Dynamic Semantics with Choice Functions

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1 INTRODUCTION

Over the last two decades, semantic theory has been marked by a continuing shift from a static view of meaning to a dynamic one. The increasing interest in extending semantic analysis from isolated sentences to larger units of discourse has fostered the intensive study of anaphora and coreference, and this has engendered a shift from viewing meaning as truth conditions to viewing it as the potential to change the "informational context".

One of the central problems of discourse analysis is the treatment of anaphoric expressions, of discourse pronouns and definite NPs. The traditional solution is to take pronouns as bound variables and to analyze definite NPs by means of the Russellian iota inversum operator; and this solution is usually taken over also by those semantic theories which take the dynamics of language at face value. However, as we try to show, theories falling in with this approach necessarily stop half way in the dynamic enterprise and, therefore, cannot achieve a satisfactory semantical analysis of anaphora.

In the present paper we propose to apply the dynamic approach uniformly to all expressions. We give a dynamic treatment not only to meanings of sentences and supersentential units of discourse, but also to those of pronouns and NPs. This is possible by exploring the intuitive idea of salience and by its formalization by means of choice functions. A definite NP *the P* is taken to refer to the most salient P (to that entity which is yielded by the actual choice function for the set of all P's); discourse pronouns are then considered as equivalent to certain definite NPs. Thus, the mechanism of choice manages to supplant both the apparatus of binding of variables (or discourse markers), on the one hand, and the Russellian analysis of definite NPs, on the other. This enables us to represent all anaphoric expressions uniformly. Salience, however is not a global and static property of a discourse, but rather a local and dynamic one - an indefinite NP can change a given salience by raising a new entity to the most salient one.[1] Therefore, a linguistic expression is semantically characterized neither by its truth conditions, nor by its potential to

*This paper has resulted from (1) the research project "Semantics of natural language" developed by Peregrin under the support of the research grant 70/94 of the Charles University; (2) the research of choice functions and natural language that were developed by von Heusinger together with U. Egli in the project 645/94 “Interaktion von Wort- und Semantik” supported by the German Science Foundation. Further, we should like to express our thanks to the Deutscher Akademische Austauschdienst, who supported us in the exchange program between the Charles University in Prague and the University of Konstanz.

[1]See Sgall et al. (1986), esp. §1.35. Choice functions, as we employ them, can plausibly be seen as a way of explicating "the hierarchy of activation of the elements in the stock of knowledge that the speaker assumes to be shared by the hearer" (ibid., p.55).

change assignments of individuals to some artificial syntactic objects such as variables or discourse markers, but rather by its *salience change potential*, which we formalize as its potential to change the actual choice function.

In an utterance such as *a man walks*, the indefinite NP *a man* is taken to refer to an arbitrarily chosen element of the class of men, and this individual is in the same time taken to update the actual choice function in such a way that it becomes the value of the function for the class of men (i.e. it becomes the most salient man).[2] A subsequent anaphoric expression like *the man* in *the man whistles* is then interpreted according to this updated choice function - and, therefore, comes to refer to the same individual that was introduced (arbitrarily chosen) by the indefinite NP in the preceding utterance. The pronoun *he* in *he whistles* is interpreted in the same way; it refers to the referent that was introduced by the indefinite NP *a man*.

The present theory is worked out as a modification of Groenendijk & Stokhof's (1991) dynamic logic and is hence based on the idea of treating the meaning of a sentence as the relation between its "input" and "output" referential links; it differs from Groenendijk and Stokhof's classical version of dynamic logic in formalizing referential links not by means of assignments of objects to discourse markers, but rather by means of choice functions. This makes it possible to analyze NPs not via quantifiers, but instead simply as terms (already Hintikka 1974); and consequently to dispose of any kind of variables or discourse markers, thus making the structure of semantic representation straightforwardly correspond to that of the analyzed discourse.[3] Furthermore, atomic formulas are taken to be both internally and externally dynamic. The theory assumes, together with discourse representation theories (cf. Kamp 1981 and Heim 1982), that anaphora and definiteness are two sides of the same familiarity principle; we take definiteness to presuppose not simply the unique existence, but rather the unique referential availability. However, we do not assume that this forces us to represent anaphora by means of binding. We agree with E-type analyses (Evans 1977, Neale 1990, Heim 1990, van Eijck, 1993) that discourse pronouns are definite descriptions, but we do not agree that this kind of definiteness could be explicated in the Russellian way. We prefer to employ an Hilbertian treatment of definite expressions with the epsilon operator, which substitutes the Russellian uniqueness condition by the principle of choice. Since Hilbert's epsilon operator, which we thus engage instead of Russell's iota inversum, expresses a global and static choice function, we have to make this function context dependent (cf. Egli 1991, von Heusinger 1995, 1996, 1997), which we realize by embedding

[2]Let us clear away a possible misunderstanding, which often occurs with respect to dynamic semantics. To facilitate readability, we sometimes speak about the meaning of a dynamically interpreted statement as if about a process - but it must be kept in mind that this is nothing more than a metaphor. The sole aim of logical analysis and logical formalization, which is what we pursue in this paper, is the articulation of truth conditions, it is not a description of any processes which might go in speakers' heads or wherever. The shift from truth conditions to a context change potential must not be literally seen as a shift to the description of some mental events underlying discourse utterances - we do not see semantics as a part of psychology. The specificum of dynamic logic is that it realizes that truth conditions of certain larger units of discourse (*A man walks. He whistles*) cannot be constructed by simply adding up truth conditions of its parts - some of the parts (*He whistles*) might simply lack their own truth conditions. So in order to arrive at truth conditions of some larger wholes we need more than truth conditions of the basic units, i.e. of sentences, we need what has come to be called *context-change potential*. However, what we do in specifying this context-change potential cannot be literally understood as describing the raising of an object to salience - we merely say that a sentence containing the NP may be true *only if* there exists an object which may be thought of as associated with the NP - whichever this object may be. If there are more such objects, then there is no question of the choice of a particular one.

[3]This accomplishment is what Quine (1986, p.15) considers "a major step in conceptual analysis". Cf. also Peregrin (2000c).

them into the Groenendijko-Stokhofian framework.[4]

The paper is organized in the following way. In section 2 we discuss the motivation for dynamic semantics as rooted in the shift from sentence semantics to discourse semantics. Connected with this shift we can perceive at least three kinds of important, and mutually interrelated problems: the basic problem of the compositional analysis of an anaphora-laden discourse, the problem of how to account for crossreference - where possible - by linguistic means, and the problem of a uniform representation of anaphoric expressions. We show that dynamic logic, although it solves - besides other - the first of these problems in a very elegant way, does not really tackle the other two. Anaphoric NPs continue to be analyzed via Russellian definite descriptions governed by the problematic uniqueness condition, and the right resolution of anaphoric links is simply presupposed. In section 3 we propose our modification of dynamic logic that would solve the latter two of the mentioned problems. We give the definition of the apparatus and we show how to apply it. Then we hint at various ways of extending the apparatus with the aim to cover further linguistic data; and, of course, we cannot avoid giving our own account of donkey sentences. Finally, we discuss further extensions of our theory to other quantifiers and events. In section 4 we give the conclusion.

