$ which equals $(\exists x \wedge (\phi \wedge \psi))$ abbreviated as $\exists x(\phi \wedge \psi)$. It should be noticed that this equivalence holds without any constraint on possible free occurrences of x in ψ. Thus, also $\exists x Fx \wedge Gx$, and $\exists x(Fx \wedge Gx)$ are seen to be equivalent. Here we see that an existential quantifier may bind free variables to its right in *DPL*.

The dynamic notion of meaning The interpretation of a formula in *DPL* is properly conceived of as dynamic, since it consists of pairs of assignments which should be conceived of as input-output pairs. If such a pair $\langle g, h \rangle$ is in the interpretation of a formula ϕ, then the interpretation of ϕ is thought of as involving a possible change of context g into h. In a similar vein, indefinite noun phrases (existentially quantified formulas) have been thought of as involving the declaration of variables, or the introduction of discourse referents, which pronouns (free variables) may refer back to. All of these are context changing acts.

The dynamic notion of meaning has been characterized as the change which a sentence is supposed to bring about in the information state of anyone who accepts the news conveyed by it (Veltman 1996, p. 221). Notice that upon this way of putting things, a sentence is still assumed to have a certain content, "the news conveyed by it". This raises the (theoretical) question of whether it is possible to spell out the ensuing changes of information states in terms of this content and other pragmatic factors.[5] In the next section we argue that

5. This has originally been proposed by (Stalnaker 1974; Stalnaker 1978). These papers are

this is indeed possible, by showing that the results of *DPL* can be obtained in a static semantics with a dynamic composition operation.

3 Semantics of *SPL*

In this section we show that the results of *DPL* can be obtained on the basis of a static meaning assignment if we allow for a somewhat richer notion of information, and a more involved notion of conjunction. Within the confines of this paper we will refer to the resulting system as "*SPL*".

Preliminaries The system of *SPL* is inspired by two observations. First there is David Lewis' observation that indefinite noun phrases behave like free variable (Lewis 1975). Indefinite noun phrases can be bound by selective or unselective binding operators like quantifying adverbs and negations. Of course, we should not *identify* the category of indefinite noun phrases with that of ordinary free variables ('pronouns'). This relates to the second observation which inspires us here. As, for instance, (Heim 1982) has made clear, we must carefully distinguish between familiar terms (definite descriptions, pronouns) and novel terms (indefinite noun phrases), because the two categories play different roles in discourse. So, if we want to conceive of indefinite noun phrases as free variables, we should bear in mind that they are a special kind of free variables.[6]

As we will see, if we take this distinction between two types of variables to heart, a formulation of a *DPL*-style account of intersentential anaphoric relationships becomes possible. Indefinite noun phrases are a kind of free variables (which we may call 'binding' variables) which are able to bind pronouns (really 'free' variables) across conjunctions. Of course things don't fall into place automatically. We also need an adjusted notion of joining information, under which this binding of free variables by binding variables is effectively realized. These things can be done in the following way.

We use a first order predicate logical language based on an ordered set of variables V and sets of n-ary relational constants R, with corresponding models $M = \langle D, E\rangle$, the same as those for *DPL*. In order to make the distinction between really free and 'Lewis'-free variables explicit, we split up our set of variables $V = \{\nu_0, \nu_1, \ldots, \nu_i, \ldots\}$ into the set of 'binding' variables $B = \{\nu_0, \nu_2, \ldots, \nu_{2i}, \ldots\}$ and the set of 'free' variables $F = \{\nu_1, \nu_3, \ldots, \nu_{2i+1}, \ldots\}$.[7]

correctly viewed as predecessors of the dynamic semantic enterprise, although they themselves distinguish the (dynamic) pragmatics of assertion, from the (static) semantics of asserted sentences.

6. It should be noticed that existentially bound variables also have this dual nature in a system like *DPL*. They behave like free variables in *DPL* to the extent that they can be (re-)bound by other quantifiers, using a technique called 'existential disclosure' (Dekker 1993). For example, if x is bound by a dynamic existential quantifier in ψ, then it turns out to be universally quantified in $\forall y(\psi \wedge x = y)$. Thus, if $\psi \equiv \exists x Fx$, then $\forall y(\psi \wedge x = y)$ is (fully) equivalent to $\forall y F y$.

7. In (Montague 1974) the same distinction is made between two classes of variables (of type $\langle s, e\rangle$) for similar techno-philosophical reasons. This has been noted by Herman Hendriks who aptly observed the connection with the interpretation of anaphora (Hendriks 1993, Ch. 1, fn. 5 and fn. 20).

(For ease of comparison, we assume that F is the set of variables used in *DPL*.)

We relate each binding variable to its successor, and, conversely, each free variable to its predecessor. A subscript $_0$ is used to refer to the binding correlate of any variable; a subscript $_1$ is used to refer to the free correlate:

(8) $\nu_{(2i)0} =_{df} \nu_{(2i+1)0} =_{df} \nu_{2i}$
$\nu_{(2i)1} =_{df} \nu_{(2i+1)1} =_{df} \nu_{2i+1}$

So if x has an even index, then x_0 is the binding variable x itself, and x_1 is its successor, the free correlate of x; conversely, if x has an odd index, then x_1 is the free variable x itself, and x_0 is its predecessor, the binding correlate of x.

