Dialogue Semantics Versus Game-Theoretical Semantics

Esa Saarinen

Academy of Finland and UCLA

In this paper I shall attempt to compare the dialogue approach originally advocated by Lorenz and Lorenzen and the game-theoretical approach of Hintikka with each other. I shall not try to present any survey of either one of the approaches and will assume that the reader is familiar with the basic ideas of these theories.

The original works of Lorenzen and Lorenz have been reprinted in their [12] while Stegmüller [28] contains a survey (in English) of the basic ideas and results. Works in this tradition which apply the approach to quantum logic include Denecke [3], Mittelstaedt ([13], [14]) Mittelstaedt and Stachow [15], Stachow ([24], [25], [26]). The reader will also find van Dunn [4], Krabbe [10], Lorenz [11] and Stachow [27] to be relevant.

The literature on Hintikka's game-theoretical semantics as applied both to different formal languages (including infinitary languages and intensional logic) and to natural language is rapidly growing. As for the latter, the reader is referred to papers by Hintikka, Carlson and myself reprinted in Saarinen [22], to Carlson and ter Meulen [2], and to Saarinen [20]. (The latter is a survey of the basic ideas. Carlson has a lot of unpublished work, including his 1975 thesis which is written in Finnish.) Works on game-theoretical semantics as applied to formal languages include Hintikka([7], [8]). Hintikka and Rantala [9], Rantala ([17], [18], [19]), and Saarinen [23].

The reader should take the terms "dialogue approach" and "game-theoretical semantics" with some caution. For one thing, we do not want to imply that in the latter no natural explication of dialogues can be given; nor that there is nothing game-theoretical in the former approach. A few comments on how well the names characterize the theories will be offered below. Meanwhile, it suffices to observe that our way of using the terms is relatively well established although there are a few exceptions. In particular, the reader should notice that what

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Stachow [27] calls "game-theoretical approach to language" is in our terminology dialogic and not game-theoretical.

The need to compare systematically the dialogue approach and the game-theoretical approach is due to the fact that there are more than superficial similarities between the two. Moreover, with the exception of Hintikka [8] and some short comments of Hintikka's elsewhere, the topic remains unexplored.

It is perhaps appropriate at this point to register one complication which necessarily arises when comparing two approaches like the dialogue approach and game-theoretical approach with each other. Let us distinguish technical problems from ideological or conceptual ones. For instance, how to present game-theoretical semantics for quantum logic or how to present dialogically the logic of backwards-looking operators is a technical problem. A conceptual or ideological problem is in turn how illuminating or how *ad hoc* such semantics is. The problem is that while the latter kind of questions are hard to answer conclusively, they are the ones that are really interesting. Our objective in the present paper is to compare the ideology of the dialogue approach with that of game-theoretical semantics. The reader should keep in mind that the nature of the problem makes the conclusions necessarily somewhat tentative.

Hintikka has argued that there is an important difference between his game-theoretical semantics and the dialogue approach of Lorenzen and Lorenz in that in the former case we are dealing with "language-games of seeking and finding" not with any kind of "parlour games" as is the case (according to Hintikka) in the former case. One could make this point somewhat more precise by saying that game-theoretical semantics is more *semantical* in its aims than the dialogue approach. Indeed, it seems doubtful whether we could speak about dialogue *semantics*. Rather, we should speak, as indeed the authors working in this tradition do, of "dialogic approach to logic", "dialogic approach to language", or dialogues as providing an "operational basis of logic".

Let us take an example to illustrate this point. When presenting game-theoretical semantics for (say) first-order logic we wish to define *truth* and *falsity* of an arbitrary formula in a model. Once this concept is defined, the relevant validity-concept is defined by quantifying over all models. In the dialogue approach, one is typically occupied in giving a definition of *validity* in terms of certain kinds of dialogues. A case in point are the original works of Lorenzen and Lorenz, surveyed by Stegmüller [28]. There is nothing in the rules or definitions which would refer to the extralinguistic reality. This does not of course render the theory technically inadequate. For the purpose of defining the set of valid formulas of first-order logic one need not use concepts that would allude to extralinguistic objects. Yet part of the job of semantics is to specify the conditions under which a given sentence is true. It is part of the job of semantics to show how language links with extralinguistic reality. A theory which fails to do this, even if it did specify non-syntactically the set of valid sentences, can be called only half-semantic. In this sense it seems that the dialogue approach is less semantic than the game-theoretical approach. It also follows that Hintikka's criticism of the dialogue approach is in this respect justified; Lorenzen's and Lorenz's dialogues are parlour games in the sense that they do not involve interaction with the reality outside the language.

