Meaning in flux

Abstract

Professor Gärdenfors devoted an epoch making book to *Knowledge in flux* . This short paper surveys and streamlines recent developments in the dynamics of *meaning* . The semantics of epistemic possibility is shown to involve a dynamic ingredient. Update semantics has been designed to capture it. The paper contains a detailed examination of the proof theory recently spelled out for Update semantics. A simplified translation of the « might »-logic into S5 is presented. A longer paper forthcoming in the *Proceedings of the Boston International Congress of Philosophy* (1998) will take Professor J.Hintkka's and Professor G.Sandu's game-theoretic approach into account.

1. Meaning as Context Change Potential

I will now briefly examine a recent contribution to semantics of natural language which stands between Montague Semantics and Game-theoretical semantics.The dynamic predicate calculus spelled out by J.Groenendijk and M.Stokhof (Groenendijk & Stokhof, 1991) can be seen as an attempt to reconcile compositionality with context-dependence. Moreover the notion of context and the notion of interpretation get interconnected: "[c]ontext and interpretation are interdependent: interpretation depends on the context but also changes the context (Groenendijk & Stokhof 1998,31)". The invention of the dynamic predicate calculus, and for that matter H.Kamp's discourse representation theory, (Kamp, 1994) are major advances in the theory of meaning. To appreciate the novelty of their approach, we have to remember how the role of the context was understood in the early seventies.

Twenty four years ago, R.Stalnaker recognized an interaction between content and context (Stalnaker 1974, 212). However he stuck to the definition of meaning that has prevailed at least since Wittgenstein: the meaning of a declarative sentence consists of its truth-conditions. The definition has been formulated in these terms by Wittgenstein in the *Tractatus* : "To understand a proposition means to know what is the case if it is true (Wittgenstein ,1922, paragraph 4.024)". Sir Peter Strawson is still more explicit when he writes: "to know the meaning of a [statement-making] sentence...is to know under what conditions someone who used it would be making a true statement (Stawson 1952, 211)".

The distinction between truth-value and truth-conditions which underlies the above definition of meaning is at the root of one of the major philosophical discoveries of the twentieth century philosophy, i.e.possible worlds semantics. The point has been made by M.J.Cresswell : "[k]nowing the meaning of [a declarative sentence]...is simply having the ability to distinguish between worlds in which it is true and worlds in which it is false.

The idea leads directly to what is called *possible worlds semantics* (Cresswell 1978,12)".We have seen above that J.Hintikka's account of *abstract meaning* as opposed to strategic meaning agrees with Cresswell's statement. In contrast, the notion of strategic meaning involves the notion of strategy. And the latter is defined for the actual world.

There is much to say in favour of the truth-conditional account of the meaning of assertive sentences. It highlights the narrow connection between truth-conditions and truth-value and at the same time the difference between the two concepts. The difference is blatant : I can know the truth-conditions of the declarative sentence "there is life on Mars" without knowing its truth-value.

For all its virtues, the classical definition has its drawbacks. It does not suffice to account for the meaning of assertive sentences just as a purely extensional semantics cannot do justice to the distinction between *informative identity statements* such as "a = b" and *non informative identity statements* such as "a = a". The following pair of sentences due to B.Partee brings out the shortcomings of the definition of meaning in terms of truth-conditions.

Consider the following sentences:

(1) <u>I dropped ten marbles and found all of them, except for one</u>. It is probably under the sofa.

(2) *<u>I dropped ten marbles and found only nine of them</u>. It is probably under the sofa.

The two underlined sentence convey the same information about the actual situation. They have the same truth-conditions. Yet the second, but not the first, produces a unacceptable discourse. Admittedly discourse (2) can be seen as an enthymeme whose missing premisse can be retrieved in the light of some principle of rationality. This line of explanation, however, fails to account for the grammatical *ill-formedness* of discourse (2).

The source of the trouble has been diagnosed in this way by J.Groenendijk and M.Stokhof. For being able to interpret the pronoun "it", one must introduce an appropriate *discourse referent* that creates the interpretation context. The opening sentence of discourse (1) supplies such a discourse referent. It introduces a first discourse referent for the group of the ten marbles which have fallen and another one for the marble which was not found. In the case of discourse (2), the opening sentence introduces a first discourse referent for the original group of ten marbles which have fallen and another one for the nine which were found but no discourse referrent is supplied for the missing marble. This is the reason why the pronoun "it" cannot be provided with an interpretation (Groenendijk & Stokhof 1998, 33).