2 THE DYNAMIC VIEW AND ITS INTRICACIES

2.1 The classical problem

The new problems brought about by extending analysis from isolated sentences to larger units of discourse and texts were extensively discussed by Geach (1962). He used classical predicate logic; examining (1) he arrived at the straightforward analysis (1′).

(1) A man walks. He whistles

(1′) $\exists$x (man(x) & walk(x) & whistle(x))

It is easy to see that (1′) is an adequate analysis of (1); and we should expect the two sentences constituting (1) to be analyzable in such a way that the two analyses would add up to (1′). However, although there is no problem with analyzing (2) as (2′), there is no straightforward way to analyze (3):

(2) A man walks

(3) He whistles

(2′) $\exists$x (man(x) & walk(x))

(3′) ???

[4]The idea of employing Hilbert's epsilon operator for the purpose of analyzing indefinite NPs in a way analogous to the employment of Russell's iota inversum for the purpose of analyzing definite NPs by means of his iota inversum is of course far from really new. However, this idea is not easy to exploit, as the nature of the epsilon operator differs from that of the iota inversum one (the former clearly does not render the indefinite article as the name of a definite function in a way corresponding to the latter's rendering the definite article as the name of the function mapping singletons on their single elements). See Peregrin (2000a).

This is the most general problem; we can call it *the problem of compositionality*. Another, affiliated and more specific, problem, concerns the link between the anaphoric pronoun *he* and its antecedent *a man* in (1). We cannot analyze (2) and (3) independently, because the argument of *man* in (2) and that of *whistle* in (3) are to be bound by the same quantifier. We shall call this *the problem of coreference*. A third problem was mentioned by Evans (1977), who criticized the Geachian way of representing pronouns as bound variables: he showed that this representation is too strong and yields inadequate truth conditions. Evans himself proposed to represent pronouns as definite descriptions which obtain their descriptive material from the antecedent sentence (plus context). However, this analysis raises new problems: the uniqueness condition implied by the Russellian analysis of definite descriptions is still too strong. We will call this problem *the problem of definite description*.

The development of a new family of semantic theories, all of which are based on a dynamic notion of meaning, was stimulated especially by a desire to solve the general problem of compositionality. Some of the most influential among them (esp. Groenendijk & Stokhof, 1991) adhere to the Geachian tradition in representing anaphoric pronouns as bound variables. An alternative view stems from Evans and represents discourse pronouns as definite descriptions (Evans 1977, Slater 1986, Neale 1990, Heim 1990, Chierchia 1992, van der Does 1993). However, such theories fail, or have difficulties, in solving the problem of definite descriptions.

2.2 The way of dynamic logic

Groenendijk & Stokhof (1991) offered an elegant solution to the problem of compositionality - they introduced a "dynamic version" of the existential quantifier, a version which binds variables even outside what would traditionally be considered as its scope. (The side effect of this move is that variables loose something of their essential character and that they become what Groenendijk & Stokhof call *discourse markers*.)[5] If we denote this version of the existential quantifier as $\exists_{dyn}$, we can analyze (2) as (2″) and (3) as (3″); the concatenation of these two formulas is then taken to yield (1″) (by way of a suitable dynamic redefinition of &), which can be seen to be - after “de-dynamization” - equivalent to (1′).

(2″) $\exists_{dyn}\mathrm{d}_1$ (man(d_1) $\&_{dyn}$ walk(d_1))

(3″) whistle(d_1)

(1″) $\exists_{dyn}\mathrm{d}_1$ (man(d_1) $\&_{dyn}$ walk(d_1)) $\&_{dyn}$ whistle(d_1)

The key to the dynamization of $\exists$ is that instead of taking the semantic value of a sentence to be a truth value it is taken to be a relation between assignments of values to discourse markers.

However, Groenendijk & Stokhof’s solution is less satisfactory on closer inspection. Our success in analyzing (2) and (3) was conditioned by the fact that we used the same discourse marker in both formulas - if we used d_1 in (2) and d_2 in (3), then we would have *not* been successful. However, if the problem is to give *independent* analyses of (2) and (3) in such a way that they could be straightforwardly concatenated into the adequate analysis of (1), then Groenendijk & Stokhof’s method evidently falls short of solving it - if we analyze (3) independently of (2),

[5] In contrast to the theories of Kamp and Heim, Groenendijk and Stokhof tried to retain as much traditional logic as possible; and they managed to show that the dynamics of discourse does not necessarily call for a framework which would eschew the basic principles of traditional logical analysis. See also Peregrin (2000b).

then the composition could work only by pure chance. The point is that analyzing (3) we can see no reason for employing d_1 rather than, say, d_2 - we can see no reason to favour one discourse marker over another. The problem seems to be rooted in the nature of discourse markers - like variables they are not anchored to any overt items of natural language, but unlike variables they are not equivalent - whistle(d_1) is not a formula equivalent with whistle(d_2).

In fact, this is only a new reincarnation of the traditional problem of how to get the antecedent of an anaphoric term. The traditional way to handle this is to interlock coreferring expressions by means of coindexing - but this clearly does not solve the problem, but only moves it outside of the theory. It is assumed that our formal model starts where coindexing, and hence anaphora resolution, is already done. Groenendijk & Stokhof accepted this common policy; they assume that the choice of right discourse markers is something which is either taken for granted, or at least a job for someone else.

2.3 Definite descriptions

Discourse representation theories (Kamp 1981, Heim 1982) reduce definiteness to the principle of familiarity according to which a definite expression refers to a familiar or already introduced discourse referent. In this way, definite and indefinite NPs can both be represented as terms (or as variables). However, such theories usually do not distinguish between different familiar discourse referents, i.e. they do not solve the problem of coreference. Dynamic logic, by contrast, usually keeps - in effect - to the classical representation of indefinite NPs as existential quantifiers and definite NPs as Russellian iota terms.

Even the dynamic interpretation of indefinite NPs with non-deterministic programs, as proposed by van Eijck, although in some aspects similar to our employment of choice functions, still cannot escape this Russellian predicament. Van Eijck (1993, p. 240) writes: "[...] in a dynamic set-up the interpretation of an indefinite description can be viewed as an act of picking an arbitrary individual, i.e. as an indeterministic action". Therefore, instead of employing the (dynamic) existential quantifier, he uses a dynamic eta term for representing indefinite NPs. The eta operator is not interpreted as a term-creating operator, but rather as dynamic quantifier: "Note that η and ι are program building operators (in fact, dynamic quantifiers) rather than term building operators, as in the logic of Hilbert & Bernays" (van Eijck 1993, p. 245). Furthermore, definite noun phrases are treated according to the Russellian uniqueness condition interpreting definite noun phrases: "It is not difficult to see that this [i.e. the interpretation conditions for ι] results in the Russell treatment for definite descriptions." (ibid.). This indicates that even this modification of dynamic logic does not suceed in applying the dynamic approach in a way such as to dispose of the classical framework which would seem to be responsible for posing the classical problems.

3 DYNAMIC LOGIC WITH CHOICE FUNCTIONS

3.1 A sketch of the solution

Here we would like to attack the classical problem via a new approach; we propose a modification of dynamic logic which makes do without discourse markers and hence without quantifiers. The idea, taking its cue from the considerations of von Heusinger (1997), is simply to replace assignment of values to discourse markers by Hilbertian choice functions. Roughly speaking, we can say that if we encounter an indefinite noun phrase, then we do not introduce anything like a discourse marker that would be assigned a referent; instead we let the referent be associated with the noun phrase itself via the extension of its predicative part.