It could be pointed out that while originally the dialogue approach was used only to define validity but not other semantic notions, this by no means does indicate an intrinsic or essential feature of the approach. Indeed, it could be pointed out, one can generalize the treatment so as to yield a definition of truth and falsity in addition to the concept of validity. (This is in fact what the distinction between "materially" and "formally" true propositions amount to. See e.g., Mittelstaedt [14].)

This does not in my judgement affect the overall situation. What remains unaffected is the point that the most natural view to reflect the dialogue approach is to take it as a half-semantic proof procedure.

First, our view is in accordance with the descriptions of their approach offered in print by scholars working in the Lorenzen-Lorenz tradition. Thus, e.g., in Stachow [24] we read: "To demonstrate the completeness (and consistency) of quantum logic, given by means of a quantum logical calculus, we show that all formulas which are deducible in the calculus can be proven within the dialogic procedure and vice versa."(p. 238, italics added). Likewise Stachow [27] describes a dialogue game as a "very general proof-procedure".

Second, the best results of the dialogue approach which appear in the literature are given by the new type of characterizations of different validity concepts. (I have here in mind such results as Lorenz's characterization of intuitionistic logic or the recent characterizations of quantum logic by Mittelstaedt, Stachow and others.)

Our first major point is then that there is a major difference between the dialogic and the game-theoretical approaches in that in the former the main novelty is the way validity is defined, whereas in the latter the main novelty lies in the way truth and falsity are defined. It is telling that in the Lorenzen-Lorenz tradition one typically wishes to find a winning strategy in all models (interpretations) whereas in game-theoretical semantics one wishes to find for each model (interpretation) a winning strategy (perhaps different in different cases). The former yields the existence of a winning strategy iff the sentence being considered is valid; the latter iff the sentence is true in the model in question .

One could also put the present point by saying that the dialogue approach is a half-semantic proof procedure in the same way as Hintikka's model sets and model systems techniques are. In both cases one can put forward illuminating non-standard characterizations of various validity concepts without having had to go via the concept of truth and falsity and without having had to refer to the extralinguistic reality. (In this light, one could say that game-theoretical semantics is related more closely to Carnap-Tarski semantics than to Hintikka's model semantics.) Thus it is typical that in the dialogue-theoretical quantifier rule and in the model set theoretic quantifier rule no reference to individuals (extralinguistic domain of discourse) is being made. In both cases one speaks about individual constants, (whose semantics is not given extralinguistically) not of individuals. (See Hintikka [6] and Stegmüller [28]. For a recent use of this kind of quantifier rule in the dialogue approach, see Denecke [3].)

It should perhaps be emphasized here that the above is not intended as a criticism of the dialogue approach. My intention has rather been to pinpoint one respect in which I believe the dialogue approach differs from game-theoretical semantics. In fact, the half-semantic nature of the dialogue approach could be seen to be an advantage of the theory over customary Carnap-Tarski semantics and over game-theoretical semantics. Thus, e.g., Stegmüller presents as an argument pro the Lorenzen-Lorenz validity-concept that "the concept of infinite set does not enter into the definition of validity." This marks a distinction to both Carnap-Tarski and game-theoretical semantics in both of which the definition of validity involves quantification over all non-empty universes.

There are two major technical differences between the dialogue approach and game-theoretical semantics which we shall now discuss.

The dialogues are games in which the two players make choices one after another so that whenever a player P_1 makes a move in the game, the next move is always made by the other player P_2 (if by anybody). In game-theoretical semantics this is not the case.

This feature of the dialogue games is essentially tied up with the basic idea of this approach and to the idea of a dialogue. A dialogue (as understood in the dialogue approach) is a series of arguments (attacks and defenses) which are stated in turn by the two players. The key idea is that if an argument of a player has been attacked by the other player, then the first one has to defend that argument at the next step or else postpone the defense by attacking an argument of the second player. In any case, once an attack or defense has been put forward by a player in a dialogue, the next move is necessarily up to the other player to make.