The occurrence of discourse referent "Except for one" does not change our information about the world but it changes our information about the discourse itself. It is somehow a self-referential item of the text. As discourse develops, both information about the *situation* and information about the *text* are updated.

The first kind of information can be described as a set of possible situations, "the set of possible situations that the agent cannot distinguish from the actual situations (Groeneveld 1995,11)". The second kind of information consists of the text items available at that stage. Updating information over the world amounts to throwing out possible situations, i.e. "eliminating alternatives". Updating information over the discourse consists of adding or withdrawing text-items.

This account, however, is still too rough. As Groenendijk, Stokhof and Veltman observe "Discourse in itself is not just a list of sentences. It has a more complex structure (Groenendijk, Stokhof, Veltman 1996, 27)". Saliency considerations matter. Consider the following example: "A man came to see the doctor. The man said...". The definite description "The man" might refer to the doctor. It is however more natural to take it as referring to the individual introduced by the indefinite description "A man". The crucial point here is the *descriptive contents* shared by "The man" and "A man".This makes *a man* "more salient *qua* object corresponding with the description ["the man"] ...than … *the doctor*...(Ibid.)".

G.Sandu argues that Game-theoretic semantics , as opposed to Dynamic predicate calculus, can treat sentences such as "If every man is given a gun, then some man will fire it". By Sandu's lights, game-theoretical semantics alone can explain the *functional dependency* between the men who are given a gun and those who fire it (Sandu 1997, 167)". His argument against dynamic predicate calculus loses much of its bite, however, if we bring saliency considerations to bear on the matter. The reason why we can rewrite the sentence as "If every man is given a gun, then some of them will fire it" lies in the *shared descriptive content* depicted by the the two occurrences of "men" in the initial sentence.

Consider however the following sentence: "If each soldier is given a rifle or a submachine gun, some soldier will have to be taught to use it". The pronoun "it" refers either to a rifle or to a submachine gun depending whether the soldier referred to has been given a rifle or a submachine gun. Sandu shows that Game- theoretical semantics can account for the dependency between soldiers and their weapons in that intricate sentence.

The question arises whether an appeal to the *logical skills* involved in restoring missing premisses in enthymemes would not provide an alternative explanation. Take the following sentence which is similar to the previous one but a little simpler: "John is a very absent-minded man. He always leaves something behind. Sometimes his hat, sometimes his umbrella. He finds it when he returns home in the evening". The hearer might pin down the referent of "it" by making a constructive dilemma: "either John leaves his hat behind or John leaves his umbrella behind. If he has left his hat behind, he finds it in the evening when he returns home. If he has left his umbrella behind he finds it in the evening when he returns home. Hence, john finds his hat or John find his umbrella in the evening when he returns home. Of course this comment is not meant to settle the issue. A large scale empirical study would be needed to compare the explanatory power of the rival accounts of complex anaphora.

Whatever the the results of such an inquiry might be, the new semantics invented by Groenendijk and Stokhof should be credited with a major innovation. We owe them a new account of meaning. The dynamic character of that account has been vividly expressed by F.Veltman: "[t]he slogan 'You know the meaning of a sentence if you know the conditions under which it is true' is replaced by this one: 'You know the meaning of a sentence if you know the change it brings about in the information state of anyone who accepts the news conveyed by it (Veltman 1996, 221)".

At first blush one might be reluctant to adopt the new definition of meaning. It seems too broad. There is, however, a remedy. As J.van Benthem observes, if we suppose that "cognitive states are ordered by some pattern of *inclusion* $\subseteq$ by informational content", we can define, among other things, the notion of *minimal updating* μ-up (P) which is formally rendered by '$\lambda xy \bullet x \subseteq y \wedge Py \wedge \neg\exists z(x \subseteq z \subseteq y \wedge Pz)$' (van Benthem 1994, 118). Taking advantage of this new operator, we can define the meaning of an assertive sentence as the *minimal change* in informatonal content the sentence triggers.

Updates can be captured by relations between a cognitive state s, the state of the hearer *before* hearing the assertive sentence ϕ and the state t, i.e. the state of the hearer *after* hearing that sentence. On this account, sentences are mapped onto relations between information states, not onto sets of possible worlds. It follows that the sequences of premisses of an argument will be mapped onto relative products, not onto Boolean intersections.