Formally, we introduce *epsilon functions* as functions from the power-set of the universe into the universe such that if e is an epsilon function, then e(s) $\in$ s for every subset s of the universe.[6] An epsilon function is thus a *choice* function: it chooses "representatives" of subsets of the universe. Semantic values of sentences are then taken to be relations between epsilon functions - this means that we can look at a sentence as something that gets an input epsilon function and yields (indeterministically) an output epsilon function.

The basic idea is that an occurrence of an indefinite noun phrase *a(n) N* obliges the actual epsilon function to choose a representative of the extension of N, and that a subsequent occurrence of the definite noun phrase *the N* can be taken to refer to this very element. Let us consider (1); i.e. (2) followed by (3). Let us assume that there is an epsilon function e which is input to (2). The evaluation of (2) results in an output epsilon function e$'$ which is just like the input function e save for the single possible difference that there is a representative of the class of men (who walks), i.e. that there is a d$\in\|$man$\|$ such that e$'$($\|$man$\|$)=d and d$\in\|$walk$\|$. This function is passed to (3) which can then identify d as the referent for *the man*. According to this intuitive motivation we make the preliminary assumption that the definite article is formalized as an "epsilon test" whereas the indefinite article is represented as an epsilon update that changes the actual epsilon function.

3.2 The theory

Let us assume that we have the non-empty universe U of individuals. An *epsilon function* (or a *choice function*) f is a partial function from the power-set of U into U such that f(s)$\in$s for every s$\subseteq$U for which f is defined. This means that the class EPS$_U$ of all epsilon functions based on U is defined as follows (where D(f) and R(f) denote the domain and the range of f, respectively):[7]

DEF1. EPS$_U$ = {f | D(f)$\subseteq$Pow(U) and R(f)$\subseteq$U and f(s)$\in$s for every s$\in$D(f)}

We further define *update functions* for epsilon functions, or *epsilon updates* in short. An epsilon update is a function of three arguments: if it is fed an epsilon-function, an element of the universe and a subset of the universe, it yields a new epsilon function. So formally we define

DEF2. UPD = {f | D(f)=EPS$\times$U$\times$Pow(U) and R(f)$\subseteq$EPS}

[6]Epsilon functions have been extensively studied by Hilbert and Bernays (1939); however, let us keep in mind that Hilbert's motivations, and consequently also his theory of epsilon functions, was quite different from the present one. See Peregrin (2000a)

Recently, choice functions have been employed for representing indefinite NPs with certain scope behaviors. See Reinhart (1997), Winter (1997), Kratzer (1998) among others. However, this analysis is neither extended to definites or anaphoric expressions, nor is it integrated into a dynamic framework.

[7]Some further restrictions might be added; we might for example require that for every epsilon function e, e($\emptyset$) is undefined, i.e. that the empty class is never assigned a representative. Or we might stipulate that for every epsilon function e and for every element d of the universe, e({d})= d (i.e. that the singleton of d is always automatically represented by d); this would make our analysis work also in cases where the classical Russellian mechanism for interpreting definite descriptions were required. We do not explore this here – since this paper aims only to bring out the basic principles, not to elaborate details.

The basic epsilon-update, which we shall denote as upd_1, is such that if it is applied to an epsilon function e, an individual d and a set s, then it outputs the epsilon function e′ which is just like e with the single possible exception that if d∈s, then e′(s)=d.

DEF3. upd_1 is the element of UPD defined as follows

$$\mathrm{upd}_1(e,d,s)(s') = \left\langle \begin{array}{l} d \text{ if } s'=s \text{ and } d\in s \\ \\ e(s') \text{ otherwise} \end{array} \right.$$

We shall write $e'=e^s$ as the shorthand for $\exists d.e'=\mathrm{upd}_1(e,d,s)$.[8] If $e_2={e_1}^s$ and $e_3={e_2}^{s'}$, then we shall also write $e_3={e_1}^{s,s'}$. upd_1 can be seen as the first approximation to the explication of an indefinite NP's salience change potential: an indefinite NP *a man* can be thought of as selecting an arbitrary man and changing the actual epsilon function so that the arbitrarily chosen man becomes the current representative for the class of men.

Now we can define a fragmentary language to illustrate how epsilon functions can be used to build dynamic semantics. We do it in three steps, describing the lexicon, the syntax and the semantics.

DEF4a. (lexicon)

There are the following categories of expressions; the constants of each category (if any) are listed in brackets:

1. sentences
2. terms (constants **he**, **she**, **it**)
3. n-ary predicates for n>0 (constants **man**, **walk**, **whistles**, **farmer**, **boring**, **woman**, **thing** for n=1; **own** and **beat** for n=2)
4. determiners (constants **a**, **the**)
5. n-ary logical operators for n=1,2 (the constant $\neg$ for n=1; $\vee$ and **;** for n=2)
6. quantifiers (constants **some**, **every**)

Note that there are neither variables, nor discourse markers within our language. This is made possible by the fact that we represent indefinite NPs as terms expressing epsilon updates, and that we do not treat anaphoric relations in any way evocative of the binding of predicate logic.

DEF4b. (syntax)

1. If P is a unary predicate and D a determiner, then D(P) is a term.
2. if $T_1,...,T_n$ are terms and R an n-ary predicate, then $R(T_1,...,T_n)$ is a sentence.
3. If S is a sentence and o a unary logical operator, then oS is a sentence.
4. If S_1 and S_2 are sentences and o a binary logical operator, then $S_1 o S_2$ is a sentence.
5. If Q is a quantifier and S_1, S_2 sentences, then $Q(S_1,S_2)$ is a sentence.

[8] $e' = e^s$ thus expresses a relation between two epsilon functions, it says that e′ differs from e at most in respect to the representative of s.

DEF4c. (semantics)

A model is a pair <U,$\|\ \|$>, where U is a set and $\|\ \|$ is a function such that (i) if T is a term, then $\|T\| \in U$; (ii) if R is an n-ary predicate, then $\|R\| \in U^n$. If T is a term and $e \in EPS_U$, then we define the value $\|T\|_e$ in the following way:

$$\|T\|_e = \begin{cases} \|T\| \text{ if T is a constant term} \\ e(\|P\|) \text{ if T is D(P) for a determiner D and a predicate P} \end{cases}$$

We extend the function $\|\ \|$ to the categories of terms and sentences so that if E is a term or a sentence, then $\|E\| \subseteq$ EPSxEPS:

1a. $\|\mathbf{a}(P)\| = \{<e,e'>|\ e'=e^{\|P\|}\}$

1b. $\|\mathbf{the}(P)\| = \{<e,e'>|\ e'=e$ and $e'(\|P\|)$ is defined$\}$

1c. $\|\mathbf{he}\| = \|\mathbf{the}(\mathbf{man})\|$

1d. $\|\mathbf{she}\| = \|\mathbf{the}(\mathbf{woman})\|$

1e. $\|\mathbf{it}\| = \|\mathbf{the}(\mathbf{thing})\|$

2. $\|P(T_1,...,T_n)\| = \{<e,e'>|$ there exist $e_0,...,e_n$ so that $e=e_0$ and $e'=e_n$ and $<e_0,e_1> \in \|T_1\|$ and... and $<e_{n-1},e_n> \in \|T_n\|$ and $<\|T_1\|_{e1},...,\|T_n\|_{en}> \in \|P\|\}$