Let us take an example. For simplicity, I am adopting the original Lorenzen-Lorenz treatment, as presented by Stegmüller. (The point could be made mutatis mutandis for other formulations of the dialogue approach as well.) The important point about this formulation of the approach is what Stegmüller calls "the three-fold asymmetry" between the two players O (opponent) and P (proponent). First, P can only put forward an atomic formula if that atomic formula has already been set forth by O in a previous move. (There is no comparable restriction for O.) Second, only P is allowed the repetition of attacks and defenses. (It has been shown by Lorenz that should we not allow repetition of defenses for P,

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we would get the intuitionistic logic instead of the classical one.) Third, O and P are disanalogous vis-à-vis winning and losing; P wins a dialogue iff after a finite number of steps a position is reached at which O can make no further move. (Thus O wins if he can prevent P from reaching an end position favourable for P in a finite number of steps.)

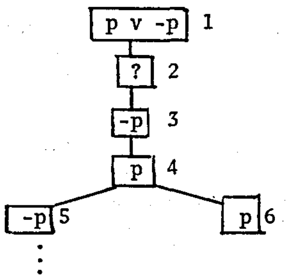
Let's see for instance why the law of excluded middle comes out valid.

O	P	rows	
	p v -p	0	
?	-p	1	
p		2	
	p	3	(repetition of defense)

The validity of a formula means that P has a winning strategy (can win no matter what moves the other player does) in the corresponding dialogue game. It is clear from the above tableau that in the case of p v -p such a strategy exists for P. (In the above dialogue there is always just one kind of move possible for O at every stage of the dialogue. With these move O loses as is seen from the tableau.)

It easy to see why defense repetition for P is essential for the validity of the law of excluded middle in this framework. Were defense repetition for P not allowed, the dialogue would end at row 2 and O would win it.

To see how dialogue games differ from the semantical games of game-theoretical semantics, let us present the above dialogue game in a way usual in game-theory, viz., by using game trees. This would look as follows:



P's initial argument

O's attack

P's defense

O's attack

P's defense repetition

P's defense repetition

By way of interpreting this dialogue game tree, recall that each node directly accessible from a given node in a game-tree represents all the different choices there are for the player at that stage. Thus we observe from the game-tree that the strategic possibilities of the two

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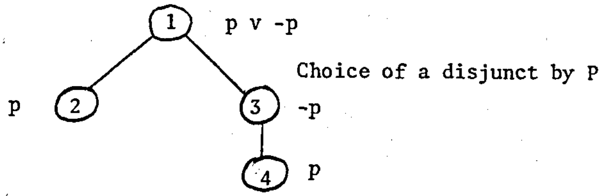
players (especially of 0) are very limited. Of the nodes explicitly represented, only at node 4 is there any choice for a player. (There are infinitely many other nodes of the kind in the paths following node 5. In each of these cases P can restate his defense infinitely many times. These paths are not relevant here, however. All that is needed is a demonstration of the existence of a winning strategy for P, and that we have done.)

The reader will perhaps point out at this juncture that the game-tree representation of the dialogue games is not very illuminating. This is perfectly true. I shall return to it in a moment.

Notice that in showing that p v -p is valid in the dialogue approach no reference to truth or falsity needed to be made.

In game-theoretical semantics, the validity of p v -p comes out quite differently. Validity is defined by reference to truth; validity of p v -p means existence of a winning strategy of player P in every semantical game associated with p v -p and a model (for propositional logic). Given such a model M, the relevant semantic game-tree will look as follows:



Winning and losing is defined by stipulating that P wins a play of a game iff the number of negations dominating the end node is even (resp., odd) and the formula attached to the end node is true in the given model (resp., false in it).

Since M is a classical model for propositional logic either $M \models p$ or $M \not\models p$. In conclusion there is always a way for P to choose a disjunct (make his move at the root of the game tree) such that he wins the game. The existence of a winning strategy does not depend on the choice of the model, and thus p v -p is valid.

The above example, though extremely simple, is instructive in a number of respects. First, notice that in the semantical game-tree for p v -p and M only the root was a node which marked a player's move. In contrast, in the dialogue game-tree for p v -p all the infinitely many nodes in the tree (with the exception of the end nodes such as node 6) are nodes marking a player's move. In many cases there is just one possibility to choose from but that does not mean it wasn't a move of the player's.)

