BLINDSPOTS, SELF-REFERENCE AND THE PREDICTION PARADOX

TJEERD B. JONGELING AND TEUN KOETSIER

Introduction

The prediction paradox has been widely discussed since it first turned up at the end of World War II. We have presented a solution that involves a certain form of self-reference (Jongeling & Koetsier, 1991). Our approach is based on the idea that somebody admits in his 'store of knowledge' a statement that refers to that store of knowledge. In a number of papers and a book Sorensen (1982, 1984, 1988) has developed a solution of the paradox based on the notion of blindspot, a statement of the form "*p* and '*A* does not know *p*'," which is perfectly innocent as long as *A* is not informed of it, but which becomes inconsistent as soon as *A* accepts it. In this paper we want to discuss similarities and differences between Sorensen's proposal and our own. We make it clear that Sorensen has failed to understand the implications of his own solution.

We want to make three points. First, we show that in important respects Sorensen's solution is similar to ours. Contrary to Sorensen's claim that his solution has nothing to do with self-reference, the store-of-knowledge solution and the blindspot solution involve similar forms of self-reference. The self-reference involved in the prediction paradox is fundamentally different from that involved in liar-type paradoxes. Recently Sorensen has claimed that, in general, self-reference plays no essential role in paradoxes. We discuss the result (which we have published elsewhere) that, on the contrary, for an important class of paradoxes self-reference is essential. Secondly we discuss the question of what a solution of the paradox is supposed to achieve. Sorensen presents a solution that is meant to guarantee that the problem no longer arises. Our aim is only to pinpoint the source of the problem, without claiming that it disappears as a result. We show that Sorensen's solution works informally in simple situations, but is very difficult to formalise. Sorensen's general claim that the paradox disappears when his solution is adopted, is not substantiated. Finally, Sorensen claims that a criterion for what constitutes a satisfactory solution is that it works not only for the prediction paradox, but also for any 'similar' paradoxes. We have suggested a less demanding criterion which only requires that a solution work for the most recalcitrant interpretation of the original paradox. Sorensen's criterion produces interesting results in some situations, but in the final chapters of his book he is carried away by it when he announces that the blindspot solution is mistaken and that the prediction paradox has to be assimilated to a type of paradox that he calls 'slippery-slope paradoxes.' We show that 'slippery-slope paradoxes' are entirely different in nature than the prediction paradox and aren't really paradoxes at all. We conclude that, on this point, Sorensen has to be protected from himself, and that there is more to his blindspot solution than he is willing to allow.

Blindspots and Self-reference

The prediction paradox is well-known. It comes in the form of various stories in which an unexpected – always unpleasant, sometimes gruesome – event is announced that will take place before the end of the week. The different versions have the same formal properties. In the paradox of the unexpected hanging (which we discussed in our first paper) a judge tells a prisoner that he is going to be hanged on a day before the end of the week that will be unexpected to him. In the surprise-examination paradox, which we consider here, a teacher announces an unexpected examination before the end of the week. The students reason that the exam cannot take place on Saturday, because on the last day of the week the exam would not come as a surprise. Once Saturday has been eliminated, Friday becomes effectively the last day of the week, so that on Thursday night the exam will be expected on Friday. This means that Friday can be eliminated. In the same way the other days can be eliminated one by one. The reasoning shows that an unexpected exam cannot be given. The paradox arises because, when the teacher gives the exam on, say, Tuesday, it is completely unexpected. In other words, the teacher's statement is first shown to be inconsistent and is then made true.

Our solution (Jongeling & Koetsier 1991) focuses on the kind of self-reference that is involved. We define an event as expected for a person if it can be derived from information in his 'store of knowledge,' the knowledge that he has accepted as true before the event takes place. Self-reference arises in the story because the statement that is presented to the students ('there will be an unexpected exam') refers to their store of knowledge via the term 'unexpected.' When they accept this statement into their store of knowledge, it refers to the store of knowledge of which it is itself an element. A unique property of the prediction paradox is that the self-reference is not permanently present. The moment the students accept the announcement, the reference of the term 'unexpected' changes and self-reference arises, because the statement refers to their store of knowledge, the content of which changes when they accept the statement. When the students conclude that the statement is inconsistent and remove it from their store of knowledge, the self-reference disappears and the statement becomes consistent and acceptable again. When the exam actually takes place, the self-reference has disappeared, because the term 'unexpected' refers to the students' store of knowledge before the exam. Others can accept the statement all the time without self-reference arising.