3. $\|\neg S\| = \{<e,e'>|\ e=e'$ and there is no e'' such that $<e,e''> \in \|S\|\}$

4a. $\|S_1\mathbf{;}S_2\| = \{<e,e'>|$ there is an e'' such that $<e,e''> \in \|S_1\|$ and $<e'',e'> \in \|S_2\|\}$

4b. $\|S_1 \vee S_2\| = \{<e,e'>|\ e=e'$ and there is an e'' such that $<e,e''> \in \|S_1\|$ or $<e,e''> \in \|S_2\|\}$

5a. $\|\mathbf{every}(S_1,S_2)\| = \{<e,e'>|\ e=e'$ and for every e_1, if $<e,e_1> \in \|S_1\|$, then there is an e_2 such that $<e_1,e_2> \in \|S_2\|\}$

5b. $\|\mathbf{some}(S_1,S_2)\| = \{<e,e'>|\ e=e'$ and there exist e_1 and e_2 such that $<e,e_1> \in \|S_1\|$, and $<e_1,e_2> \in \|S_2\|\}$

Let us add some explanations to bring out the insights behind the apparatus. An indefinite NP *a P* is taken to express an epsilon-update, i.e. its function is taken to be the updating of the actual epsilon function e to a new epsilon function e′. e′ then differs from e at most in the representative of the set of P; the NP is taken to refer to this representative. We write $e^{\|P\|}$ for an e′ resulting from the evaluation of *a P* with the input e.

A definite NP *the P* is taken to refer to the representative of the set of P's according to the current epsilon function; it is taken to express the trivial epsilon-update.[9] Further, it is required that there is at least one P - this expresses the existential presupposition of definite NPs. There is no uniqueness condition - it is replaced by the condition that there exists the representative of the set of P's. A pronoun is defined to be semantically equivalent to the impoverished definite NP expressing merely the corresponding gender.[10]

The atomic sentence is semantically characterized via its potential to change the current epsilon function e to the updated function e′ by way of the subsequent application of the updates expressed by its terms. Thus, e and e′ must be connected by a sequence of epsilon functions such that the adjacent pairs of the sequence fall into the respective updates expressed by the terms; and the referents of the terms must fall into the extension of the predicate. Here we differ essentially from usual dynamic logic in that we consider atomic sentences as internally and externally dynamic.

The logical operators $\neg$ and $\vee$ are static (they act as tests); they are in fact the classical operators only formally dynamized. **;** is the dynamic conjunction suitable for conjoining subsequent sentences. The actual choice of operators is not important (it would, of course, be possible to employ others); it is not important for our present purpose. Note too that our quantifiers are simply other logical operators.

The semantic interpretation for the quantifier **every** consists in the condition that every epsilon function which is an output of its first argument sentence can serve as an input function for the second argument sentence; thus, our **every** is in fact Groenendijk & Stokhof's $\rightarrow$. **every**(S_1,S_2) can be thought about as corresponding to the classical formula $\forall ...(S_1 \rightarrow S_2)$, where $\forall ...$ indicates $\forall$ unselectively binding all what there is to bind in S_1. The condition for **some** is that there is at least one epsilon function which is an output of its first argument acceptable as an input for the second argument; hence it can be imagined as corresponding to $\exists ...(S_1 \rightarrow S_2)$. (**some** corresponds to the cardinality reading of English *some*; that reading of the English word which licenses anaphoric relationships is considered as representable by the operator **a**). Both the quantifiers are externally static, they act as tests; but they are internally dynamic. This accounts for the fact that a term in the first argument sentence can be the antecedent of an anaphoric expression occurring in the second argument.

3.3 Examples of discourse anaphora

In this section we discuss some simple examples illustrating the mechanism of establishing anaphoric links by linguistic means. As already mentioned, we assume that the semantic contribution to finding the adequate antecedent can be described in terms of the salience change

[9] This semantics provides a unified treatment of definite and indefinite NPs. Both determine their referents by using an epsilon function. This similarity of definite and indefinite NPs was pointed out by Egli (1991). See also von Heusinger (1996, 2000).

[10] This view meets the E-type analysis of discourse pronouns; it could be seen as stemming from Quine (1960, 102f.): "Often the object is so patently intended that even the general term can be omitted. Then, since 'the' (unlike 'this' and 'that') is never substantival, a *pro forma* substantive is supplied: thus 'the man', 'the woman', 'the king'. These minimum descriptions are abbreviated as 'he', 'she', 'it'. Such a pronoun may be seen thus as a short singular description, while its grammatical antecedent is another singular term referring to the same object (if any) at a time when more particulars are needed for its identification."

potential of expressions.[11] This salience change can be thought about as a first formal approximation to the intuitive notion of familiarity that is used in traditional grammars and that was introduced into dynamic frameworks by Heim (1982).

We start our analysis with a simple atomic sentence with an indefinite NP.

(4) A man walks

(4′) Walk(a(man))

$$\|\mathrm{Walk(a(man))}\| =$$

$$\{<e,e'>|\ <e,e'>\in\|\mathrm{a(man)}\| \text{ and } \|\mathrm{a(man)}\|_{e'}\in\|\mathrm{walk}\|\} =$$

$$\{<e,e'>|\ e'=e^{\|man\|} \text{ and } e'(\|\mathrm{man}\|)\in\|\mathrm{walk}\|\}$$

Sentence (4) is assigned the formula (4′); this formula is then interpreted according to the definitions given above. As we have noted, a pair of epsilons $<e,e'>$ falls into the update expressed by an atomic sentence iff e and e′ are connected by a sequence of epsilons such that the adjacent pairs of the sequence fall into the respective updates expressed by the terms and the referents of the terms fall into the extension of the predicate. Since we have only one term in (4), this reduces to the condition that $<e,e'>$ falls into the update expressed by *a(man)* and that the referent of *a(man)* falls into the extension of *walk*. This yields $e'=e^{\|man\|}$ and $e'(\|\mathrm{man}\|)\in\|\mathrm{walk}\|$. The resulting set of pairs is clearly non-empty just in case $\exists d.d\in\|\mathrm{man}\|\&d\in\|\mathrm{walk}\|$ (i.e. if the intersection of $\|\mathrm{man}\|$ and $\|\mathrm{walk}\|$ is nonempty); and our formula (4′) is thus in this sense equivalent to the classical formula $\exists x(\mathrm{man}(x)\&\mathrm{walk}(x))$.

(5) The man whistles

(5′) Whistle(the(man))

$$\|\mathrm{Whistle(the(man))}\| =$$

$$\{<e,e'>|\ <e,e'>\in\|\mathrm{the(man)}\| \text{ and } \|\mathrm{the(man)}\|_{e'}\in\|\mathrm{whistle}\|\} =$$

$$\{<e,e'>|\ e=e' \text{ and } e'(\|\mathrm{man}\|)\in\|\mathrm{whistle}\|\}$$

Sentence (5) with the definite NP *the man* is represented and interpreted similarly to (4). The only difference is the condition on the epsilon function - the interpretation of the definite NP is static. The only condition is that the referent of the NP, determined by the actual epsilon function, falls within the extension of the predicate. The difference between the definite and the indefinite NP thus lies in the different behaviour with respect to the epsilon function - the indefinite NP updates it, whereas the definite NP acts merely as a test. In both cases, the referent of the NP is yielded by the actual epsilon function.

