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Scenario development and practical decision making under uncertainty

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Abstract

In this paper, we address the question of how flesh-and-blood decision-makers manage the combinatorial explosion in scenario development for decision making under uncertainty. The first assumption is that the decision-makers try to undertake 'robust' actions. For the decision-maker, a robust action is an action that results in sufficiently good result whatever the events are. We examine the psychological as well as the theoretical problems raised by the notion of robustness. Finally, we address the false feeling of decision-makers who talk of 'risk control'. We argue that risk control results from the thinking that one can postpone action after nature moves. This 'action postponement' amounts to change look-ahead reasoning into diagnosis. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Uncertainty; Decision-making scenarios; Robustness

1. Introduction

Decision theory [28] offers a framework to think about decision making under uncertainty. In this model, each nature state encompasses the past, the present and the future in a very comprehensive concept [29]. In most practical situations, information and knowledge relative to past and present dramatically differs from information and knowledge about future, the former being much more certain and generally accurate than the latter. This is the reason why we have, from a practical point of view, proposed to distinguish between diagnosis and look-ahead [21]. This distinction is consistent with decision-makers' practice to deal with future by using 'what-if' analysis and/or scenario thinking. Each scenario can be regarded as a branch of a decision tree. However, it is easy to imagine that, in any real situations with many possible events, the decision-maker faces a combinatorial explosion of the number of branches. This large number of branches prevents the decision-maker from really developing the whole decision tree. For this reason, the decision-maker reduces or prunes the decision tree. In this paper we examine the different means used by decision-makers to reduce the exponential complexity of scenario thinking and suggest some ideas for scenario management.

More striking than the reduction of scenario trees is the fact that many decision-makers think that they are more or less able to 'manage' the risk [1,15]. We

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analyze this situation as 'action postponement'. In terms of requirement analysis, this means that many external events are 'forced' to occur before any system processing [23].

In Section 2 of this paper, we examine the question of robustness and in Section 3, we address the problem of 'risk control'.

2. Robustness and scenario management

In what follows, we denote actions or alternatives (especially in a multi-criteria setting) the elements of a choice set. We mainly focus on look-ahead [21] so that when we refer to nature states, we think to the states that will occur in the future. The true state of nature is given after the nature's bet or move. A nature's move is represented by a chance node from which emanates the many possible events (see Ref. [25] for basic notions about decision trees). Practically, let us think about the choice of introducing or not a new product, the choice of the features of a privatization law [13, p. 249], the design of a good railway timetable [24]. Gilboa and Schmeidler [5] mentioned the choice of a baby-sitter or Clinton's decision about Bosnia. What characterizes such situations is, first of all, the uncertainty about the possible reactions of competitors or other agents (for example, unions in the case of a privatization law or other countries in the Bosnia case). From these examples, it appears that the choice at hand, in many real situations, is the choice between scenarios. These scenarios form a sequence of decision-maker's and nature's moves.

In the framework of classical decision theory, the decision-maker chooses an alternative, then the nature's move occurs and the decision-maker accordingly gets his result. Actually, the decision-maker does not choose a simple alternative but a policy according to different events that might occur at different moments. This is what is generally called a scenario (Fig. 1).

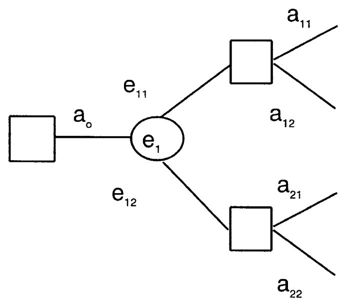

Fig. 1. Scenario development.

In Fig. 1, $\{a_o, a_{11}$ if e_{11}, a_{22} if $e_{12}\}$ is the beginning of a scenario when two events, e_{11} and e_{12}, are possible at the first chance node e_1. The development of the scenarios results in a tree. Indeed, events and alternatives happen to be very numerous, so that the decision-maker faces a combinatorial explosion. How do people practically reason to manage this combinatorial explosion? According to our examples, we suggest two ways of coping with the combinatorial explosion in scenario development.

The first way was observed in the system for evaluating timetables [24] and also in previous systems such as for the choice of a privatization law [13]. The characteristic of these cases is a large number of events whereas the number of alternatives is relatively small (about five). The decision-maker can theoretically define many sub-actions for each branch of an event node, but in fact he tries to define only one action which is 'good enough' for all the branches of a chance node. Following Roy [26], we propose to call this notion of 'good enough for every possible realization of the chance node' as *robustness*. A selected action following a chance node is robust as long as it gives 'good enough' results against any event of the chance node. In this case the decision-maker can skip the chance node and the tree is flattened (Fig. 2). In Fig. 2, the action a_1 is robust relative to the two events, e_{11} and e_{12}, of the chance node e_1. Thus, the same unique action answering the two events, it implies that the chance node e_1 disappears because the decision-maker chooses a_1 in any case.