This is a significant change indeed. Relational algebra is richer than Boolean algebra. A fine-grained account of the relationship between the premisses of a given argument becomes available. The new modelling at our disposal can account for the role of the sequential order of the statements in a discourse.

Updates can also be captured by functions: a sentence can be seen as a function ϕ which takes an information state I as its argument and an updated information state I' as value: $[\phi]I = I'$. In the next section, I shall follow F.Veltman and adopt the second account of updates. Not much hinges on this choice. As J. van Benthem observes, "[t]here is no conflict between relational and functional approaches. Functions are deterministic total relations. And conversely, every binary relations R on [a set of states] *S* induces a function $R^{\#}$ from pow(*S*) to pow(*S*)...(van Benthem 1996, 18)".

3. Update semantics and its logics

The switch from the static account of meaning in terms of *truth-conditions* to the dynamic account of meaning as *context change potential* gives rise to a bunch of new concepts of logical consequence . I shall consider one of them only. In standard semantics, the statement ϕ is said to be a logical consequence of a set Γ of statements if it is true in every models in which the members of Γ are true. In dynamic semantics, an argument is declared valid if and only if its conclusion is accepted in all information states in which we arrive after accepting the premisses *in the order in which they are given* .

This is by no means a trivial difference. I shall mention just one illustration of the role of the order of the premisses. The contrast between static and dynamic semantics plays a crucial role in the characterization of the difference between the *physical modality* "it is possible" at work in "It is possible that there is life on Mars", a sentence which means "It is compatible with the *laws of nature* that there is life on Mars" and the *epistemic modality* "It might be" in "It might be raining", a sentence which means "It is compatible with the speaker's *information state* that it is raining".

F.Veltman extended classical propositional logic with the modal epistemic operator "might" and worked out an *update semantics* which I shall recall before examining the proof-theory which has been designed for it. Veltman aims at representing an agent's knowledge. An agent's information state *I* can be viewed a the set of possible worlds. Let us conceive of possible worlds i.e. *w* , as sets of atomic sentences true in that world . A world *w* has the form {p,r,s,...}. It is a *set* of atoms valued true. An information state *I* has the form {{p,r,s...},{q,r,t...},...}. It is a *set of sets* of atoms valued true.

Let A be the set of atomic sentences of the language and W the power set of A. Information states *I* are subsets of W. The symbol $\varnothing$ designates the absurd information state. Making use of this modicum of terminology, Veltman provides his modal propositional language with a semantics which for each formula ϕ and each state of information *I* says how the state changes when somebody in that state accepts that sentence. In what follows, '[p] I ' is the formal rendering of "the information state I updated by the propositional atom 'p' ".

$[p]\, I = I \cap \{ w \,/\, p \in w \}$

$[\neg \phi]\, I = I \sim [\phi]\, I$

$[\phi] \bullet [\psi]\ I = [\psi]([\phi](I))$ (The $\bullet$-operator is not commutative)

$[\phi \vee \psi]\, I = [\phi]\, I \cup [\psi]\, I$ (The $\vee$ - operator is commutative)

$[\text{might } \phi]\, I = I$ if $[\phi]\, I \neq \emptyset$

$[\text{might } \phi]\, I = \emptyset$ if $[\phi]\, I = \emptyset$

As J. van Eijck and F.J. de Vries observe [I slightly change the symbols to increase homogeneity], : "a statement *might* ϕ is acceptable, given an information state I, if there is at least one world $w \in I$ for which ϕ is accepted in the sense that $w \in [\phi]\,(I)$. If such a w can be found, the output information state of *might* ϕ is equal to its input information state (van Eijck & de Vries, 1995, 24)".

To see the semantical and logical interest of the *might* operator, consider the following two discourses:

(i) "It might be raining. ... .It is not raining. ..."

(ii) *"It is not raining. ...It might be raining. ..."

The former is acceptable. The latter is odd. The reason why discourse (ii) is odd is clear: " [a]fter an information state has been updated with the information that it is raining, it is no longer consistent with the information that it might be raining. If, as in (i), things are presented in the opposite order, there is no problem (Groenendijk, Stokhof, Veltman 1996, 195)". The sentence "It might be raining" uttered by me means "it is is compatible with my information state that it is raining". Such a modal statement does not say anything about the world. It says something about available information about the world. "It might be raining" should be set off against the physical modality which occurs in "It is possible that there is life on Mars" .