The analysis of the concatenation of (4) and (5) now shows how the referent of the anaphoric NP *the man* gets identified with that of its antecedent *a man*.

(6) A man walks. The man whistles

[11]Obviously there are several other non-linguistic factors that influence and rule the relation between the antecedent and the corresponding anaphoric expression, but they are not subject to the present considerations.

(6′) Walk(a(man)); Whistle(the(man))

$\|\text{Walk(a(man)); Whistle(the(man))}\|$ =

$\{<e,e'>|$ there is an e'' such that
$<e,e''>\in\|\text{Walk(a(man))}\|$ and $<e'',e'>\in\|\text{Whistle(the(man))}\|\}$ =

$\{<e,e'>|$ there is an e'' such that
$<e,e''>\in\{<e,e'>|\ e'=e^{\|man\|}$ and $e'(\|\text{man}\|)\in\|\text{walk}\|\}$
and $<e'',e'>\in\{<e,e'>|\ e=e'$ and $e'(\|\text{man}\|)\in\|\text{whistle}\|\}\}$ =

$\{<e,e'>|$ there is an e'' such that $e''=e^{\|man\|}$ and
$e''(\|\text{man}\|)\in\|\text{walk}\|$ and $e''=e'$ and $e'(\|\text{man}\|)\in\|\text{whistle}\|\}$ =

$\{<e,e'>|\ e'=e^{\|man\|}$ and $e'(\|\text{man}\|)\in\|\text{walk}\|$ and $e'(\|\text{man}\|)\in\|\text{whistle}\|\}$

$<e,e'>$ falls into the update expressed by (6′) if and only if there is an epsilon function e'' such that $<e,e''>$ falls into the update expressed by (4′) and $<e'',e'>$ falls into the update expressed by (5′). Using the results of the above analyses and eliminating redundancies, we reach the result that $<e,e'>$ falls into the update expressed by (6′) iff e' differs from e at most in the representative of the class of men and this representative is a walker and a whistler.

This derivation shows the basic mechanism of relating anaphoric expressions to their antecedents; it illustrates how the semantic principle of familiarity can be explicated in terms of the salience change potentials of the expressions involved. The information that a new object is raised to salience can be thought about as passed on by the updated epsilon functions; and since the subsequent definite term is interpreted according to these updated epsilon functions, it comes to refer to the very same object.

Let us now turn our attention to sentences about farmers and donkeys.

(7) A farmer owns a donkey

(7′) Own(a(farmer),a(donkey))

$\|\text{Own(a(farmer),a(donkey))}\|$ =

$\{<e,e'>|$ there is an e'' such that $<e,e''>\in\|\text{a(farmer)}\|$ and $<e'',e'>\in\|\text{a(donkey)}\|$ and
$<\|\text{a(farmer)}\|_{e''},\|\text{a(donkey)}\|_{e'}>\in\|\text{own}\|\}$ =

$\{<e,e'>|$ there is an e'' such that $e''=e^{\|farmer\|}$ and
$e'=e''^{\|donkey\|}$ and $<e''(\|\text{farmer}\|),e'(\|\text{donkey}\|)>\in\|\text{own}\|\}$ =

$\{<e,e'>|\ e'=e^{\|farmer\|,\|donkey\|}$ and $<e'(\|\text{farmer}\|),e'(\|\text{donkey}\|)>\in\|\text{own}\|\}$

(8) The farmer beats the donkey

(8′) Beats(the(farmer),the(donkey))

$\|\text{Beat(the(farmer),the(donkey))}\|$ =

$\{<e,e'>|$ there is an e'' such that $<e,e''>\in\|\text{the(farmer)}\|$ and
$<e'',e'>\in\|\text{the(donkey)}\|$ and $<\|\text{the(farmer)}\|_{e''},\|\text{the(donkey)}\|_{e'}>\in\|\text{beat}\|\}$ =

$\{<e,e'>|$ there is an e'' such that $e''=e$ and $e'=e''$ and $<e''(\|farmer\|),e'(\|donkey\|)>\in\|beat\|\} =$

$\{<e,e'>|\ e'=e$ and $<e'(\|farmer\|),e'(\|donkey\|)>\in\|beat\|\}$

The atomic sentence (7) contains two indefinite NPs. Since both terms lead to modifications of the actual epsilon function, the eventual output function is modified in respect to its values for both the set of farmers and the set of donkeys. For each of the two sets, a new representative is chosen; the two representatives must be such as to stand in the relation of owning. The sentence (8) does not lead to any updating, since both its terms are definite and act as mere tests. Therefore, its output epsilon function is identical with the input one. Again, the concatenation of the two sentences shows how the epsilon function updated by the first conjunct creates a new context according to which the definite expressions in the second conjunct are interpreted.

(9) A farmer owns a donkey. The farmer beats the donkey.

(9′) Own(a(farmer),a(donkey)); Beat(the(farmer),the(donkey))

$\|$Own(a(farmer),a(donkey)); Beat(the(farmer),the(donkey))$\|$ =

$\{<e,e'>|$ there is an e'' such that $<e,e''>\in\|Own(a(farmer),a(donkey))\|$ and $<e'',e'>\in\|Beat(the(farmer),the(donkey))\|\} =$

$\{<e,e'>|$ there is an e'' such that $<e,e''>\in\{<e,e'>|\ e'=e^{\|farmer\|,\|donkey\|}$ and $<e'(\|farmer\|),e'(\|donkey\|)>\in\|own\|\}$ and $<e'',e'>\in\{<e,e'>|\ e'=e$ and $<e'(\|farmer\|),e'(\|donkey\|)>\in\|beat\|\}\} =$

$\{<e,e'>|$ there is an e'' such that $e''=e^{\|farmer\|,\|donkey\|}$ and $<e''(\|farmer\|),e''(\|donkey\|)>\in\|own\|$ and $e''=e'$ and $<e'(\|farmer\|),e'(\|donkey\|)>\in\|beat\|\} =$

$\{<e,e'>|\ e'=e^{\|farmer\|,\|donkey\|}$ and $<e'(\|farmer\|),e'(\|donkey\|)>\in\|own\|$ and $<e'(\|farmer\|),e'(\|donkey\|)>\in\|beat\|\}$

These simple examples show the general principles of linking anaphoric expressions to their antecedents. The indefinite expression changes the informational context so that the subsequent definite expression refers to the object which it has selected. The last example has demonstrated that the epsilon function can carry information about more than one object.

3.4 Improving updates

We have seen that classical examples are adequately analyzable by our apparatus introduced so far; however, there are still simple cases which remain outside its scope. We are now going to show that such cases are analyzable by way of various simple enhancements of the apparatus.

We saw that we were able to adequately analyze (6); and in force of DEF4c (1c) the same holds for (10) - the point is that the semantics of *he* is - by definition - the same as that of *the man*.

(10) A man walks. He whistles

(10′) Walk(a(man)); Whistle(he)

$\|$Walk(a(man));Whistle(he)$\|$ = $\|$Walk(a(man));Whistle(the man)$\|$

This does not work in case of (11) or (12) - *he* is not defined to be semantically equivalent to *the farmer*.