The tree being flattened the decision-maker thinks in term of a sequence of actions (Fig. 2). It is the reason why we coined the term 'fully expanded alternative' to describe this type of 'alternative' [24]. One may wonder how the decision-maker reaches the conclusion that a sub-action is sufficiently robust. Again, from a theoretical point of view, the decision-maker ought to use a folding back proce-

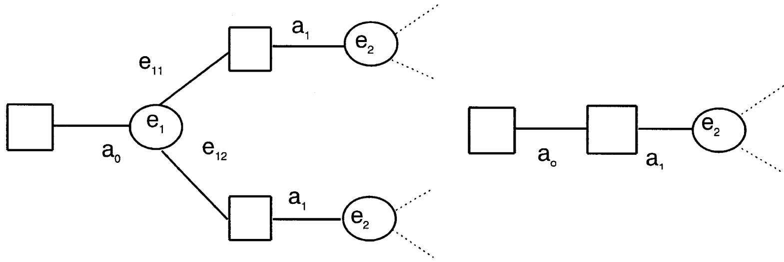

Fig. 2. Transforming a tree by using a robust action a_1.

dure and a pessimistic choice criterion such that maximin of minimax-regret. An alternative view consists of defining as satisficing (in Simon's sense) the actions that, for each event, provide an outcome superior to a given 'aspiration level' (see Refs. [16,17] for an abstract formalization of this point of view). In many cases, for real decision-makers, the most robust action is that which avoids dramatic loss (ruin) whatever the events happen to be [15]. This sensitivity to the worst result for loss is well documented [15,35]. More generally Tversky and Simonson [34] talk of 'extremeness aversion'. Rubinstein [27] and Leland [12] tried to explain this sensitivity to the outcome values by multi-steps decision models in which a comparison of the values of the outcomes intervenes. Shafir et al. [30] propose an advantage model which, in a lottery, takes into account separately the relative advantages of the values of the outcomes vs. the difference between the two probabilities. They also introduced a different behavior for gains and loss as regards these advantages. This difference of behavior is commonplace and it seems that many decision-makers actually, consciously or not, use a maximin criterion for loss. In the case of timetable robustness, at each chance node, the decision was made by an expert system which, depending on various information, gave what seems to be the better (most robust) action. For the choice of a privatization law, as well as for the introduction of a new product, most of chance nodes actually model the behavior of other agents (unions, competitors, etc.). In the just mentioned systems, the other agents were modeled and simulated by knowledge-based systems. Then, according to the possible moves of the other agents, an action was chosen, either for its robustness or because the expert system reaches the conclusion that the other agents should behave 'almost certainly' in a given direction.

Using a maximin criterion in order to get actions 'good enough' for any nature's move leads to overly pessimistic behaviors and raises the problem of considering events with very small probabilities. One must remember that human beings have difficulties to rationally process probabilities especially the small ones. Small probabilities are either overestimated [35] or ignored [15]. Moreover, optimistic bias and inside views [7] also entail that decision-makers tend to neglect possible events and leads to 'anchoring on the easier to built scenarios' or on the most detailed even if the details are illusions [33]. Thus, what may appear as a robust action is simply so because some possible events are ignored by the decision-maker. Moreover, very often the decision-maker tries to persuade himself that the probabilities of events which do not favor the chosen 'robust' alternative are very small. This 'search for dominance' has been pointed out by Montgomery [19,20]. Montgomery [19] describes different ways used to bolster attributes (or events in our framework) that back an alternative while the ones that do not support them are more or less discarded. Thus, our former definition of a robust action as an action which gives 'good enough' (or satisficing in Simon's sense) results against any events of a chance node, is too strong. We cannot avoid the discussion about events with (very) small probabilities or, in other words, according to the context, events that are negligible or not. This is the reason why, following Roy [26], we will also consider *approximately* robust actions. An approximately robust action is an action that results into satisficing outcomes for almost all the events of a chance node. For the decision-maker, the question is then to appreciate the events that can be neglected. In a risky setting, one can think that the less probable events are negligible. Actually, this negligibility depends on the decision-maker and on the context.

The concept of negligibility is, in fact, central in any realistic scenario reasoning. In a recent work, Lehmann [11] proposed a definition of a negligible event in the framework of Savage's theory. Roughly speaking, a given event is negligible if the decision-maker's preferences for a particular action is not changed by any change of the value of the outcomes for this given event. A close concept is that of 'liability exposure to something undesirable' [6]. In this later framework, each action is measured in terms of its utility and 'liability exposure'. This latter measures the strength of the reject of a given action for each event. According to Stirling and Goodrich [31] an action is robust when a compromise between the desirability of an action and its liability exposure is larger than a given threshold.