From this account it is clear that the prediction paradox is actually a paradox within a paradox. The situation before the exam is reminiscent of the liar's paradox. If the information is accepted into the students' store of knowledge, an inconsistency can be derived and the statement is seen to be unacceptable. When it is removed from the store of knowledge, there is nothing wrong with it, and it becomes acceptable again. The instability of the status of the statement results from the impermanence of the self-reference. Much more paradoxical is the fact that this statement, which is inconsistent when accepted by the students, is later made true without any problem. This is again the result of the impermanence of the self-reference, which disappears completely when the actual exam arrives.

It is important to realise that there is a fundamental difference between the nature and the role of the self-reference involved in the liar's paradox and of that in the surprise-examination paradox. In the liar's paradox there is a statement that refers directly to itself. In the prediction paradox there is a statement that refers to a set of which the statement itself is an element. The role that the self-reference plays is also different. In the liar the self-reference is permanent and causes instability in the ascription of truth value. In the prediction paradox the self-reference is itself instable and impermanent.

Sorensen's solution is based on the notion of blindspot, which can be defined as follows. A proposition p is an epistemic blindspot for person A if and only if p is consistent, while the statement 'A knows p' is inconsistent. An example of an epistemic blindspot is 'It is raining but Bob doesn't know this.' This is an epistemic blindspot for Bob, but not for others. A proposition is called a conditional blindspot if it is equivalent to a conditional whose consequent is an epistemic blindspot. Sorensen now claims that if a proposition is a conditional blindspot for a person A, then it is possible for A to know the proposition and it is possible for A to know the antecedent, but it is not possible for A to know both the proposition and the antecedent. Blindspots and conditional blindspots are statements with a special status. When somebody is informed of a statement that is a blindspot for him, he will have to recognise it as a blindspot and conclude that it is unknowable for him, not that it is false. Similarly, a conditional blindspot may become unknowable when somebody knowing it is informed of the antecedent.

The teacher's announcement is a conditional blindspot for the students. Once they know that the exam has not been held on Friday, their knowledge turns into a blindspot: they know that the exam will be held on Saturday and that they cannot know this. According to Sorensen's rule the announcement becomes unknowable for them once the exam has not been held on Friday. This means that the students cannot reason backwards. They cannot conclude that the assumption that the exam has not yet been held on Friday leads to a contradiction. It only leads them to conclude that they are saddled with a blindspot, which is unknowable for them. Sorensen goes on to show that this solution works for all variants of the paradox that he had invented earlier (1982).

It is clear that an important element of Sorensen's solution is the same as that of ours. We locate the problem in a statement that is consistent if not known and inconsistent if known. This is precisely what Sorensen calls a blindspot. Curiously, Sorensen claims that the blindspot solution is fundamentally different from self-reference solutions. His most important argument is that a self-reference solution only explains why the teacher's announcement seems inconsistent initially, but not how it can be made true (1988, pp. 298 and 308). He gives a reconstruction of what he calls 'the' self-referentialist interpretation, in which the students' reasoning involves arguments whose premises indirectly refer to their own validity. As we have indicated above, the self-reference is to be found elsewhere, in the fact that the announcement refers implicitly to the content of the students' store of knowledge, which changes the moment they accept the statement and add it to their store of knowledge.

Recently Sorensen (1998) has claimed that self-reference is neither a necessary nor a sufficient condition for liar paradoxes to arise. He bases his claim on Yablo's paradox (Yablo 1993), which consists of an infinite sequence of statements and which does not involve self-reference. Elsewhere (Koetsier et al. 1999) we have shown that Sorensen's claim is incorrect. For liar-type paradoxes, sequences of sentences in which all sentences are either undefined (atomic) or defined in terms of other sentences of the sequence, we have derived the following result: a paradox either contains a self-referential cycle or it is infinite. This result is easy to understand intuitively: if the chain of reference is finite, it ends in statements that have unambiguous truth values. From these termini the truth values of the other statements can be determined by reasoning backwards. Problems can only arise if the chain of reference is infinite, which can only be the case if the set of statements contains at least one referential cycle or consists of an infinite number of statements. It seems likely that the result that finite paradoxes always involve self-reference applies to paradoxes in which the self-reference is different in nature as well.