(11) A farmer walks. He whistles

(12) A farmer owns a donkey. He beats it

However, this can be improved by replacing our epsilon update upd_1 in DEF4c (1a) by a slightly more sophisticated version. We distinguish certain mutually disjoint subsets of U, which we shall call *categories*, namely M=$\|$man$\|$, W=$\|$woman$\|$ and T=$\|$thing$\|$, and we assume that the occurrence of *a P* fixes not only the value chosen from $\|$P$\|$, but also that chosen from the category containing $\|$P$\|$ (if any). This means that the occurrence of *a farmer* triggers not only the choice of a representative of the class of farmers, but that it also forces the same individual as the representative of the class of men and thereby as the potential referent for *he*.[12]

DEF5. Let CAT={M,W,T} be a subset of Pow(U) such that M=$\|$man$\|$, W=$\|$woman$\|$ and T=$\|$thing$\|$. Let Ct be the function from Pow(U) into CAT such that if there is a c$\in$CAT such that s$\subseteq$c, then Ct(s)=c and Ct(s) is undefined otherwise.
upd_2 is now the element of UPD defined as follows

$$\mathrm{upd}_2(e,d,s)(s') = \left\langle \begin{array}{l} d \text{ if } (s'=s \text{ or } s'=Ct(s)) \text{ and } d\in s \\ \\ e(s') \text{ otherwise} \end{array}\right.$$

If we now modify 1a of DEF4c by substituting upd_2 for upd_1, we can readily handle both (11) and (12). The point is that now not only $\|$he$\|$ = $\|$the(man)$\|$, but if $e'=e^{\|farmer\|}$, then also e′($\|$man$\|$) = e′($\|$farmer$\|$); similarly if $e'=e^{\|donkey\|}$, then also e′($\|$thing$\|$) = e′($\|$donkey$\|$).

(11′) Walk(a(farmer)); Whistle(he)

$\|$Walk(a(farmer)); Whistle(he)$\|$ =

{<e,e′>| there is an e″ such that
<e,e″>$\in\|$Walk(a(farmer))$\|$ and <e″,e′>$\in\|$Whistle(he))$\|$} =

{<e,e′>| there is an e″ such that <e,e″>$\in${<e,e′>| $e'=e^{\|farmer\|}$ and
e′($\|$farmer$\|$)$\in\|$walk$\|$} and <e″,e′>$\in${<e,e′>| e=e′ and e′($\|$man$\|$)$\in\|$whistle$\|$}} =

[12]In the English case - in contrast to languages like German or Czech - this is not wholly correct, for a NP like *a farmer* does not force a subsequent pronoun to be masculine, it may equally well be followed by *she*. This indicates that the extension of *farmer* must be taken to comprise both male and female farmers, and consequently it does not fall into any single category; thus no representative of the class of men is established, and the use of *he* is not licensed. This means that the success of anaphora resolution in this case is conditioned by the accommodation of the presupposition *The farmer is male* triggered by the second sentence. Again, we do not elaborate on this here but keep with the simple transparent version of the apparatus.

$\{<e,e'> \mid$ there is an e'' such that $e''=e^{\|farmer\|}$ and
$e''(\|farmer\|)\in\|walk\|$ and $e''=e'$ and $e'(\|farmer\|)\in\|whistle\|\} =$

$\{<e,e'> \mid e'=e^{\|farmer\|}$ and $e'(\|farmer\|)\in\|walk\|$ and $e'(\|farmer\|)\in\|whistle\|\}$

(11′) Own(a(farmer),a(donkey)); Beat(he,it)

$\|$Own(a(farmer),a(donkey)); Beat(he,it)$\| =$

$\{<e,e'> \mid$ there is an e'' such that
$<e,e''>\in\|$Own(a(farmer),a(donkey))$\|$ and $<e'',e'>\in\|$Beat(he,it)$\|\} =$

$\{<e,e'> \mid$ there is an e'' such that $<e,e''>\in\{<e,e'> \mid e'=e^{\|farmer\|,\|donkey\|}$ and
$<e'(\|farmer\|),e'(\|donkey\|)>\in\|own\|\}$ and $<e'',e'>\in\{<e,e'> \mid e'=e$ and
$<e'(\|man\|),e'(\|thing\|)>\in\|beat\|\}\}=$

$\{<e,e'> \mid$ there is an e'' such that $<e,e''>\in\{<e,e'> \mid e'=e^{\|farmer\|,\|donkey\|}$ and
$<e'(\|farmer\|),e'(\|donkey\|)>\in\|own\|\}$ and $<e'',e'>\in\{<e,e'> \mid e'=e$ and
$<e'(\|farmer\|),e'(\|donkey\|)>\in\|beat\|\}\} =$

$\{<e,e'> \mid$ there is an e'' such that $e''=e^{\|farmer\|,\|donkey\|}$ and
$<e''(\|farmer\|),e''(\|donkey\|)>\in\|own\|$ and $e''=e'$ and
$<e'(\|farmer\|),e'(\|donkey\|)>\in\|beat\|\} =$

$\{<e,e'> \mid e'=e^{\|farmer\|,\|donkey\|}$ and $<e'(\|farmer\|),e'(\|donkey\|)>\in\|own\|$ and
$<e'(\|farmer\|),e'(\|donkey\|)>\in\|beat\|\}$

We can, of course, go further and let an indefinite noun phrase *a P* update not only the value chosen from $\|P\|$ and that chosen from the corresponding category, but the values chosen from all supersets of $\|P\|$ whatsoever. This would lead to the following simple epsilon-update.

DEF6. upd_3 is the element of UPD defined as follows

$$upd_3(e,d,s)(s') = \left\langle \begin{array}{l} d \text{ if } s\subseteq s' \text{ and } d\in s \\ \\ e(s') \text{ otherwise} \end{array} \right.$$

Plugging upd_3 instead of upd_1 into 1a of Def4c would result into an apparatus which would allow for the right resolution in cases like (12); on the other hand, it might lead to successful resolution also in cases when it is doubtful that such a resolution factually takes place, like in (13).

(12) A boxer walks. The sportsman whistles.

(13) A woodchuck from Hradec Králové walks. The East-Bohemian groundhog whistles.