As usual, all (free and binding) variables can be used freely in atomic and existentially quantified formulas. However, if x occurs freely, it is interpreted as if it really is or were the free variable x_1. An existential quantifier binds free variables in the formula ϕ in its scope. Since the existential quantifier, like an indefinite noun phrase, is associated with a free variable of the binding sort, the information ϕ has about the values of the free variable x_1 is hung on the binding variable x_0.

SPL *interpretation* The meaning of an (open) formula is classically conceived of as a set of variable assignments, the set of variable assignments under which the formula is true.[8] In systems of dynamic interpretation, a somewhat richer notion of information is called for. For the present purposes we also employ so-called 'discourse information', which tells us which variables label binding slots. The meaning of an *SPL* formula is therefore spelled out as a pair, consisting of a set of (binding) variables, and a set of verifying variable assignments.

The set of binding variables $B(\phi)$ of a formula ϕ is defined as follows:

(9) $B(Rx_1 \ldots x_n) = B(\neg\phi) = \emptyset$;
$B(\exists x) = \{x_0\}$; $B(\phi \wedge \psi) = B(\phi) \cup B(\psi)$

Binding variables are introduced by existential quantifiers, only. The assignments verifying a formula ϕ are characterized by the following satisfaction relation:

(10) $g \models R\nu_{i_1} \ldots \nu_{i_n}$ iff $\langle g(\nu_{i_1 1}), \ldots g(\nu_{i_n 1})\rangle \in E(R)$
$g \models \exists x$ always
$g \models \neg\phi$ iff for no h: $g[B]h$ & $h \models \phi$
$g \models \phi \wedge \psi$ iff there are $f \models \phi$ and $h \models \psi$: $g[B(\psi)]f\langle B(\phi)\rangle h[B_1(\phi)]g$

where $g[X]h$ iff $\forall x \notin X$: $g(x) = h(x)$
$f\langle X\rangle h$ iff $\forall x \in X$: $f(x_0) = h(x_1)$
$B_1(\phi) = \{x_1 \mid x \in B(\phi)\}$

The interpretation of an atomic formula $R\nu_{i_1} \ldots \nu_{i_n}$ is a set of variable assignments, precisely those which map the *free* variables $\nu_{i_1 1}, \ldots, \nu_{i_n 1}$ to individuals $d_1, \ldots, d_n$ which stand in the relation R (in that order). All that matters to an existential quantifier $\exists x$ is that it involves the binding variable x_0: $B(\exists x) = \{x_0\}$. An assignment g verifies a negated formula $\neg\phi$ iff g's valuation of the *free* variables of ϕ falsifies ϕ.[9] The most complicated notion is that of

8. The meanings of open expressions are functions from the valuations of their open positions to the interpretations obtained under these valuations.

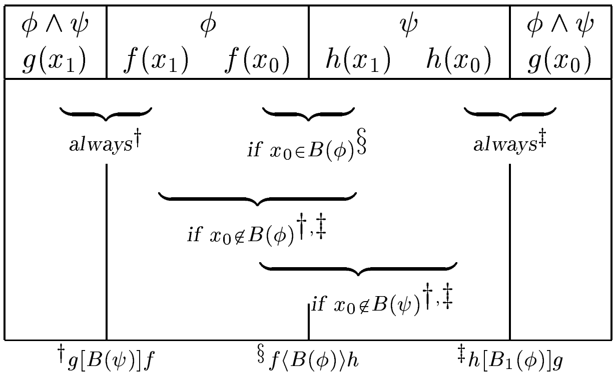
9. A negation $\neg\phi$ thus invokes unselective binding of all the binding variables in ϕ.

conjunction.

In the clause dealing with conjunction, anaphoric connections get established. By means of the condition $f\langle B(\phi)\rangle h$ the values of free variables in ψ (given by h) are identified with corresponding binding variables in ϕ (given by f); the condition $h[B_1(\phi)]g$ tell us that these variables, free in ψ, are not any longer free in $\phi \wedge \psi$. The additional condition that $g[B(\phi)]f$ is required to account for the fact that binding variables in ϕ in the *DPL* system may be 'reset' by other occurrences of $\exists x$ in ψ.[10]

The various conditions on the free and bound variables of ϕ and ψ are spelled out in the following chart. We find that $g \models \phi \wedge \psi$ iff there are $f \models \phi$ and $h \models \psi$ such that:

(11)



(In this chart $\underbrace{a \quad b}$ indicates identity of a and b.) This chart indicates that the information about free variables in ϕ and about binding variables in ψ is preserved in their conjunction; that information about free variables in ψ is preserved in their conjunction if the variables are not bound by ϕ; and that information about binding variables in ψ is preserved if it is not blocked by synonymous variables in ψ.