Second, it is already clear from the above example that the game-tree

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representation is very unilluminating and unnatural for the dialogue games. It is no wonder that scholars working in this tradition never use this way of characterizing their games (but use instead a tableau representation). The reason for this state of affairs is two-fold. For one thing, the dialogue game rules allow as it were "too many" possibilities. This is a consequence of the possibility of defense and attack repetition. For instance, in the original dialogue games for classical logic of Lorenzen and Lorenz, the proponent is allowed to repeat a defense at any stage of the game. On the other hand, game-trees represent <u>all</u> the different possibilities a player has at a given stage of the game. It follows that game-trees for dialogue games are bound to be complicated. Because of the possibility of defense and attack repetition, game-trees for dialogue games will have to represent a number of "unnecessary" paths. An example is provided by the infinitely many paths that emerge from node 5 in the above dialogue game tree. For another thing, game-tree representation is clumsy for the dialogue-games because of the rule which requires that the moves of the dialogue be carried out by the two players one after the other. In game-trees, this requirement also produces a number of "unnecessary" nodes --"unnecessary" in the sense that the players do not have any real alternatives to choose from at these stages of the game.

These features of the dialogue approach are essentially tied up with the basic notion of this approach, viz., with the notion of a dialogue. For instance, it is a reasonable constraint on dialogues that a move of one player always follows that of another one, and never to allow two moves by the same player in a row. In game-theoretical semantics the basic concept is that of a semantical game on which no comparable constraint can naturally be imposed. Rather, it is reasonable to follow the game theoretical practice and define that a given situation marks a move of a player only if there is (at least in principle) something for the player to choose from.

In game-theoretical semantics, the rules of the games are designed in such a way that a formula which is being considered at a later stage of a game is always shorter than a formula considered at an earlier stage of that game. In other words, the formula being attached to a node in a semantical game-tree can never be longer that the formula which is attached to its immediate (or, for that matter, any) predecessor. This is not the case in dialogue games. In dialogue games, the possibility of defense and attack repetition entails a possibility to introduce at a later stage of a game a formula longer than (or at least as long as) the one considered at a given earlier stage. Thus for instance in the dialogue-game about $p \vee -p$ constructed in terms of the game-tree above, the formula considered at nodes 5 and 6 are both of them longer than or as long as the formula considered at their immediate predecessor.

It should perhaps be stressed that attack and defense repetition in the dialogue approach seem to be an essential feature of the theory. Indeed, attack and defense repetition was originally used by Lorenzen

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and Lorenz in their dialogic characterizations of classical and intuitionistic logic and recently Mittelstaedt, Stachow and others have used it in their characterizations of quantum logic. Also in the dialogic framework itself there do not seem to be good intuitive reasons for ruling out such repetition, and constraints to this effect would consequently seem to be ad hoc.

The present observations tie up with the general point we made in the beginning of this paper. A natural way to look at a play of a semantical game G(S,M) about a sentence S is to view it as an attempted verification or falsification of S with respect to M. Verification and falsification are essentially semantical concepts. To verify a sentence like

(1) (Ex) (x is a UCLA linebacker & x weighs over 250 lbs.)

is to produce a person (call him "Jerry") and be ready to verify that Jerry satisfies the open sentence

(2) (x is a UCLA linebacker & x weighs over 250 lbs.)

Thus in order to verify (1) we must explore the world, the extralinguistic reality. In this sense plays of semantical games (understood as attempted falsifications or verifications) tie up the language with reality. (This is what Hintikka means when he speaks about semantical games as "games of exploring the world" or as "language games of seeking and finding".)

Also, in an attempted verification (or falsification) of (1) we cannot end up considering sentence (1) again. Indeed to verify (1) is to verify (2) of some individual Jerry, and to verify (2) is to verify both of the conjuncts--and that's it.

More generally, there is an ample rationale and intuitive justification for demanding that in an attempted verification and falsification we must proceed from complicated sentences to simpler ones, and never the other way around. Similar intuitive justification for a comparable restriction on dialogues cannot be given.

There are two major advantages in game-theoretical semantics over traditional recursive Carnap-Tarski semantics. It will be useful to discuss these novel features of game-theoretical semantics here, partly because they provide us a good testing ground for comparing game-theoretical semantics and the dialogue approach.