It can be maintained that the blindspot solution of the paradox does not involve self-reference. As will be discussed more extensively in the next section, according to Sorensen the paradox is avoided if the students are made to reason 'correctly', i.e. according to Sorensen's rules. Therefore no self-reference is involved in the solution. This does not mean, however, that no self-reference is involved in the original paradox. Presumably Sorensen's answer to the question of what gives rise to the paradox is: treating a blindspot as if it is a normal statement. He seems to assume that it is self-evident that treating blindspots as knowable will lead to paradoxical results. But if we look for those properties of blindspots that produce their paradoxical behaviour, it is obvious that self-reference is involved. The blindspot "*p* and '*A* does not know *p*'" can be taken to refer to *A*'s knowledge, what we have called *A*'s store of knowledge: it implies that *p* is not part of *A*'s knowledge, or *p* is not in *A*'s store of knowledge. As soon as *A* accepts this statement, it becomes self-referential because it refers to *A*'s store of knowledge of which it is itself an element. It is therefore obvious that self-reference is involved in the blindspot account in the same way as in the store-of-knowledge account.

Does the paradox disappear?

Sorensen has a different notion of what a solution should achieve than we. Our aim is to indicate the root of the problem, Sorensen's to develop a procedure that guarantees that the problem no longer arises. He states that just indicating the root of the problem does not constitute a solution, it only classifies the paradox as being of a certain type (1988, p. 299). When he presents his own solution he seems to assume that once the root of the problem is known, it is immediately evident how the problem is avoided. He is so sure on this point that he does not take the trouble to be very clear. He claims that the notion of blindspot solves the problem in that the paradox no longer arises once we realise that blindspots have to be handled in a special way. He suggests that there are special rules for dealing with blindspots, although his account is more explicit on what goes wrong if blindspots are handled incorrectly than on how they are to be handled correctly. The basic idea that can be distilled from his account is the following. A statement that is a blindspot to some person has the property that it may be true and at the same time cannot be known to be true by that person. This means that once a person has reached a blindspot in his reasoning, he will have to stop believing the information from which he has inferred the blindspot, but he will *not* be able to conclude that this information is false. Therefore when the students start reasoning backward hypothetically (if the exam has not yet taken place on Friday night, it will have to take place on Saturday and will be expected, which leads to a contradiction), they will have to realise that they have derived a blindspot, and that although their assumptions lead to contradictory conclusions, they cannot conclude that these assumptions have to be false. As a result they cannot reason backwards. They cannot even conclude that the exam cannot take place on Saturday.

When we try to formalise this rule, it is immediately clear that far-reaching measures are required. A three-valued logic is needed. If 'A knows p' is written KAp, there are, from A's point of view, three categories of statements: true ones, false ones and unknowable ones, statements of the form p & $\neg$KAp belonging to the last category. Although A can derive a contradiction from such a blindspot as soon as he adds it to his store of knowledge (because from p he can conclude that he knows p: KAp), he cannot conclude that the blindspot is false. In the case of a conditional blindspot whose antecedent is known – A knows both q and $q \Rightarrow (p$ & $\neg$K$Ap)$ – A cannot conclude from the inconsistency of the blindspot that q or the conditional blindspot is false. If a blindspot is inconsistent, it may be unknowable instead of false. If other 'knowers' are allowed, the status of a statement will depend on which knower is considered. 'p & $\neg$KAp' is unknowable for A but not for B. This means that not only do we need a three-valued logic, but in addition truth becomes a two-place predicate. Something can only be said to be true or unknowable for a certain person. (False statements would seem to be equally false for everybody.)