Equivalence of DPL *and* SPL   In order to establish the effective equivalence of *SPL* with *DPL*, it is convenient to define the notion of a "*DPL*-representative":

(12) $g \overset{dr}{\models} \phi$ iff $g \models \phi$ & $g\langle B \setminus B(\phi)\rangle g$

An assignment g is a *DPL*-representative for a formula ϕ, $g \overset{dr}{\models} \phi$, if it verifies ϕ and, for all binding variables x not in $B(\phi)$, the values of x_0 and x_1 are identified. It is relatively easy to establish that:

(13) $g \models \phi$ iff $\exists g'$: $g[B \setminus B(\phi)]g'$ & $g' \overset{dr}{\models} \phi$

10. In structures in which one and the same variable x is multiply quantified it has to be decided which occurrence of $\exists x$ should be able to bind later free occurrences of x. In *DPL* it is the 'second' one that 'wins' in such a situation, but we might as well choose the first one as a winner. Alternatively, in what has become known as the 'Zeevat merge', multiple occurrences of $\exists x$ are unified (Zeevat 1989, cf., also, Kamp and Reyle 1993 and Visser 1994, pp. 225–6). We think there are no decisive intuitive arguments for or against any one of these options, basically, because the question is a technical one and does not seem to correspond to any real issue in the interpretation of natural language. For the purposes of natural language interpretation it is simply immaterial which specific variables are associated with anaphoric elements and their potential resolvents.

In other words, $\overset{dr}{\models}$ and $\models$ characterize each other when $B(\ )$ is given. If we concentrate on representatives, our chart (11) can be drastically simplified:

(14)

$$\begin{array}{|c|cc|cc|c|}\hline \phi\wedge\psi & \phi & & \psi & & \phi\wedge\psi \\ g(x_1) & f(x_1) & f(x_0) & h(x_1) & h(x_0) & g(x_0) \\ \hline \multicolumn{6}{|c|}{\underbrace{\qquad\quad}_{always}\qquad\qquad\underbrace{\qquad\quad}_{always}\qquad\qquad\underbrace{\qquad\quad}_{always}} \\ \hline\end{array}$$

For either $x_0 \in B(\phi)$ and then we have that $f(x_0) = h(x_1)$ as in (11), or $x_0 \notin B(\phi)$, but then $f(x_0) = f(x_1)$ (definition of representatives) and $f(x_1) = h(x_1)$ (as in the previous chart). Having $f(x_0) = h(x_1)$ the other two conditions relating f and h in chart (11) are also satisfied.

With *DPL*-representatives it is fairly easy to establish the equivalence of *DPL* and *SPL*. Given the following *bijection* $\mathcal{S}$ from H^2 to G:

(15) $\mathcal{S}(\langle f,h\rangle) = \bigcup_{x\in F}\{\langle x_1, f(x)\rangle, \langle x_0, h(x)\rangle\}$[11]

we find that:

(16) $f[\![\phi]\!]h$ iff $\mathcal{S}(\langle f,h\rangle) \overset{dr}{\models} \phi$

which is proved by induction on the complexity of ϕ. The only non-trivial case is, of course, the one dealing with conjunction. Let f_1, g_1, h_1 range over assignments in D^F, and h_0, g_0, f_0 over assignments in D^B. Chart (11) can be used to verify that:

(17) $(f_1 \cup h_0) \overset{dr}{\models} \phi\wedge\psi$ iff $\exists(g_1\cup g_0)$:
$g_0\langle V\rangle g_1$; $(f_1\cup g_0) \overset{dr}{\models} \phi$; $(g_1 \cup h_0) \overset{dr}{\models} \psi$

For h_1 such that $h_0\langle V\rangle h_1$ we have $(f_1\cup h_0) = \mathcal{S}(\langle f_1,h_1\rangle)$, $(f_1\cup g_0) = \mathcal{S}(\langle f_1,g_1\rangle)$, and $(g_1\cup h_0) = \mathcal{S}(\langle g_1,h_1\rangle)$, so:

(18) $\mathcal{S}(\langle f_1,h_1\rangle) \overset{dr}{\models} \phi\wedge\psi$ iff $\exists g_1$: $\mathcal{S}(\langle f_1,g_1\rangle) \overset{dr}{\models} \phi$; $\mathcal{S}(\langle g_1,h_1\rangle) \overset{dr}{\models} \psi$

iff, by the induction hypotheses:

(19) $\exists g_1$: $f_1[\![\phi]\!]g_1$ and $g_1[\![\psi]\!]h_1$, i.e., iff $f_1[\![\phi\wedge\psi]\!]h_1$

Our findings in (13) and (16) show that we can compute the *DPL*-interpretation of a formula ϕ from its *SPL*-interpretation; conversely, $\overset{dr}{\models} \phi$ can be derived from $[\![\phi]\!]$, and using $B(\phi)$, this gives us $\models \phi$. The only thing which we cannot in general determine from the *DPL*-interpretation of a formula ϕ is its set of binding variables $B(\phi)$.