(a) The notion of an information set. I shall comment on this feature of game-theoretical semantics below. Before it, we shall be interested in the following feature of game-theoretical semantics:

(b) The semantical properties of sentences are not spelled out recursively on the length of the subformulas. Rather, those properties are spelled out by reference to a game which is attached to that sentence, and that game need not be a function of semantic games attached to the subformulas of that sentence. Another way to put this novel feature of game-theoretical semantics is to say that in game-theoretical semantics we have an exact counterpart to the notion of a step-wise evaluation which proceeds from the outside in, and which at every stage of the evaluation can recall every earlier stage. The advantages of this kind of approach come out best when we consider various kinds of context dependencies, e.g., anaphoric phenomena. In such cases, a step-wise evaluation of a sentence may lead us to consider a subsentence whose semantic properties depend on the evaluation so far. (In other words, depending on the evaluation as carried out before the subsentence came to be considered, the semantic properties of the subsentence will be different.)

An example will hopefully clarify the point. Our example draws from tense logical analysis of natural language tenses. Consider

(3) Everyone who ever supported the Vietnam war now thinks he was an idiot then.

The natural formalization of (3) that we shall discuss below is

(4) $(x)\boxed{\leftarrow}(x \text{ supports the Vietnam war } \rightarrow NT_x \text{Then}(x \text{ is an idiot}))$

where "Then" is a special kind of operator. In this kind of analysis of (3) we make the extremely natural assumption that the following is a subsentence of (3):

(5) He was an idiot then.

(This is the case because (6)

(6) Then (x is an idiot)

is a subsentence of (4) and has "then" as its main logical symbol.) (5) and (6) are however different semantically alone and when considered as a part of a larger sentence (and this is the case even if an interpretation of "he" or "x" is given). The reason is the tense particle "then". This particle makes the sentences (5) and (6) become void of clear meaning -- they do not make any clear statement -- and yet when these sentences occur as a part of a larger sentence as in (3) or (4), it does make a clear contribution to the meaning of the sentence.

Intuitively, "then" in (3) and (4) refers to the time when the supporting took place, i.e., the past tense implicit in the quantifier phrase "everyone who ever supported the Vietnam war" as it were binds the occurrence of "then" (in the same way as the quantifier "everyone" binds the anaphoric pronoun "he").

(Thus we could easily account for the meaning of "then" if we took tenses as explicit quantifiers and "then" as a bound variable. There are a number of arguments against such a theory, however. For one thing, notice that we would have to give up the natural assumption that (5) is a semantic unit in (3).)

In customary Carnap-Tarski type recursive semantics for tense logic there is no way to represent the semantics of (4) adequately. We cannot give adequate recursive semantics for "Then S" with respect to the customary semantic basic concept "truth of a sentence at a moment of time (in a model)". The semantic properties of sentence (6) are different when it is considered alone and when it is considered as a part of a larger sentence as in (4) (and as parts of different larger sentences its semantics is different).

There are ways to handle anaphoric tenses like "then" in the recursive truth-definitional framework. Vlach [30] has shown that this can be done by adopting a basic concept with a new parameter -- "truth of a sentence at a moment of time with respect to a moment of time (in a model)". (The intuitive idea of course is that the first moment of time is the one where the given sentence is being considered, and the second one a moment which gives an interpretation of "then".) I think such an approach to tense anaphora is ad hoc, conceptually misguided, and technically inadequate to capture the whole complexity of natural language tense anaphora. I cannot argue for this point here in any detail. (On the topic, see Saarinen [21], [22].) Here I shall only point out how naturally the above kind of tense anaphora can be represented in game-theoretical semantics, and thereby try to convey the reader an idea of the present novel feature of game-theoretical semantics.

In game-theoretical semantics, the semantics of (4) is spelled out by reference to certain games which are well-defined once a model (for the interpretation of non-logical symbols and atomic sentences) is given. The game proceeds from the outside in (in the sense that if an expression syntactically dominates another expression in the relevant sentence, then the former is analysed semantically before the latter). The game associated with (4) need not be a function of games associated (with the same model and) with the subsentences of (4). Indeed, in the case of (6), the overall game cannot be a function of the semantical games associated with subsentence (6). (It is even questionable whether the latter kind of game is well-defined.) This does not cause problems, however, because the rules for semantical games are designed in such a way that subsentences need to be considered only as parts of the original larger sentence.