F.Veltman's semantics is equipped with the conceptual tools needed for explaining the difference. On that semantics the succession of sentences is not interpreted as an intersection of classes or relations but as a relative product or as a composition of functions (depending whether we adopt a relational or a functional interpretation of sentences). The non-commutativity of relative product and function composition captures the meaning attached to the sequential order of the sentences in a discourse. Moreover Veltman's semantics distinguishes between two kinds of statements: statements which play the role of *updates* and statements which play the role of *tests* . Updating with a test leaves us where we are.

With these notions in hand, J. van Benthem explains the acceptability of (i) and the oddity of (ii) in this way: "The difference will show up as one of sequential processing...Given initial options {s, ¬ s}[i.e. an information state made up of a world in which s is true and a world in which s is false], the instruction (i) will produce successive states {s, ¬ s} (successful test), { ¬ s} (successful update), whereas the instruction (ii) will produce { ¬ s} (successful update), ∅ (failed test) (van Benthem 1996, 19)".

Standard modal logic cannot do justice to the contrast between discourse (i) and discourse (ii) if we rest content with translating *might* by the diamond. The trouble is that (i) $\Diamond p \wedge \neg p$ is logically equivalent to (ii) $\neg p \wedge \Diamond p$. A new logic designed to capture the difference between (i) and (ii) is needed. Several systems have been invented to fill the gap. W. Groeneveld has spelled out a sound and complete sequent calculus in which inconsistency - represented by the propositional constant "F" (False) - cannot be derived from discourse (i) whereas it can be derived from discourse (ii). It is called UTC, i.e. Update to Test Consequence, as it formalizes a notion of *logical consequence* which is sensitive to the sequential order in which the premisses are presented

The proof that (2) entails inconsistency is quite easy. It rests upon axiom (1) of the non modal propositional calculus and rule (2) which licenses the introduction of "might" on the left side of a sequent.

We start with the axiom (1) where Π stands for a finite, possibly empty, sequence of formulae.

$$(1)\ \frac{}{\Pi, \phi, \neg\phi \Rightarrow F}$$

Next we use the rule (2)

$$\frac{\Pi, \phi \Rightarrow F}{\Pi, \text{might } \phi \Rightarrow F}\ (2)$$

In axiom (1), first we take Π as empty and we substitute *p* for each occurrence of ϕ. Next we apply the rule of *permutation* to '*p* , ¬*p* '.

We get ¬*p* ,*p* ⇒ F (1’)

In rule (2), we fill Π with ¬*p* and substitute *p* for ϕ. This turns the premisse of rule (2) into the instance formula (1’) just obtained.

The above-mentioned sequent calculus licenses the derivation of an inconsistency (F) from < ¬*p*, *might p* > but not from <*might p* , ¬*p* >..

If <*might p,* ¬*p* > ⇒ F could be derived from <¬*p*, *might p* > ⇒ F by *permuting* the sentences occurring in the antecedents, the difference between discourse (i) <*might* • *p,* ¬*p* > and discourse (ii) <¬*p* • *might p* > would vanish. This does not happen, however, in UTC. In the latter calculus, the structural rule of permutation applies *only* to *formulae of the non modal language* (i.e. formulae in which *might* does not occur).

The fact that the difference between dynamic logic UTC and ordinary modal logic S5 lies in the *structural rules* reveals how deep the gap is bewteen dynamic and static logics. As the familiar notion of maximal consistent set and that of canonical model rely on the structural rules of classical modal logic (Groeneveld 1995, 46), the standard methods for building completeness proofs go by the board. A dynamic version of Henkin construction will be needed (Groeneveld) or altogether different methods, such as those resting upon representation theorems (van Benthem 1996).

The sequent calculus for UTC is not only sound and complete, it is also decidable (Van der Does, Groeneveld, Veltman 1997, 379). The algorithm for UTC however is not as simple as Hughes and Cresswell's algorithm for S5. Hence it would be nice to be able to translate formulae of UTC into formulae of S5 and then test the formulae thus obtained for consistency within S5. This is precisely what J.van Eijck and J.F. de Vries have shown to be possible. Before presenting their results, I have to meet an objection. One might think that a translation of $<$*might p* , $\neg$*p* $>$ and $<\neg$*p* , *might p* $>$ into S5 will blur the logical difference between them . This is not the case. As we shall see, they translate respectively into the S5-consistent formula $\Diamond p \wedge \neg p$ and the S5-inconsistent formula $\neg p \wedge \Diamond(p \wedge \neg p)$.