Discussion Since the *DPL*-interpretation of a formula can be derived from its *SPL*-interpretation, we have a static formulation of *DPL*'s dynamic semantics. This result is not extremely impressive, technically speaking, for it is obvious, of course, that a relation between two types of entities (e.g., variable assignments) can be coded as a function on a domain of a certain merged type of entities (e.g., disjoint unions of variables assignments). Theoretically speaking, however, we think it is of interest. Our findings indicate that the results obtained in a dynamic or *DRT*-style semantics, can be obtained without giving up a classical notion of meaning.

11. The inverse $\mathcal{D}$ is given by $\mathcal{D}(g) = \langle\{\langle x, g(x_1)\rangle \mid x \in F\}, \{\langle x, g(x_0)\rangle \mid x \in F\}\rangle$

The *SPL* notion of meaning can be motivated without any reference to changing contexts or update potentials. The special treatment of free and binding variables is given in by the observations of Lewis and Heim about the behavior of indefinite noun phrases and pronouns, and the use of satisfying assignments is pretty classical. Surely, the *SPL* notion of conjunction is dynamic, but that, then, shows no more than that the dynamics of interpretation can be fleshed out on the basis of a static meaning assignment.[12]

4 Anaphoric Predicate Logic

In the previous section we have assigned the dynamics of interpretation to the merging operation by means of which information gets conjoined. Intuitively, of course, the merging of information is an inherently dynamic thing, and, thus, it can be expected to be somewhat involved. However, the *SPL* notion of conjunction was more involved than is intuitively digestible.

In this section we will show that the required notion of merging information need not be anything special really. If we treat pronouns as respectable semantic entities of their own, and if pay due attention to the linear structure of discourse, the essential properties of dynamic conjunction can be readily accounted for. We will show this by reformulating dynamic conjunction in an anaphoric predicate logic *APL*.

Guiding ideas The system of *APL* is set up on the basis of three ideas which are supposed to be uncontroversial. Firstly there are terms (indefinite noun phrases) which behave like free variables and which can be bound by quantifying adverbs and by a negation operator. Secondly there are terms (pronouns) which behave like free variables and which are longing to be resolved in (preceding) discourse. Thirdly such presuppositional pieces of discourse may meet pieces of discourse which provide the missing clues, when the two pieces are conjoined like two pieces of a puzzle. As we have shown in (Dekker 1994; Dekker 1996) we can account for coreference between indefinite noun phrases and anaphoric pronouns, without having to assign them the same indices.

We present a compositional interpretation of the language of predicate logic, which is extended with anaphoric pronouns. Existentially quantified formulas are treated in compliance with the observations of Lewis and Heim. Although an existential quantifier $\exists x$ in $\exists x\phi$ binds free occurrences of x in ϕ, it also relates to an open slot: a slot which can only be occupied by individuals which satisfy the conditions imposed upon x by ϕ. Pronouns typically refer back to such slots.

Anaphoric pronouns $\mathtt{p}_1, \mathtt{p}_2, \ldots$ come with indices which indicate how many terms back in a discourse their antecedents must be found. A pronoun $\mathtt{p}_i$ thus

12. A possible objection may be that *SPL* is *dynamic*, essentially, because its notion of conjunction can be *explained* using dynamic jargon: x_0 indicates **0**utput, x_1 indicates **1**nput, etc. In a similar spirit, one may insist that any notion of meaning is dynamic by definition if it is employed in a treatment of presupposition and anaphora. I can agree with both points, since I am not against reformulations and definitions. However, notice that both objections threaten to render the term ‘dynamic’ entirely vacuous.

carries the presupposition that it is used in a discourse where (at least) i terms have gone before. It is not required that these antecedents carry the same indices, or any indices at all.

Although the semantics of *APL* itself is static, its notion of conjunction is truly dynamic. The two conjuncts of a conjunction in *APL* are, in a sense, interpreted at different time intervals: first the first conjunct, the second conjunct next. Since, as in *DPL*, the main highlights in the meaning of a sentence are the various potential antecedents which the formula may supply for future (co-)reference, the length of these intervals is measured in terms of the number of ('active') existential quantifiers. Thus, the possible referents of such quantifiers can be see to make up such a metaphoric 'interval'.

Formal details In line with the above observations the interpretation of a *APL* formula ϕ involves, firstly, a specification of its *length* $n(\phi)$:

$$\begin{array}{llll} n(Rt_1 \dots t_m) & = 0 & n(\exists x\phi) & = n(\phi)+1 \\ n(\neg\phi) & = 0 & n(\phi\wedge\psi) & = n(\phi)+n(\psi) \end{array}$$

The length of a formula ϕ is the number of existential quantifiers in ϕ which are not in the scope of a negation sign. The interpretation will be completed, below, by the *APL* definition of a Tarskian satisfaction relation. First we have to say what *APL* models are and what the *APL* interpretation of terms is.