Let's consider the semantical game associated with (4). Assume for the purpose that a model M = (T,$\leq$,t,U,R,I,V) is given (where T is a set of moments of time, $\leq$ is the ordering of T, t$\in$T is the "now" moment, U is a set of possible worlds, R is a set of alternativeness relations, one for each i$\in$I, I is the set of individuals, and V is a valuation). The exact rules which determine the game are not relevant here as we are interested in the general principles underlying game-theoretical

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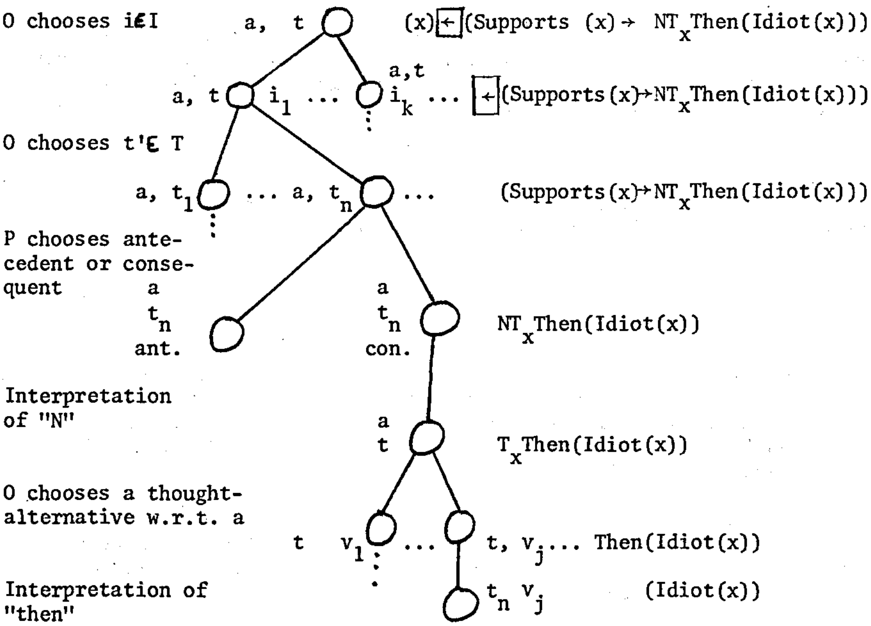
semantics. We shall therefore not bother to state explicitly the rules which we shall make use of below.

The following general observation concerning semantical game rules is however in order. Recursive Carnap-Tarski type truth clauses define the truth condition of certain sentences in terms of the truth conditions of simpler sentences. In contradistinction to this, in game-theoretical semantics we define the truth of a sentence by reference to a certain game, a game which is determined by game rules which indicate how to continue a game once it has reached a certain stage. At every stage of the game a sentence is being considered (with respect to a model, moment of time, and possible world). What game rules do is that they run recursively through the possible sentences of the language, and define possible continuations for a game. The output of a game rule is typically a simpler sentence than the one which was considered before the rule was applied.

The key point is that game rules themselves are context-dependent: they define how a game which has reached a certain stage can be continued. Also, game rules do not say anything of the truth value of the sentences under consideration. That is specified by a whole game only.

The semantical game associated with (4) could be represented in terms of a game tree, part of which looks like this:



Consider now the play fully represented in the picture. (There are of course numerous other plays not represented in the picture.) In this play of the semantical game, the moment when i_1 (the person relevant in this play) supported the Vietnam war is t_n. Thus, in order for our semantics to be faithful for the meaning of (4), "then" in the subsentence (6) should _in this play_ also refer to t_n. This it does, as is witnessed in the step from the penultimate node to the ultimate one.

The key point here is that the recalcitrant subsentence "x was an idiot then" has to be considered _only_ when a play of the game has already proceeded that far (until that subsentence) and thus, in particular, the antecedent of "then" has already been evaluated (a moment has already been selected for the supporting to take place). Since "the game" here means "the game associated with sentence (4), sentence (6) is considered in a very concrete sense of the word as a part of that larger sentence. No problems arise due to the fact that (6) has different semantical properties alone and as a part of (4).