However, the rule that blindspots are unknowable is not sufficient. Suppose that A knows both p => q and $p \Rightarrow \neg$KAq. His knowledge implies a conditional blindspot, but is not itself a blindspot or conditional blindspot. Now, if he learns that p (or hypothetically assumes that p), he can derive the blindspot q & $\neg KAq$, and decide that it is unknowable, but he can also directly derive q and hence KAq from the first statement, and $\neg KAq$ from the second statement. This means that he can derive a contradiction without first encountering a blindspot. He will conclude (incorrectly) that p cannot occur. The rule that blindspots are unknowable therefore does not prevent him from drawing incorrect conclusions in such a case.

Apparently a blindspot can be implicitly present in a set of statements. It is far from clear what sort of rules should have to be introduced to deal with such sets. Sorensen's solution remains in the informal sphere. It works for simple situations. In formal logic a set of rules is needed that works in all situations.

Sorensen emphasises that a consequence of his solution is that conditional blindspots are knowable and informative. A simple blindspot is unknowable and therefore uninformative, but a conditional blindspot can be known without leading to a contradiction, and therefore other information in which no blindspot is involved, can be derived from it. Sorensen does not elaborate on this point, but it is easy to think of examples. From the conditional blindspot 'there will be an exam on an unexpected day' it follows 'there will be an exam on some day,' from which the students can conclude that they better prepare.

What is a good solution?

As we have suggested earlier (1991), past discussions of the paradox have sometimes been confused because it was not clear what should count as a satisfactory solution. We have proposed a criterion based on the fact that different interpretations of the paradox are possible. The surprise-examination paradox is presented in the form of a simple story couched in everyday language. Some of the details of the story vary between different versions. In order to pinpoint the source of the problem, the story has to be made more precise, a particular version has to be chosen and it has to be fleshed out or formalised to some extent. This can be done by replacing the students in the story by an ideal agent, who reasons in accordance with a fixed set of unambiguous rules. These rules are not self-evident. The ideal reasoner may completely stop reasoning when he comes across an inconsistency, as a computer might do, or he may conclude that it is false, or that it is unknowable. There are various other options that can be considered. In our paper we discussed the possibility that the ideal agent be allowed to reason at a metalevel: he imagines someone else who is in a similar situation; about this other case he can reason in a way that he cannot about his own; he can then try to apply some of his conclusions to his own situation, as his own situation and the imaginary one are isomorphic. Various 'pragmatic' interpretations have been proposed in which, for example, the students are not very clever. Clearly, some interpretation is required and quite a few different interpretations are possible.

We feel that a satisfactory solution of the paradox has to be able to cope with the most recalcitrant interpretation of the paradox, for the simple reason that the most recalcitrant interpretation constitutes the most interesting problem. Our criterion rules out a number of solutions. Weintraub (1995) has proposed a pragmatic interpretation of the paradox, which results, she claims, in various solutions. In a practical, real-life context the teacher's statement can, for example, be viewed as a promise that should be construed non-literally. The teacher is taken to mean no more than that an exam will be held sometime during the week. No paradox arises. A second possibility is to assume that the logical insight of the students has its limitations. The students have to be taken to be rational, but 'logical omniscience isn't a condition for rationality.' Due to their limitations they may not notice that the teacher's statement is paradoxical. Obviously, these solutions do not work for slightly different interpretations of the paradox, viz. interpretations in which the statement is construed literally and the students are very clever or replaced by ideal thinkers. (Apart from our criterion, Weintraub's approach is unsatisfactory in general. Many problems in philosophy evaporate when presented to not very clever students, who simply don't see the difficulties involved.) Our criterion also rules out the solution proposed by Quine (1953). Quine argues that if the student (in his presentation the prisoner) is allowed to conclude that the teacher's announcement is false, because it leads to a contradiction, he has to take the possibility that the announcement is false into account at an earlier stage. If he does so, no contradiction can be derived. When the story is slightly changed, however, the paradox returns. Let the possibility that the announcement is false never be considered. The student only concludes that the announcement is inconsistent. Then the paradox remains that an announcement that is inconsistent can be made true.