Terms and formulas are evaluated relative to models $M = \langle D, E\rangle$, which consist of a domain of individuals D and an interpretation E for the non-logical constants. Neglecting the presuppositions associated with names, such an interpretation function E (rigidly) assigns individuals to individual constants, and it assigns sets of n-tuples of individuals to n-ary relation expressions.

There are three types of individual terms (t): individual constants (c), variables (x) and pronouns (p_i). The interpretation $[t]_{M,g,e}$ of a term t relative to a model $M = \langle D, E\rangle$, an assignment g and a sequence of individuals e is obvious:

(20) $[c]_{M,g,e} = E(c) \qquad [x]_{M,g,e} = g(x) \qquad [\mathrm{p}_i]_{M,g,e} = e_i$

The semantics of *APL* is presented as a Tarskian satisfaction relation, which determines when an (infinite) sequence of individuals satisfies a formula with certain open places. When a formula ϕ is satisfied by a sequence e in a model M and relative to an assignment g, this will be written as $M, g, e \models \phi$. The sequences e here play the Tarskian role of filling the open places in ϕ, but in reversed order. The first $n(\phi)$ individuals $e_1, \dots e_{n(\phi)}$ in e are possible witnesses, simultaneously, for the $n(\phi)$ holes in ϕ, where $e_{n(\phi)}$ is a witness for the first hole, $e_{n(\phi)-1}$ for the second, ..., and e_1 for the last ($n(\phi)$-th) hole.

In the definition below the evaluation of a conjunction $\phi \wedge \psi$ relative to a sequence e involves the evaluation of ϕ relative to $e{-}n(\psi)$, which is ϕ's evaluation $n(\psi)$ terms *before* that of ψ. We use $e{-}m$ here to indicate the sequence $e_{m+1}e_{m+2}\dots$, which is the interval e for $\phi \wedge \psi$ with the contribution of ψ stripped of.

(21) $M, g, e \models Rt_1 \dots t_m$ iff $\langle [t_1]_{M,g,e}, \dots, [t_m]_{M,g,e} \rangle \in E(R)$
$M, g, e \models \neg\phi$ iff $\neg\exists c \in D^{n(\phi)}$: $M, g, ce \models \phi$
$M, g, e \models \exists x\phi$ iff $M, g[x/e_1], e{-}1 \models \phi$
$M, g, e \models \phi \wedge \psi$ iff $M, g, e{-}n(\psi) \models \phi$ and $M, g, e \models \psi$

We quickly run through the four clauses above. Atomic formulas are evaluated in a Tarskian way, relative to sequences of individuals and variable assignments. The negation of a formula ϕ tells us there is no way to fill the free holes of ϕ, or, rather, that ϕ has no future. The existential quantifier $\exists x$ has the double-hearted nature of Lewis' indefinites. Like an ordinary quantifier it binds (free occurrences of) the variable x in its scope; but it also behaves like a free variable itself, since it relates to the sequence with respect to which it is evaluated. As a matter of fact, it occupies the first and foremost open slot in the interpretation of $\exists x\phi$. The *APL* notion of conjunction is truly dynamic, since it involves the evaluation of the first conjunct in the past of that of the second.

Like we said, *APL*'s sequences of individuals mirror the order of the corresponding quantifiers in a formula. If a sequence e satisfies a formula ϕ, then e_1 corresponds to the last term in ϕ, e_2 to the next-to-last-one, etc. So a conjunction $\exists xFx \wedge \exists xGx$ is true relative to a sequence e if e_1 is a G and e_2 is an F.[13]

Because our sequences reverse the order of the corresponding quantifiers, it can be convenient to write them in reverse order themselves. Thus we can picture the clause for conjunction in the following way. Suppose i is the length $n(\psi)$ of ψ. Then:

(22)
$$\begin{array}{lll} M, g, \dots d_{i+1} d_i \dots d_1 & \models \phi \wedge \psi & \text{iff} \\ M, g, \dots d_{i+1} & \models \phi & \text{and} \\ M, g, \dots d_{i+1} d_i \dots d_1 & \models \psi & \end{array}$$

Applications Let us see how *APL* handles two key-note examples:

(23) A bird hurt a nerd. $[\exists x(Bx \wedge \exists y(Ny \wedge Hxy))]$

$$M, g, e \models (23) \text{ iff } \begin{array}{l} M, g[x/e_1], e{-}1 \models Bx \\ M, g[x/e_1][y/e_2], e{-}2 \models Ny \\ M, g[x/e_1][y/e_2], e{-}2 \models Hxy \end{array} \text{ iff } \begin{array}{l} e_1 \in E(B) \\ e_2 \in E(N) \\ \langle e_1, e_2 \rangle \in E(H) \end{array}$$

(24) She deferred his concert. $[\exists z(Cz \wedge OFz\mathrm{p}_2 \wedge D\mathrm{p}_1 z)]$

$$M, g, e' \models (24) \text{ iff } \begin{array}{l} M, g[z/e'_1], e'{-}1 \models Cz \\ M, g[z/e'_1], e'{-}1 \models OFz\mathrm{p}_2 \\ M, g[z/e'_1], e'{-}1 \models D\mathrm{p}_1 z \end{array} \text{ iff } \begin{array}{l} e'_1 \in E(C) \\ \langle e'_1, e'_3 \rangle \in E(OF) \\ \langle e'_2, e'_1 \rangle \in E(D) \end{array}$$