The right solution seems to be somewhere in between upd_2 and upd_3 - it seems that in order to cross-link *a P* and *the P′* it is not enough that $\|P\|\subseteq\|P'\|$, it is in addition required that it is in some sense *obvious* that $\|P\|\subseteq\|P'\|$. However, on the other hand, if the hearer perceives that there is nothing else to be cross-linked with *the P′* save *a P*, then (s)he may take it as an information about the fact that $\|P\|\subseteq\|P'\|$.[13]

Another kind of problem is posed by proper names. We are as yet unable to account for (14). However, this is easy to repair. Let us add *John* as a new constant to our category of terms, let us write $e'=e^d$ as the shorthand for $e'=upd_3(e,d,\{d\})$; and let us enrich DEf4c by the new clause 1f:

1f. $\|T\| = \{<e,e'>|\ e'=e^{\|T\|}$ if T is **John** (or any other proper name)$\}$

This allows us to give the analysis of (14) (note that if $e'=e^{\|John\|}$, then $e'(\|John\|) = e'(\|man\|)$):

(14) John walks. He whistles

(14′) Walk(John); Whistle(he)

$\|$Walk(John); Whistle(he)$\|$ =

$\{<e,e'>|$ there is an e'' such that $<e,e''>\in\|Walk(John)\|$ and
$<e'',e'>\in\|Whistle(he))\|\}$ =

$\{<e,e'>|$ there is an e'' such that $<e,e''>\in\{<e,e'>|\ e'=e^{\|John\|}$ and
$e'(\|John\|)\in\|walk\|\}$ and $<e'',e'>\in\{<e,e'>|\ e=e'$ and $e'(\|man\|)\in\|whistle\|\}\}$ =

$\{<e,e'>|$ there is an e'' such that $e''=e^{\|John\|}$ and
$e''(\|John\|)\in\|walk\|$ and $e''=e'$ and $e'(\|man\|)\in\|whistle\|\}$=

$\{<e,e'>|\ e'=e^{\|John\|}$ and $e'(\|John\|)\in\|walk\|$ and $e'(\|man\|)\in\|whistle\|\}$=

$\{<e,e'>|\ e'=e^{\|John\|}$ and $e'(\|John\|)\in\|walk\|$ and $e'(\|John\|)\in\|whistle\|\}$

3.5 Donkey sentences

Donkey sentences serve as a touchstone for every semantic theory since they combine several intricate problems. In what follows, we try to show how we can cope with this kind of sentence within the proposed framework. The main problem is how an indefinite NP embedded in the restrictive clause can furnish the antecedent for a subsequent expression. This is the case of the indefinite NP *a donkey* in (15).

(15) Every farmer who owns a donkey beats it

Before we analyze this sentence, let us inspect a simpler one to see how the definition of the universal quantifier works.[14]

[13]It might seem that we need an update changing not only supersets of the class referred to by the predicative part of the indefinite NP, but also its subsets. We may follow the utterance *A sportsman walks* by *The boxer whistles* and get the referent of *the boxer* to be identified by that of *a sportsman*, although the class of boxers is a subclass of that of sportsmen rather than its superclass. But this anaphora resolution is not "automated" -it is conditioned by the accommodation of a substantial presupposition triggered by the second utterance, namely *The sportsman is a boxer*; therefore we do not recommend that it should be accounted for in our present terms.

[14]Note that as our semantics is such that sentences are assigned the same type of semantic values as terms (namely sets of pairs of epsilon functions), it would be only a trivial matter to extend our quantifiers so as to accept as arguments not only sentences, but also terms. Then (16′) could be alternatively stated as *every(a(farmer),boring(the farmer))*, which corresponds straightforwardly to the natural language *Every farmer is boring*.

(16) Every man who is a farmer is boring

(16′) every(farmer(a(man)),boring(the(man)))

$\|\text{every(farmer(a(man)),boring(the(man)))}\| =$

$\{<e,e'> \mid e=e'$ and for every e_1, if $<e,e_1> \in \|\text{farmer(a(man))}\|$,
then there is an e_2 such that $<e_1,e_2> \in \|\text{boring(the(man))}\|\} =$

$\{<e,e'> \mid e=e'$ and for every e_1, if $<e,e_1> \in \{<e,e'> \mid e'=e^{\|man\|}$ and
$e'(\|man\|) \in \|farmer\|\}$, then there is an e_2 such that
$<e_1,e_2> \in \{<e,e'> \mid e'=e$ and $e'(\|man\|) \in \|boring\|\}\} =$

$\{<e,e'> \mid e=e'$ and for every e_1, if $e_1=e^{\|man\|}$ and $e_1(\|man\|) \in \|farmer\|\}$,
then there is an e_2 such that $e_2=e_1$ and $e_2(\|man\|) \in \|boring\|\} =$

$\{<e,e'> \mid e=e'$ and for every e_1, if $e_1=e^{\|man\|}$ and
$e_1(\|man\|) \in \|farmer\|\}$, then $e_1(\|man\|) \in \|boring\|\} =$

$\{<e,e'> \mid e=e'$ and $\|man\| \cap \|farmer\| \subseteq \|boring\|\}$

The analysis of the sentence yields a test that succeeds if every output epsilon function of the first clause can serve as an input to the second clause. One branch of the test can be imagined as, first, picking up a new representative of the set of men such that he is a farmer (the first clause), and, second, testing whether this representative is boring (the second clause); the whole test is successful if all such possible branches are. The testing is independent of an input epsilon function, i.e. either every epsilon function passes it, or none does.

The crucial problem of donkey sentences is solved by quantifying over epsilon functions instead of over individuals, which is the result of our disposal of variables and binding. The problem concerns the anaphoric link between the embedded indefinite NP *a donkey* and the pronoun *it* - this link cannot be accounted for by the classical means of variable binding, since the pronoun has to be located outside the scope of the quantifier governing the indefinite NP. Since we do not establish anaphoric links in terms of binding, but rather via context information, this problem fades away. The analysis of a sentence such as (15) proceeds straightforwardly.

(15′) every(Own(a(farmer),a(donkey)),Beat(he,it))

$\|\text{every(Own(a(farmer),a(donkey)),Beat(he,it))}\| =$

$\{<e,e'> \mid e=e'$ and for every e_1, if $<e,e_1> \in \|\text{Own(a(farmer),a(donkey))}\|$,
then there is an e_2 such that $<e_1,e_2> \in \|\text{Beat(he,it)}\|\} =$

$\{<e,e'> \mid e=e'$ and for every e_1, if $<e,e_1> \in \{<e,e'> \mid e'=e^{\|farmer\|,\|donkey\|}$ and
$<e'(\|farmer\|),e'(\|donkey\|)> \in \|own\|\}$, then there is an e_2 such that
$<e_1,e_2> \in \{<e,e'> \mid e'=e$ and $<e'(\|farmer\|),e'(\|donkey\|)> \in \|beat\|\}\} =$

$\{<e,e'> \mid e=e'$ and for every e_1, if $e_1=e^{\|farmer\|,\|donkey\|}$ and
$<e_1(\|farmer\|),e_1(\|donkey\|)> \in \|own\|\}$, then there is an e_2 such that
$e_2=e_1$ and $<e_2(\|farmer\|),e_2(\|donkey\|)> \in \|beat\|\} =$

$\{<e,e'> \mid e=e'$ and for every e_1, if $e_1=e^{\|farmer\|,\|donkey\|}$ and
$<e_1(\|farmer\|),e_1(\|donkey\|)> \in \|own\|\}$,
then $<e_1(\|farmer\|),e_1(\|donkey\|)> \in \|beat\|\}$

Again, the whole expression acts as a test that succeeds if every epsilon function resulting from interpreting the first clause can successfully act as input for the second clause. Since there are two indefinite NPs within the first clause, they both modify the input epsilon function, and so we have to apply the test connected with the second clause to all such functions differing from the basic output of the whole sentence in the representatives of the class of farmers and donkeys which pass the test connected with the first clause. Thus the anaphoric relation is encoded in the context information and in this way it can cross the scope of the indefinite NP.[15]

3.6 Events

Another way to enhance our apparatus is by the introduction of events and event-quantification. A way to do this is to introduce the new category E coinciding with the extension of the new predicate **event**, and to add the new constants terms **then**, **once**, whose semantics is defined as follows:

$\|\mathbf{then}\| = \|\mathbf{the}(\mathbf{event})\|$
$\|\mathbf{once}\| = \|\mathbf{a}(\mathbf{event})\|$

Then we can analyze (17) as follows:

(17) If a farmer owns a donkey, he beats it.