The reader should take particular care to notice that subsentence (6) is considered only when a _play_ of the game has reached it and that this means that the moment "then" refers to is well defined. This is the case even though for different persons the moment of supporting may be different, and even though for some persons there may be several different moments of supporting. (In other words, we need not assume that there was any _the_ moment of supporting in any sense.)

Another way to put the present point is the following. The way game-theoretical semantics is designed allows the introduction of game rules which refer to earlier stages of the same game. Thus, for instance, the following game rule for a "then" operator is perfectly well defined:

(G.then) Assume (a play of) a game has reached a moment of time t, possible world u and a sentence of the form

Then S.

Assume the moment of time which was selected when the antecedent of this occurrence of "then" (in the original sentence) was evaluated ("played off") earlier in that play is t'. Then the game is continued with respect to sentence S, possible world u and moment of time t'.

The important thing is that game rules like (G. then) presuppose information concerning earlier stages of the play which has led us to considering the present sentence. Such information is not forthcoming

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in usual recursive Carnap-Tarski type semantics, unlike in game-theoretical semantics. The reason is the fact that the recursive clauses of Carnap-Tarski type semantics is replaced by game rules which define how to continue a play of a game which has already reached a certain stage. Thus it is presupposed at the outset that we are considering the given sentence in the middle of a game, and therefore it is possible to make the next steps in the game to depend on the ones carried out earlier.

The present feature of game-theoretical semantics is important for many purposes. It plays an important role, e.g., in Rantala's urn models (which among other things help to make sense of the puzzling "impossible possible worlds"), in my backwards-looking operators (which can be used for the logical analysis of tense anaphora, for instance, to the analysis of "then" in uses exemplified above), and in the analysis of various kinds of anaphoric phenomena in general. I cannot go into the details of these matters here. The point that suffices for our purposes is a much more modest one. Indeed, what I merely want to do here is to make clear a respect in which game-theoretical semantics does differ from customary recursive Carnap-Tarski semantics. How that novel feature can be put to work is another question and will not be studied here. (The present novel feature of game-theoretical semantics is not often appreciated. Even Peacocke [16] apparently fails to notice it in his otherwise insightful commentary on game-theoretical semantics.)

The present feature of game-theoretical semantics allows us to locate one important difference between the dialogue approach and game-theoretical semantics. Briefly put, it seems to me that game-theoretical semantics differs also from dialogue approach in this respect.

On the basic level, the dialogue approach is better off than customary recursive Carnap-Tarski semantics in the relevant respect. The dialogue approach has, unlike Carnap-Tarski semantics, a built-in memory (as we might say) just like game-theoretical semantics does. (On "memory", see Gabbay [5] and Saarinen, [23].) In other words, at any given stage of a dialogue game it is possible to recall every step carried out earlier in that game. This is an observation which is obvious once we notice that just like semantical games so can dialogue games be represented in terms of game trees, and one of the characteristic features of the trees is that any given node in a given path has a uniquely determined history (which indicates what kind of moves led to the given position).

What however complicates matters is the possibility of attack and defense repetition in the dialogue approach. I haven't seen dialogue games developed for intensional (or tense) logic, but it is fairly clear that this could be done without too much trouble. For instance, one could presumably use a similar idea to Hintikka's when he generalized his model set techniques to intensional logic by using model systems. (Thus we would interpret intensional operators as a kind of quantifier which introduces us to a number of dialogue games.) Again the details do not matter.

How the possibility of defense and attack repetition in the dialogue approach affects the situation can be best seen if we again consider dialogue games in terms of game trees. The reason why the semantics of an expression like "then" can be so easily spelled out in game-theoretical semantics is that if there is a syntactic antecedent of that expression in the sentence we are considering, then in every play of the corresponding semantical game there is one and only one moment of time which is introduced when the antecedent is "played off". Due to the possibility of defense and attack repetition, this is *not* the case in dialogue games. Antecedent of "then" can be defended and attacked several times, and since different moments of time may be selected in those different defenses and attacks, it follows that before the game reaches "then" there can be several different candidates for the "then" to refer to.

It may be that this feature of dialogue games could be dispensed with by defining suitable restrictions on defense and attack repetion. Could this be done in a way which would not turn the dialogue games essentially similar to the corresponding semantical games remains to be seen.

A second important novelty in game-theoretical semantics is also essentially tied up with the very basic ideas of the approach. This is the possibility of using the notion of an *information set*, familiar from game theory, for certain semantical purposes.