Sorensen has proposed a slightly different criterion, which is more demanding than ours. A solution should work not only for the most recalcitrant version of the original paradox, but also for other, similar paradoxes. This criterion is sometimes very helpful. It has been suggested by some authors (Wright & Sudbury 1977) that time plays an important role in the paradox, because the students have to remember on later days of the week what happened before. It is claimed that a 'temporal retention principle' is therefore needed to formulate the paradox. This would imply that the paradox can be solved by not accepting the temporal retention principle. Sorensen presents a paradox which shows that the temporal element in the original paradox is irrelevant. Imagine a number of students placed in a row so that each can see the backs of the students in front of him. The teacher announces that he will place a gold star on the back of one of the students and a silver star on the backs of the others, that the student with the gold star will be given a special exam, and that the student with the gold star will not know he has been designated until the students leave the formation. The students now reason that if the last student in the row has the gold star on his back, he sees that no one in front of him has the gold star. He can therefore conclude that he himself has the gold star and his being the designated student does not come as a surprise. As in the original paradox, all the other students can be eliminated by reasoning backwards. It can therefore be shown that the announcement cannot be made true. And then, of course, the teacher makes the announcement true by designating one of the students in the way indicated. It is clear that this paradox is isomorphic to the original one, but that the temporal retention of information in the original paradox has been replaced here by simultaneous observation. The designated-student paradox therefore shows that temporal retention is irrelevant.

A problem with Sorensen's criterion is that it is not immediately clear when two paradoxes should be called similar. If a seemingly satisfactory solution of the surprise-examination paradox does not work for another paradox that looks similar, the possibility arises that the similarity is only super-ficial, and the fact that the same solution does not work for both of them may be taken to show that, contrary to appear-ances, they are basically different. It may often be possible to argue for or against the similarity on independent grounds, but at the very least application of the criterion requires great care. Actually we want to argue that Sorensen has been led astray by his own criterion. After presenting a convincing case for his solution of the paradox in terms of blind-spots, he says that he is dissatisfied with it, because it does not work for a group of paradoxes that he calls 'slippery-slope fallacies.' The result is that, having looked into the promised land of a satisfactory treatment of the prediction paradox, Sorensen turns round and walks back into the desert.

In the last-buyer paradox an experimental economist offers a hot potato for sale for $100 to any member of a small group of traders. A trader who sells it to another trader will be paid one million dollar by the economist. Side payments are not allowed and the traders will never see each other again. A final condition is that one can only sell to somebody whose name is alphabetically lower than the seller's; A can sell to B, but B cannot sell to A. The economist predicts that at least one of them will buy the potato. One of the traders objects that the last potential buyer will not buy, because he cannot sell. This means that the last but one becomes effectively the last one, and won't buy either. Repetition of the argument shows that nobody will. Yet, says Sorensen (1988 p. 334), "it seems clear, especially as the number of traders grows, that someone would risk $100 and buy the potato in the hope of selling it to someone else."

Sorensen formalises the paradox as follows. Let p_1 denote 'a is the last buyer,' and p_2 'b is the last buyer,' etc., while $K_a p_1$ stands for 'a knows that he is the last buyer.' The economist's prediction and the rest of the information available to the traders can then be written as:

(A)$[(p_1 \Rightarrow \neg K_a p_1) \& (p_2 \Rightarrow \neg K_b p_2 \& K_b \neg p_1) \& \ldots \& (p_n \Rightarrow (\neg K_n p_n \& K_n(\neg p_1 \& \neg p_2 \ldots \& \neg p_{n-1})] \& (p_1 \vee p_2 \vee \ldots \vee p_n)$

This formula states that there will be a last buyer, that a trader buys only if he does not know that he is the last buyer, and that he knows that his purchase will eliminate the preceding traders as last buyers.

However, the formula can also be used to describe the situation in the designated-student paradox. Let p_1 stand for 'a is the designated student', p_2 for 'b is the designated student', etc. The statement (A) then represents the announcement in the designated-student paradox. The students and the traders in the two stories all know the announcement, and they all know that all the others know it. The structure of both stories can therefore be represented as: $(x)K_x[(y)K_y(A)]$, so that the arguments used in the two stories can be formally reconstructed in the same way. Sorensen shows that this statement is inconsistent in any quantified normal modal analysis of epistemic logic. This means that the sceptical arguments used in the two stories can be formally reconstructed in the same way.