(17′) every(Own(once,a(farmer),a(donkey)),Beat(then,he,it)).

$\|\text{every(Own(once,a(farmer),a(donkey)),Beat(then,he,it))}\|=$

$\{\langle e,e'\rangle \mid e=e'$ and for every e_1, if $\langle e,e_1\rangle \in \|\text{Own(once,a(farmer),a(donkey))}\|$,
then there is an e_2 such that $\langle e_1,e_2\rangle \in \|\text{Beat(then,he,it)}\|\} =$
$\{\langle e,e'\rangle \mid e=e'$ and for every e_1, if $\langle e,e_1\rangle \in \{\langle e,e'\rangle \mid e'=e^{\|event\|,\|farmer\|,\|donkey\|}$ and
$\langle e'(\|\text{event}\|),e'(\|\text{farmer}\|),e'(\|\text{donkey}\|)\rangle \in \|\text{own}\|\}$, then there is an e_2 such that
$\langle e_1,e_2\rangle \in \{\langle e,e'\rangle \mid e'=e$ and $\langle e'(\|\text{event}\|),e'(\|\text{farmer}\|),e'(\|\text{donkey}\|)\rangle \in \|\text{beat}\|\}\} =$
$\{\langle e,e'\rangle \mid e=e'$ and for every e_1, if $e_1=e^{\|event\|,\|farmer\|,\|donkey\|}$ and
$\langle e_1(\|\text{event}\|),e_1(\|\text{farmer}\|),e_1(\|\text{donkey}\|)\rangle \in \|\text{own}\|$, then there is an e_2
such that $e_2=e_1$ and $\langle e_2(\|\text{event}\|),e_2(\|\text{farmer}\|),e_2(\|\text{donkey}\|)\rangle \in \|\text{beat}\|\} =$
$\{\langle e,e'\rangle \mid e=e'$ and for every e_1, if $e_1=e^{\|event\|,\|farmer\|,\|donkey\|}$ and
$\langle e_1(\|\text{event}\|),e_1(\|\text{farmer}\|),e_1(\|\text{donkey}\|)\rangle \in \|\text{own}\|$,
then $\langle e_1(\|\text{event}\|),e_1(\|\text{farmer}\|),e_1(\|\text{donkey}\|)\rangle \in \|\text{beat}\|\}$

The relationship between (15′) and (17′) now depends on how we treat events, namely which kind of relationship between sets like

$\{\langle x,y\rangle \mid \text{farmer}(x)\ \&\ \text{donkey}(y)\ \&\ \text{own}(x,y)\}$
and
$\{\langle x,y,e\rangle \mid \text{farmer}(x)\ \&\ \text{donkey}(y)\ \&\ \text{event}(e)\ \&\ \text{own}(e,x,y)\}$

we stipulate. It seems to be clear that the latter set can be projected on the former and hence that (17′) implies (15′); the other direction of inclusion and implication is, however, doubtful - but we do not elaborate on this here.

[15]This treatment of donkey sentences uses a kind of unselective binding and, therefore, it cannot represent asymmetric readings. As in other theories, additional constraints must be imposed to license asymmetric readings.

3.7 Further ways of elaboration

Even after the enhancements sketched in this chapter, the framework remains in many respects too simple to allow for a satisfactory analysis of some statements and pieces of discourse. However, this was - at least partly - intentional: we wanted first and foremost to bring out the basic principles of the way we think the idea of the exploitation of salience can be formalized and put to work. Let us now mention - briefly - directions in which the possibility of further elaboration of the framework seems to be obvious.

1. **Adding more structure to choice functions.** The way we have exploited the concept of salience so far makes it possible for every class to acquire a representative. The real content of the concept of salience is, of course, much richer. This could be accounted for by means of replacing our simple choice functions by some more complicated ones: we could, for example employ functions which would allow to pick up not merely a single representative, but both a representative and a "vicerepresentative". Or we may utilize functions which for each class would yield a partial ordering of elements of the class. The fine-tuning of the optimal version of such a function would have to draw on the empirical results concerning salience, activation, and the stock of shared knowledge.

2. **Going beyond extensions.** In some cases, we cannot make do working with extensions, we need something more fine-grained. Thus for example in case when discourse participants do not see coextensionality of two predicates, they may well let their respective predicates license different references. This would call for going beyond extensions - we could allow the representatives to be assigned to intensions or to the predicates themselves. However, before accepting the latter solution, we should have to realize that we would then have to painfully stipulate the relations between predicates which we get for free on the level of extension (such as the relation between *farmers* and *men* - we saw that stating the rule that the choice of a new representant of a set forces the representant to represent also some/all supersets of the sets automatically leads to the right resolution of many basic cases).

3. **Reintroducing variables.** In claiming that we can account for anaphora without making use of the traditional apparatus of variables and binding, we did not claim that this apparatus is of no use whatsoever. There is nothing in our framework which would prevent it from being combinable with the more classical apparatus - we may well enrich it by introducing variables for the sake of coping with, say, relative clauses. This may call for making predicates dynamic, but this need not pose a major problem.

4. **Accounting for the topic/focus articulation.** Anaphora and crossreference are not satisfactorily analyzable without taking into account their interplay with the topic/focus structure. As argued elsewhere (Peregrin 1994; 2000c), the logical formalization of this structure requires that we see linguistic utterances as consisting of two subsequent parts, one differing from the other in that the failure of the interpretation of the first of them (the topic, determining what the utterance is about) results in the whole utterance being meaningless (or at least infelicitous), whereas that of the second (the focus, spelling out something new) results in it being simply false. This interacts with the anaphoric links (the consequences of the failure of referential availability in connection with the definite description differ according to whether the failure concerns the topic or the focus - *viz* Hajičová's (1993) distinction between presupposition and allegation). Therefore, we would have to somehow

render this two-stage process making the difference between an utterance which is infelicitous and that which is false. Here no obvious ways of modification of our framework are in sight; but it is clear how to seek them.

4 CONCLUSION

In this paper we have proposed a modification of Groenendijk & Stokhof's dynamic logic, a modification based on the employment of choice functions. Dynamic logic was developed to give a compositional semantic account of discourse, i.e. primarily to cope with the problem of coreference extending sentence boundaries. However, it did not tackle two important problems - the problem of resolving linguistically detectable anaphoric links and the problem of a uniform representation of anaphoric expressions, i.e. of definite NPs and pronouns. We have tried to show that modifying it in the proposed way can yield a feasible account of both these problems. Both definite and indefinite NPs are represented as proper terms; they are taken to express choice-function-updates and to refer to actually chosen representatives. The definiteness lies in the fact that a definite NP refers to the already established representative, whereas an indefinite NP picks up a new element, which then becomes the new representative. In this way, the anaphoric linkage is encoded in the contextual information, which is passed on by epsilon functions. No preceding coindexing is necessary. Furthermore, the formalism yields a uniform representation of all definite expressions, i.e. of definite NPs and pronouns.

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