(25) $M, g, e' \models (23) \wedge (24)$ iff $M, g, e'{-}1 \models (23)$ and $M, g, e' \models (24)$ iff
e_2, a bird who hurt e_3, a nerd, deferred e_1, the concert of e_3

Before we turn to the second example, notice what the *APL* evaluation of an implication amounts to if it is defined in the usual way in terms of negation and conjunction: $(\phi \rightarrow \psi) = \neg(\phi \wedge \neg\psi)$:

13. However, mind that the hole corresponding to an existential quantifier does not relate to the position of the quantifier, but to that of its closing bracket. Thus, if e satisfies $\exists x(Fx \wedge \exists y(Dy \wedge Oxy))$, then e_1 codes the possible values of x, and e_2 the possible values of y.

(26) $M, g, e \models \phi \rightarrow \psi$ iff
$\forall c \in D^{n(\phi)}$ if $M, g, ce \models \phi$ then $\exists a \in D^{n(\psi)}$: $M, g, ace \models \psi$

Now consider the following 'donkey-sentence':

(27) If a paysant owns a hinny, he feeds it.
$[\exists x(Px \wedge \exists y(Hy \wedge Oxy)) \rightarrow F\mathtt{p}_1\mathtt{p}_2]$

This formula will be satisfied by a sequence e if every peasant feeds every hinny (s)he owns, the standard interpretation.

It may be worthwhile to point out that *APL* allows for two forms of normalization. Firstly, the pronouns in all resolved *APL* formulas can be eliminated by putting the formulas in 'normal binding form'. This type of normalization requires us to 'stretch' the scope of the pronouns' antecedent quantifiers long enough to be able to replace the pronouns by variables bound by these quantifiers. If it is done smartly, this kind of normalization is meaning preserving.

Conversely, all bound variables can be eliminated, given that, for instance, $\exists xFx$ is equivalent to $\exists x\top \wedge F\mathtt{p}_1$, and that the last formula might just as well be written as $\exists \wedge F\mathtt{p}_1$, with obvious interpretation. Proceeding in this way all bound variables can be eliminated. Needless to say, of course, it will not be possible to eliminate pronouns and variables in one go.

Like we said, the evaluation of a conjunction $\phi \wedge \psi$ relative to a sequence e requires the evaluation of ψ relative to e, and the evaluation of ϕ relative to the sequence we had $n(\psi)$ terms before that: $e{-}n(\psi)$. Conjunction, thus, can be seen to derive from ordinary intersection. The *APL* notion of conjunction involves the intersection of the contents of ψ with the contents ϕ had at the time of its utterance. We use the $-$ shift here, because we need to characterize the contents of the first conjunct from a different point in time, viz., after ψ has appeared.

Something essentially similar has been observed by Gottlob Frege almost a century ago: "Wenn jemand heute dasselbe sagen will, was er gestern das Wort "heute" gebrauchend ausgedrückt hat, so wird er dieses Wort durch "gestern" ersetzen."[14] Our notion of conjunction takes this observation to heart. If someone yesterday said "Es regnet heute", and today "Es regnet heute nicht", then the conjunction of what she said should be the conjunction of the proposition that it rained *yesterday*, and the proposition that it doesn't rain today.

5 Generalized notions of conjunction

The previous sections may have served to show that the dynamics of interpretation can be very well equated with the dynamics of conjoining information, rather than with the dynamics of meaning. The system of *APL* provides for a very simple reformulation of the *DPL* account of anaphoric relationships, by means of a motivated notion of dynamically conjoining static meanings. The dynamics of interpretation has, thus, been moved from the semantic realm of meaning, to the more pragmatic area where information merges.

14. Frege's 'donkey-sentence' in Frege 1918, p. 64: "If somebody wants to say, today, what he expressed yesterday using the word "today", then he should replace this word by "yesterday".

We even think such a move is a precondition for a more general outlook on the (dynamic) interaction between meaning and context. Before we turn to such a more general perspective, however, it may be useful, first, to inspect the motivation which another phenomenon has been said to adduce for a dynamic notion of meaning. This is the phenomenon of presupposition.

Backgrounds and assertions Phenomena other than anaphoric binding have been comfortably accommodated within dynamic semantic or *DRT*-style frameworks. Two major approaches to the phenomenon currently are the dynamic semantic satisfaction theory and the *DRT*-style binding and accommodation theory.[15] Both approaches are concerned with aspects of the dynamics of presupposing, such as the behavior of presuppositions in the logic of information update, and the procedures of presupposition binding and accommodation, respectively.

The relative success of these dynamic approaches to presupposition may indicate that presupposition really is a dynamic phenomenon, which requires us to adopt a dynamic notion of meaning. We agree with the first bit, that presupposition, like dynamic conjunction, is a dynamic phenomenon. However, we think it does not necessarily require a dynamification of our notion of meaning. Without being able to go into the required details here, we present circumstantial evidence for this point.