3. Scenario pruning and risk 'control'

We have argued that, in some cases, decision-makers try to reduce scenario expansion by introducing fully expanded alternatives, deleting a chance node by using robust actions (or sub-actions). Another solution to control the combinatorial explosion is to prune the tree by using contextual knowledge or case-based reasoning. Case-based reasoning is now well known in artificial intelligence [10] but it has rarely been used for decision making. Case-based reasoning is very appealing to model some well-known features of naturalistic decision making (see Ref. [9] for a survey). Immediate decision making by matching the current situation is supported by psychologists [8,9,14] as well as by neurobiologists (see Refs. [2,22] for an overview). In other words, the important step in this type of decision, is diagnosing the current state of the world, then each recognized state immediately triggers a decision [21]. Klein [8] coined the term Recognition-Primed Decision (RPD) for this decision process.

Gilboa and Schmeidler [5] proposed a very comprehensive model for case-based decision which parallels Savage's theory. In their model a case is represented as a triple (problem, action, result) and decision making is based on the similarity with recorded cases. However, they do not address the problem of implementing their similarity function. Another example of merging decision making and case-based reasoning is given in Ref. [32]. In this system each case is a chemical compound enjoying some pharmaceutical properties. Case retrieval is used to determine the possible outcomes and uncertain or missing features of the case at hand. Then, the decision theory is used to find the compound which has the higher probability to fit to wished pharmaceutical properties.

Finally, Monnet et al. [18] give a formal syntax for a similarity function on cases described by Horn clauses. They introduced the concept of negligibility of a set of clauses. These two concepts of similarity and negligibility try to capture decision-maker's behavior. In scenario thinking, case-based reasoning should be used to avoid the total development of branches. As soon as the beginning of a branch matches with a recorded case, modulo some negligibility, then the decision-maker can retrieve the outcomes of the actions at hand (Fig. 3). In this figure, when the decision-maker recognizes the sequence (a_1, e_{11}, a_2), then he makes the same decision as in the recorded case. He can also reach the same conclusion even if there are negligible differences between the two cases—for example, about the probability of e_{11}.

Case-based reasoning exempts from developing the whole scenario because, if a part of the current case matches, even approximately, the recorded case, it is assumed that the end of the story is similar to the recorded case (Fig. 3). Generally, the degree of matching is measured by a similarity function defined on couple of cases. Case-based reasoning, by allowing the decision-maker to refer to past decisions, introduces a short-cut between action and result. This amounts to say that, due to decision-maker's experience (recorded cases), in a given situation, when the decision-maker undertakes the action a_j, he thinks that he will get the result r. In decision theory, the result is a function of actions and nature states, i.e. the result depends on the true state of nature. In other words, the similarity measure between the recorded case and the current case tends to evaluate the feeling of the decision-maker about the true nature state. As such, this is a way to delete

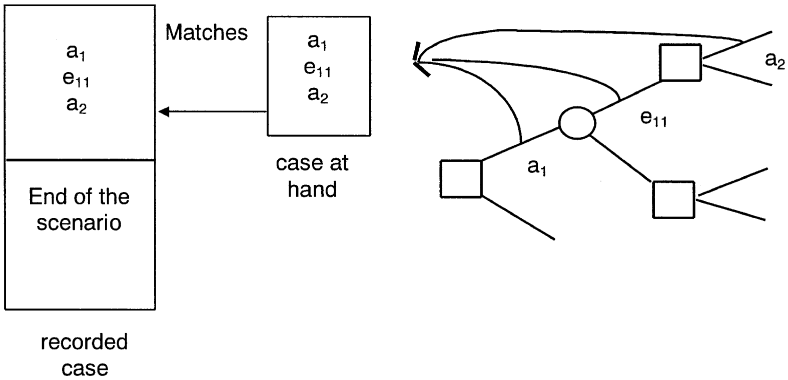

Fig. 3. Case-based scenario thinking.

many event nodes by referring to some recorded experience.