4. The link between dynamic and static logic

Information flow, as dynamic semantics describes it, has much in common with the execution of an imperative program. This suggests that the concepts and methods of computer science could be used for axiomatizing dynamic phenomena in logic and language. J. van Eijck and his co-writers have developped a bunch of Hoare/Pratt style calculi to deal with phenomena which fall outside the scope of standard first order and modal logic such as discourse anaphora , pragmatic presuppositions and the logic of *might* [On Hoare logic see P.Gochet & P.Gribomont 1994].

As J.van Eijck and F.J. de Vries observe, reading a text can be seen as running an imperative program π for updating one's knowledge. From that viewpoint it is sensible to ask "[w]hat is the weakest formula ϕ such that any knowledge implying ϕ remains consistent during the process of absorbing the information from text π ? (J.van Eijck & F-J. de Vries, 1995, 21)". In the computer scientist's terminology, this weakest formula is called the *weakest precondition* for the successful processing of the text π.

J.van Eijck and F.-J. de Vries operate with the notion of *weakest precondition* . In our attempt to link dynamic and static logics pointwise, we can also avail ourselves of the related notion of *strongest postcondition* . We may ask what is the formula ψ to which the execution of the program π moves us, starting from a set of states described by the predicate P. Answering such a question amounts to defining the *strongest postcondition* of P under π: SP(P,π) (J.van Benthem 1994, 128).

The predicate P denotes the information state which will be updated by processing discourse π . We assume that the information state P we start with is consistent. Our initial information state *might* consist of a conjunction of atomic propositions all of which are true. Such eventuality can be formally represented by substituting the propositional constant T (true) for P in "SP(P,π)". This idealization will play a crucial role in the formulation of a consistency test for update logic.

Both weakest preconditions and strongest postconditions provide us with, - to use J.van Benthem's words, - a "static tracing of dynamic procedures". They allow us to "take snapshots of truth conditions at various stages in the discourse processing (J.van Eijck & F.-J. de Vries, 1992, 3)".

The following recursion clauses enable us to map the source language of Update logic onto the target logic of standard modal logic. They are borrowed [but in a slightly modified form which fits our purpose] from J.van Benthem who uses them "for performing an on-line computation of the classical content of update semantics in the modal logic S5 (J. van Benthem 1994, 128)".

$SP(P, q) = P \wedge q$

$SP(P, \phi \bullet \psi) = SP(SP(P, \phi), \psi)$ (the • - operator is non commutative)

$SP(P, \phi \vee \psi) = SP(P, \phi) \vee SP(P, \psi)$ (the $\vee$-operator is commutative)

$SP(P, \neg \phi) = P \wedge \neg SP(P, \phi)$

$SP(P, \textit{might } \phi) = P \wedge \Diamond SP(P, \phi)$

J.van Benthem reduces the dynamic notion of logical consequence to the classical one by the following proposition: "the premisses $R_1,\dots,R_n$ dynamicallly entail the conclusion S if and only if the strongest postcondition of $(A, R_1 \bullet \dots \bullet R_n)$ classically entails the strongest postcondition of (A,S) for arbitrary sets A of information states (J.van Benthem 1991, 19)".

From the above definition, J.van Eijck and F.J.de Vries have shown how to extract a decision procedure which discloses the consistency (or inconsistency) of a discourse π by correlating it with a consistent (respectively inconsistent) formula ϕ of standard modal logic S5 (for which there are well-known algorithms. (See Hughes & Cresswell, 1996)).

The derivation of that important result requires several lemmas, theorems and definitions. We shall just mention these definitions and lemmas. The proofs can be found in the original paper.

(1) Definition: A discourse π is said to be *consistent* if and only if there is at least one information state which does not become the empty information state ($\varnothing$) when it is updated with π.

(2) Lemma 1: Discourse π is consistent if and only if there is a S5-consistent formula ϕ such that $\vdash \phi \leftrightarrow \langle\pi\rangle T$, i.e. '$\phi$' is equivalent with '$\pi$ terminates'.