The study of the interaction between presuppositions and context dates back to the seminal (Stalnaker 1974; Stalnaker 1978), and to the less known (Strawson 1964). Related ideas have been worked out in more detail in the more linguistically oriented (Jackendoff 1972), in which sentences are split up into a 'background' and an 'assertion' part, and in the two-dimensional theory of (Karttunen and Peters 1979), in which a distinction is made between the 'extensions' and 'implicatures' of the expressions of a Montagovian fragment of natural language. None of these theories employs a dynamic notion of meaning. The dynamic theories mentioned above have been constructed after theories like these had seemed to have come to a dead end. Our point here is that the main problem of these pre-dynamic theories of presupposition, can be easily solved, nowadays, without needing to resort to a dynamic setting.

Karttunen and Peters themselves have observed that their two-dimensional theory of presupposition runs into a serious problem when presupposing verbs are existentially quantified. Consider Karttunen and Peters' own example (28):

(28) Somebody managed to succeed George V on the throne of England.

According to Karttunen and Peters' theory as originally formulated, this sentence presupposes that someone had a hard time trying to succeed George V, and it asserts that someone did succeed George V. Thus, it fails to account for the intuition that the one who is asserted to have succeeded George V is the one who is presupposed to have had a hard time doing that. The bug, really, is pretty bad, and with the tools available at the time it has seemed irreparable.

15. Representative for the first approach are (Karttunen 1974; Heim 1983; Heim 1992; Beaver 1995); for the second (van der Sandt 1989; van der Sandt 1992; Kamp and Roßdeutscher 1994; Geurts 1995). (Zeevat 1992) presents an appealing blend of the two trends.

Indeed, for some, this 'binding problem' may have meant the death warrant for the two-dimensional theory of presupposition, if not for the whole theory of presupposition as such.

Upon reflection, however, it may become clear that, by now, the 'binding problem' is not a serious problem at all. Fully in the spirit of the two-dimensional theory of presupposition, the example can be said to presuppose that someone had a hard time succeeding George V, and to assert that *he* did succeed George. Upon such a reformulation, what example (28) calls for is not so much an entirely different theory of presupposition or meaning, but simply an account of anaphoric binding! As we have argued at length above, a treatment of anaphora does not force a great change in the traditional notion of meaning.

The evidence which we here provide for the viability of a treatment of presupposition in a static semantics is circumstantial and indecisive, of course. For one thing, we have said nothing to show that all of the concepts and tools which have been developed in dynamic semantic and discourse representation theoretic frameworks can be used or modified so as to apply equally successfully in the types of frameworks of the pre-dynamic era. In response to this, however, armchair introspection makes it appear to us that, for instance, an approach along the lines of Karttunen and Peters can be upgraded so as to cover the principles and parameters of the most successful theory of van der Sandt.[16] The details need not concern us here. Surely the burden of the proof that presupposition presupposes a dynamic notion of meaning, is on the ones who like to stand up and claim that it does.

Other forms of conjunctions Systems of dynamic semantics generally focus on the interaction between meaning and context in one dimension only, that of the temporal succession of assertions or that of the 'left-to-right' ('top-to-bottom') order of written contributions. This holds for most dynamic accounts of intersentential anaphoric relationships, as well as for dynamic accounts of presupposition. On both accounts interpretation involves some kind of one-way traffic, a permanent movement from what has been established to what is yet to come. This elegant simplification characterizes both the update notion of meaning of *DPL* and related systems, as well as the *APL*-notion of conjunction.

However, to our opinion, the study of the dynamics of interpretation should be concerned with the more general question of what (pronominal and non-pronominal) resolutions, equations and projections may take place when information from two different sources gets merged. This issue does not only concern linguistic conjunction in discourse, but the evaluation of utterances and phrases relative to contexts more in general. Here we not only want to include indexical, conditional and quantified contexts, but also functional application, or even any from of distributed information.

It appears to us that, for a generalization of the envisaged kind, a system like *APL* constitutes a safer point of departure than an update semantic

16. Karttunen and Peters' implicatures can be looked upon as semantic interpretations of van der Sandt's discourse representation theoretic *representations* of presuppositions, and their framework could quite naturally accommodate semantic / pragmatic correlates of van der Sandt-style mechanisms of projection, accommodation and binding.

framework. In an update semantics the linear perspective on interpretation is hard-wired into the notion of meaning itself, while the incremental aspects of interpretation in APL are characteristic of its notion of conjunction only. Consequently, it seems, the dynamics of merging information is easier generalized in APL, where it involves adjusting its notion of conjunction, than in an update semantics, where it seems to require an adjustment of the underlying notion of meaning itself.