Another way to diminish the number of chance nodes is related to what decision-makers call 'risk control'. Although this illusion of control is mentioned in many empirical studies [1,7,15], this does not make sense as regards decision theory. However, we think that this illusion is related to what we suggest to call *action postponement*. We observed this behavior in many situations. Many decision-makers actually try to postpone the action after, as much as possible, nature's moves. A typical example is given by the controllers of a subway line. In Fig. 4, we give a sub-tree of actions and events in case of incident in a subway control (system SART [3,4]). In this case we observed that the controllers postpone as much actions as possible after events identification. Then it is possible to consider this sequence of actions without any chance nodes as a 'macro-action'. A macro-action differs from a fully expanded alternative because it does not result from a reduction process deleting chance nodes but from a direct grouping of actions without chance nodes because nature's move took place before action. Macro-ac-

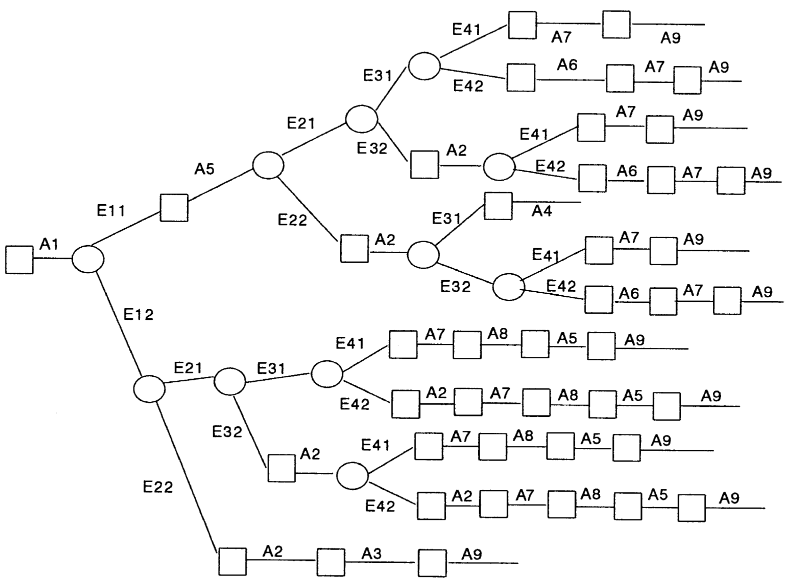

Fig. 4. A tree in which many actions are postponed to the end of the branches. (The names of the actions and events are given in the Appendix A.)

tions are often robust because the decision-maker tries to tackle most of the events relative to the event node preceding the macro-action. In Fig. 4, one can identify several macro-actions existing on different branches (e.g., A6–A7–A9).

Macro-actions as well as fully expanded alternatives are designed by the decision-maker so that they are insensitive to events (i.e., they are robust). In the system for evaluating timetable robustness [24] at each step, the expert system chooses a robust action that can resist to any new occurring events. Note that, like in SART, this is possible because there are actually few possible actions, none of them being dramatically bad. In some sense, an expert system is a primitive way of using contextual information to reduce the complexity of decision trees. However, it is not clear whether the simplification results from reducing the number of events (e.g., in the privatization law) or finding robust actions (e.g., the timetable robustness). In many systems, the two issues are tangled and the two ideas are very involved.

Another interpretation of this phenomenon observed in SART is that the controllers try to diagnose, as carefully as possible, in which branch of the tree they are. They use to gather the maximum quantity of contextual information in order to match a branch with the perceived situation. This is a typical case of action postponement after the diagnosis of the current situation. Each recognized state triggers an action according to a kind of recorded table resulting from operator experience [21]. Then, the question of the quality of the diagnosis of the current state arises which leads to the question of the number of possible states according to the context, because the number of possible states is potentially very important.

4. Conclusion

Up to now, there were few attempts to reconcile decision theory and pragmatism. In this paper we propose different ideas to bridge this gap. The first concept is that of robust action and fully expanded alternative which tends to replace a sequel of events and actions by a sequence of actions resisting to every event. The second idea is to replace the function which gives the outcome resulting from an action and a chance moves by a case-based reasoning system. Finally, we introduce the ‘action postponement’ behavior, which seems to be very familiar to flesh-and-blood decision-makers and which theoretically moves the burden of scenario thinking to diagnosis and information seeking. These three practical ways to alleviate the exponential expansion of scenarios are generally instinctively used by decision-makers.

Thus, examining scenario development in the light of decision theory and practice suggests some ideas for a systematic reduction of scenario tree complexity that can be worth thinking about in practical decision making.

Appendix A. Some Actions (A) and Events (E) in case of incident on an underground line

A1	Disconnect regulation function of the damaged train	E11	Damaged train in a station
A2	Emergency exit of the travelers from all trains on the line	E12	Damaged train in the tunnel
A3	Make damaged train attain next station	E21	Immediate repair possible
A4	Lead the damaged train to the terminus	E22	Immediate repair impossible
A5	Exit of travelers from the damaged train	E31	Few trains in section line
A6	Lead next train to the nearest station	E32	Many trains in section line
A7	Emergency exit of the travelers from the next train	E41	Next train in a station
A8	Push damaged train to the next station	E42	Next train in tunnel
A9	Push damaged train to the terminus		

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