From this result Sorensen draws the conclusion that the last-buyer paradox is a variant of the designated-student paradox and the prediction paradox. We think this conclusion is unwarranted. The various stories are called paradoxes, not because they all contain an inconsistent statement, but because the inconsistent statement is somehow made true. In this respect the stories are fundamentally different. In the prediction paradox the announcement is made true by the decision of an outsider, the teacher, who unexpectedly announces the exam. In the last buyer, the prediction is made true by an insider, one of the traders, who decides that he will buy the potato after all. The conclusion that nobody will buy is based on the assumption that all traders are 'rational thinkers' who decide rationally on the basis of certain rules, one of which is the assumption that all the others can be assumed to be rational as well. If one of the traders decides to buy, it is on the assumption that the others may not be rational thinkers in this particular sense. It is clear that if there are a number of traders who decide to buy, there will be a last buyer, who cannot sell and who therefore has made a patently irrational decision. The first trader who makes the decision to buy is therefore not rational in the original sense either. This does not mean that traders who decide to buy are not rational in some wider sense. It is surely possible to analyse the story in terms of a different notion of rationality, e.g. game-theoretic notions, which allow risk-taking and estimating the likelihood's that others will take certain risks. In such terms it may be perfectly rational to take the risk of being the last buyer in view of the fact that the profit if one is not the last buyer is enormous.

This means that there is no real paradox involved in the last buyer. The announcement is shown to be inconsistent on the basis of ascribing a certain form of rationality to the participants, and then the announcement is made true by allowing the participants a different form of rationality. In the prediction paradox, on the other hand, the announcement is made true without a shift in the rationality of the participants. The rationality of the participants does not play any role in the way the announcement is made true. We therefore conclude that the last buyer paradox and the prediction paradox are fundamentally different, and that the last buyer is not a paradox at all.

That the last-buyer paradox is fundamentally different from the prediction paradox is also shown by the fact that the last-buyer paradox does not work with only two traders – on any notion of rationality the first trader will realise that the second trader will not buy, and therefore will not buy himself, so that the experimental economist's claim is not made true – while the designated-student paradox is as paradoxical as ever with only two students.

Conclusion

We have shown that a central element of the blindspot solution and of the store-of-knowledge solution of the prediction paradox as presented by Sorensen and ourselves is basically the same. Sorensen claims that the paradox can be solved in terms of a type of statements that are consistent when not known and inconsistent when known, which he calls blindspots. We have made the same claim without using the term blindspot. An important difference between the solutions is that in Sorensen's account blindspots have to be handled in such a way that the paradox no longer arises. As a result he does not see that the original paradox contains an element of self-reference. We have pointed out here for the first time that the kind of self-reference involved in the prediction paradox is fundamentally different from that involved in the liar. The self-reference in the liar is permanent and causes instability in the ascription of truth values. The self-reference in the prediction paradox, on the other hand, is itself impermanent and instable. We have shown that Sorensen's claim that self-reference plays no role in paradoxes is incorrect. On the contrary, at least in some finite paradoxes self-reference is essential for a paradox to arise. There are other serious flaws in Sorensen's account. Incorrect is his claim that the paradox disappears once it is clear that blindspots are the source of the problem and that blindspots have to be handled in a special way. His criterion of what constitutes a good solution is to some extent helpful, but it leads him astray when he assimilates the prediction paradox to slippery-slope paradoxes, and as a result abandons his own blindspot solution.

TJEERD B. JONGELING
ARRUPE COLLEGE
JESUIT SCHOOL OF PHILOSOPHY AND HUMANITIES
18 LINK ROAD, MOUNT PLEASANT
HARARE
ZIMBABWE
e-mail: tbjongeling@zol.co.zw

TEUN KOETSIER
DIVISION OF MATHEMATICS AND COMPUTER SCIENCE
VRIJE UNIVERSITEIT
DE BOELELAAN 1081
NL-1081HV AMSTERDAM
THE NETHERLANDS
e-mail: teun@cs.vu.nl

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