(3) Lemma 2: There is a S5-consistent formula ϕ such that $\models \phi \leftrightarrow \langle\pi\rangle T$ if and only if and only if for all information states I, the interpetation (i.e. of denotation) of the expression "the strongest postcondition of the program π starting in the set of states described by the propositional constant T" is identical with the interpretation of the formula ϕ. (formally: $\|SP(T,\pi)\|_I = \|\phi\|_I$

i.e. the interpretation of discourse π applied to information state I (here T) is the interpretation of the weakest precondition (evaluated at I) for which program π terminates (formally $\langle\pi\rangle T$).

With this conceptual apparatus, we can test the consistency (respectively the inconsistency) of $\langle \neg p$, *might p* $\rangle$ and $\langle$*might p* , $\neg p \rangle$.

The letter P in the recursion clauses for the translation of dynamic into static logic has to be read "T". The rationale behind is this ; what is true is *a fortiori* consistent.

5.Application

Let us apply the method just describe and show that *might q* , $\neg q$ is consistent .

(1) SP(P, *might* q • ¬ q)

(2) SP(SP(P, *might* q), ¬q) From (1) by Composition Elimination

(3) SP(P ∧ ◊SP(P, q) ¬q) From (2) by *might* Elimination

(4) SP(P ∧ ◊(P∧ q), ¬q) From (3) by Comma elimination

(5) P ∧ ◊(P ∧ q) ∧ ¬ SP(P ∧◊(P ∧ q)), q) From (4) by Negation elimination

(6)P ∧ ◊(P ∧ q) ∧ ¬ ((P ∧◊(P ∧ q)) ∧ q) From (5) by comma elimination

(7) ◊q ∧¬ q From (6) since P=T

There are S-5 models verifying (7).

Trivial transformations lead from (6) to (7): (T is erased in conjunctions and F in disjunctions)

T ∧ ◊ (T∧ q) ∧ ¬ ((T ∧◊(T ∧ q)) ∧ q)

◊q ∧ ¬ (◊q ∧ q)

◊q ∧ (¬ ◊ q ∨ ¬q)

(◊q ∧ ¬◊q) ∨ (◊q ∨ ¬q)

F ∧ (◊q ∨ ¬q)

◊q ∧¬ q

Let us now show that $\neg q$, *might q* is inconsistent.

(1) SP(P, ¬q •*might* q)

(2) SP(SP(P, ¬q), *might* q) From (1) by Composition Elimination

(3) SP(P ∧¬SP(P, q) , *might* q) From (2) by Negation Elimination

(4) SP(P ∧ ¬(P∧ q), *might* q) From (3) by Comma Elimination

(5) P∧¬ (P ∧ q) ∧SP ◊(P∧ ¬ (P∧ q), q) From (4) by *might* -Elimination

(6) P∧¬ (P ∧ q) ∧ ◊((P∧ ¬ (P∧ q)) ∧ q) From (5) by Comma-Elimination

(7) ◊(q ∧ ¬q) ∧ ¬q From (6) since P=T

(8) F (Inconsistency) From (7) by trivial modal transformations

6 Conclusion

In this survey paper devoted to recent developments of Semantics and logic, I gave a short presentation of Game-theoretical semantics and Dynamic predicate calculus. Although these two epoch-making contributions to semantics are sometimes seen as rivals, I am inclined to think that they complete each other in so far as the practice of natural language rests upon *logical* as well as *linguistic* competence.

Dynamic predicate calculus handles changing anaphoric bindings. Update semantics deals with information flow and epistemic changes. The treatment of complex linguistic phenomena requires a combination of these two formalisms. The examination of the recent proposals made for an integration of Dynamic predicate calculus with Update semantics would take us too far away. The interested reader is invited to have a look at "Coreference and Modality" mentioned above.

Update semantics has given rise to original developments in proof theory. I gave an application of the sequent calculus spelled out to capture it. I stressed that the proof theory of Update logic diverges from standard logic to the same extent that relevant or linear logics do, i.e. at the level of structural rules.

Translating Update logic into S5 was was by no means a negligeable achievement.. The original presentation of the former translation (J.van Eijck & J.F. de Vries 1995) made use of a very ingenious device invented by M.Kracht, i.e. the operator of localisation (↓) (Kracht 1993). I offered instead a simplified formulation of the translation which does not use such a device.

7.Bibliography

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