In terms of information sets one can define games with perfect information. (These are games where information sets are unit sets.) In games with perfect information players know exactly all the earlier moves of that game. (They know exactly where they are on the game tree.) In games without perfect information, this is not the case. Thus, e.g., chess is a game with perfect information, whereas most card games, e.g., poker, are not.

Once these ideas of game-theory are applied to semantical games, interesting things happen. In particular, extremely natural semantics for the so called branching quantifiers can be given.

Let's take an example:

(7) $\left.\begin{matrix}(x)\ (Ey)\\(z)\ (Eu)\end{matrix}\right> M(x,y,z,u)$

In the semantical game associated with (7) (and a given *first order* model M) the choice of "(Eu)" depends only on the choice of "(z)" not on the choice of "(x)". (Similarly for "(Ey)".) In this kind of

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game-theoretical semantics for (7) the import of (7) will be the same as its import in Carnap-Tarski semantics in which the import is expressed in terms of the second order formula

(8) (Ef)(Eg)(x)(z)M(x,f(x),z,g(z)) .

The important thing however is that individuals that the quantifiers in the branching prefix of (7) range over are the usual order individuals. All choices of individuals relevant for the semantical game G are made from the domain of individuals of the first order model M. The abnormal force of (7) does not come about by enriching the domain our quantifiers range over, but by making use of a game theoretical notion, viz., of the notion of an information set.

Even though the game rules in the semantical game G operate linearly (and the quantifiers are eliminated one at a time, one after another) and even though the quantifiers are taken to range over the domain of the first order model M, the right semantics is obtained because from the point of view of the player's strategy the relevant choices are not made linearly. (This point has not been appreciated by, e.g., Stenius [29].)

Branching quantifiers are an important test case for game-theoretical semantics for a number of reasons. For one thing, here we have a situation where an idea of mathematical game theory has been put to use in game-theoretical semantics. At the very least this gives a rationale for using game-theoretical terminology in semantics. However, what is even more important is that game-theoretical semantics for branching quantifiers is in certain important respects superior to the alternative semantics given to them in the literature.

To see this point, it is necessary to recall some properties of branching quantifiers. In his paper on branching quantifiers, Jon Barwise [1] shows that the relation

S is true in M

where S is a sentence with essential use of branching quantification and M is a first order model, is not inductively definable at all. Thus, in general, one cannot define the semantics of (7) inductively in the Carnap-Tarski fashion. Given that the game rules in the semantical game for (7) operate recursively (eliminate one quantifier at a time), it follows that in this semantics for branching quantifiers we really have to make essential use of the notion of an information set and thereupon essential use of game theory. The game theoretical perspective not only yields an alternative formulation of a phenomenon but opens possibilities which were not even technically accessible before.

What has just been stated does not of course mean that in the

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traditional semantical framework it is impossible to spell out the semantics of (7). In that framework we can handle (7) by taking the quantifier prefix as a whole and interpret the sentence in second order logic. But what couldn't one do in higher order logics?

Branching quantifiers provide us a testing ground for the differences between dialogue games and semantical games as well.

First a general point. As long as dialogue games are viewed as "proof procedures" of any kind, they cannot yield semantics for branching quantifiers. This is the case because there is no complete proof procedure for the logic of branching quantifiers. (I owe this point to Hintikka.) This marks an important difference between game-theoretical semantics and the dialogue approach, because as we pointed out above there are good reasons for taking the dialogue games as a very general proof procedure (this being even the way scholars working in this tradition themselves describe the approach).

One could perhaps say that after all we need not view dialogue games as proof procedures and that since dialogue games are games in the sense of game theory, one could introduce the notion of an information set to this approach as well.

Presumably one could do that. It remains to be seen whether the logic of branching quantifiers could be formulated in the dialogue approach along these lines.

A more general point is suggested by these considerations. For both the important two novelties of game-theoretical semantics that we have discussed here are essentially connected with game theory. (It is standard to represent games in terms of game trees and the notion of an information set is a standard notion.) In the dialogue approach neither one of these game theoretical notions are made use of. More strongly put, I know of no specifically game theoretical idea which would have been made use of in the dialogue approach. In this respect game-theoretical semantics and the dialogue approach differ sharply. It also gives a further motivation for reserving the title "game-theoretical semantics" for the Hintikka-type approach.

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