More in detail, it can be observed that linguistic meaning relates to context in many ways, and that it is not always concerned with the preceding discourse context only. Demonstrative pronouns and names constitute an interesting case in point. They have to be resolved in the context, too, but in a non-linguistic one. Besides, their anaphoric potential is entirely different from that of anaphoric pronouns and indefinite noun phrases. Yet other forms of contextual dependence are *kataphoric* relationships, or interdependencies which go both ways, as in Bach-Peters sentences. One may also think of the conjunction of information presentend at two internet pages which refer to each other.

Apparently there exists quite a variety of ways of merging information, which one should like to be able, in principle, to account for. Of course, one could get along by positing a *semantically* multiply ambiguous notion of conjunction, but we think this not to be a necessary or even welcome move. Instead, we opt for acknowledging it to be a pragmatic variety, a variety of merging information which is pragmatically derived from one basic notion of information conjunction.

From this more general perspective it is hard to see how the notion of a context change potential would fit in. Systems of update semantics seem to delimit the dynamics of conjunction to one specific form of contextual resolution, which is hardly seen to generalize to other forms. But the notion of conjunction as composition also resists being reduced to (static) conjunction. The dynamic notion of conjunction of APL does fit the general perspective better. As was pointed out above, the APL notion of conjunction is a temporally adjusted form of set intersection. For this reason it can be suitably allocated to the more pragmatic variety of merging information, which is derived from the classical notion of conjunction in a perspicuous (Fregean) way.

6 Conclusion

In agreement with Grice's dictum that meanings are not to be multiplied beyond necessity, we think it worthwhile, in general, to dissect pragmatically driven variation of information from semantic content. Surely, this does not deny the unmistakable pragmatic effects upon interpretation, which are systematic indeed. These pragmatic effects simply should not lead us to sacrifice our underlying semantic notion of meaning. What we need, in our opinion, is a semantically motivated notion of meaning sufficiently qualified to interact with pragmatic principles, so as to enable us to model the dynamics of interpretation.

With this paper we have tried to contribute to this issue. With regard to the interpretation of intersentential anaphoric relationships, we have tried to determine where the dynamics of interpretation enters semantic theory. In section 3 we have shown it is not in the notion of meaning. In section 4 we argued that the dynamics of interpretation, as standardly modeled, really involves the temporal or linear structure of discourse. In section 5 we finally considered the preceding results from a more general and programmatic perspective, and argued that a more general account of the contextual merging of information is called for. In the meantime, we found that, although the logic of anaphora and presupposition apparently motivates a notion of dynamic interpretation, it does not presuppose a dynamic notion of meaning.

The key features of systems like *SPL* or *APL* are the following. Firstly, a distinction is made between 'free' and 'binding' variables and the binding variables of a formula are counted. Secondly, the semantics has the form of a satisfaction relation. Thirdly, a notion of conjunction is adopted which can be properly called dynamic. The first feature is fully motivated by the observations of Lewis and Heim about the special behavior of indefinite noun phrases. The definition of a Tarskian satisfaction relation relative to sequences of individuals is fairly standard. No locutions involving 'changing contexts' are involved in motivating these two features of *SPL* and *APL*.

Surely, however, in both systems the proposed notion of conjunction is dynamic: it involves binding of free variables (pronouns) in one conjunct by binding variables (existentials) in the other. But does this show our semantics to be 'dynamic' after all? We don't think so. The fact that a certain formal system accommodates an operation which can be called 'dynamic' does not at all show that the basic objects of that system are dynamic. Our basic semantic objects are sets of variables and sets of variable assignments and there is nothing dynamic about them.[17]

The interpretation of intersentential anaphora appears to require a special notion of information about free variables and a proper treatment of presupposition projection and accommodation seems to require some notion of information structure involving a distinction between backgrounds and assertions. Surely the two types of structure are motivated by the characteristic roles which the structures play in discourse, because the notions have been developed to enable an account of this characteristic behavior in the first place. However, the fact that information needs some structure in order to account for the ways in which it merges in discourse and dialogue, simply does not serve to show that meanings are context change potentials.

This paper may serve to show that those are wrong, who believe that a dynamic notion of meaning is key to the understanding of anaphora and presupposition. However, we also think it serves to show that those are wrong, who believe that a dynamic semanticist would have to believe so in the first place. The moral of this paper can be given a more constructive turn. If, as we argue, systems of dynamic interpretation do not presuppose a dynamic notion of meaning, these systems can be *sold* to people who do not want to *buy* a dynamic notion of

17. Very much the same observation can be made with regard to standard predicate logic. The interpretation of an existentially quantifying formula $\exists x\phi$ can be properly called dynamic, since it may involve a *change* of the current context (variable assignment) into a different one, for a proper evaluation of the quantified formula ϕ. But does this show (static) predicate logic to be dynamic? If it would, the term *dynamic* would lose much of its bite.

meaning. We think this to be solid PR.

Dynamic and *DRT*-style theories of anaphora and presupposition have more to offer than just a semantics for pronouns and presuppositions. Both are concerned with the logic of updating contexts and with the dynamics of reasoning. These constitute highly respectable and important subjects of study by themselves, and the only qualification we offer about that area of work is that it does not presuppose a queer notion of meaning.

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