Either, Or. Exploration of an Emerging Decision Theory.

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Exploration of an Emerging Decision Theory

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Abstract

A novel decision theory is emerging out of sparse findings in economics, mathematics and, most importantly, psychology and computational cognitive science. It rejects a fundamental assumption of the theory of rational decision-making, namely, that uncertain belief rests on independent assessment of utility and probability, and includes envisioning possibilities within its scope. Several researchers working with these premises, independently of one another, arrived at the conclusion that decision is made by highlighting the positive features of the alternative that will be chosen while opposing it to a loosing alternative, whose unpleasant aspects have been stressed.

This article frames together contributions from different disciplines, often unknown to one another, with the hope of improving the coordination of research efforts. Furthermore, it discusses the status of the novel theory with respect to our current idea of rationality.

> A famished fox, when she saw grapes hanging from a vine, wanted to reach them and could not. Going away, she said to herself: "They are sour".
>
> Aesop, VI century B.C.

1   Introduction

According to the ancient Greek tale reported above, the fox was not smart. In fact, after measuring the probability to reach the grapes (by jumping), she preferred to change her evaluation of their utility (they are sour) rather than updating her probability assessment (the grapes are too high).

The tale of the fox and the grapes entails a basic requirement of our idea of 'rationality', namely, that judgments about the likelihood of certain events — in modern terms, the probabilities of the consequences of certain actions — are made independently of judgments about the desirability of these events — in modern terms, the utility of these consequences. On this presumption, the utilities of the consequences of an action can be weighed by their probabilities to yield the 'expected utility' which, according to the theory of rational decision-making, should be maximized in order for a decision to be qualified as "rational".

The theory of rational decision-making has been criticized for not providing an adequate description of decision processes. However, most criticisms can be accommodated by slight modifications of the basic procedure. In particular Ellsberg's paradox [23], which rests on differential sample sizes, can be accommodated by substituting additive probabilities with sub-additive probabilities (see Appendix A) [32] [107] [33]. Likewise, Allais' paradox [1], which is due to distortions caused by events with very low probability, can be accommodated by non-linear transformations of utilities and probabilities as prescribed by Prospect Theory (see Appendix B) [50] [139].

The case of Slovic's paradox is quite different. A long series of experiments, even if carried out by unsympathetic researchers, have shown that preferences between two alternative bets can be reversed if subjects are asked to evaluate selling prices for the two bets (e.g. a lottery ticket), rather than choosing one of them (see Appendix C) [124] [123] [59] [125] [126] [39] [37] [60]. Other experiments have shown that the reason is that when thinking about betting people focus on the probability to win, whereas when thinking about selling a lottery ticket people focus on what prize can be won (i.e., utility) [105] [75] [122] [140] [28]. Thus, it appears that human beings do not evaluate utilities independently of probabilities, just as the fox of the tale did.

Several other contexts have been identified, where preference reversal occurs [138]. Preference reversal is destructive for the theory of rational choice. In fact, it suggests that preferences are neither stable nor coherent. But if preferences are neither stable nor coherent, no utility function exists. Thus, preference reversal suggests that decision-making should be viewed as problem-framing and problem-solving, rather than optimization of a given utility function [142] [53] [121] [58]. In this perspective, both probabilities *and* utilities must be discovered in the process of decision-making, and not independently of one another [67] [2] [4].

Several attempts to reconcile preference reversal with the theory of rational choice

have been made. Preference reversal can be accommodated with the theory of rational choice if either violations of transitivity [61] [29], or of independence [41] [51], or of completeness [22] of preferences are accepted. While the attempts to reconcile preference reversal with the theory of rational decision by relaxing transitivity or independence of preferences did not receive much attention because these properties are essential for our idea of rationality, the more recent idea of dropping completeness deserves some discussion. In fact, allowing preferences to be incomplete amounts to accept the idea that a utility function can be defined, at most, for *some* alternatives. Possibly, just the simplest and most repetitive ones.

Thus, this stratagem actually suggests that the theory of rational decision-making does not provide a guidance to decision-making whenever the problem to be solved is sufficiently novel. A radically different theory of uncertain reasoning is in order, one where judgment is not split into a utility function and a probability distribution.

By splitting judgment into a utility function and a probability distribution, the theory of rational decision-making makes an enormous simplification. In fact, utility function and probability distribution are defined on the same domain, namely, the set of the consequences of actions (henceforth, 'set of possibilities' or 'possibility set'). Thus, utilities and probabilities can be modified independently of one another if the possibility set is given. Consequently, the theory of rational decision-making can limit itself to analyze decision-making once the possibility set, the utility function and the probability distribution are known. And indeed, the prototypical setting of the theory of rational decision-making is that of a gambler facing a known game, such as playing dice.

On the contrary, a theory where judgment is not split into utility and probability should afford to include the formation of the possibility set within its scope, which amounts to include the cognitive processes whereby possibilities are conceived, modified or forgotten. Its prototypical settings might be that of a firm revising its values and its experience in order to conceive a strategy for an uncertain future, a Government elaborating a long-term policy or an individual making fundamental choices for his life. In all these cases, the content of the possibility set is not self-evident as in the case of gambling games. It is the outcome of interpretation, and the cognitive processes that yield this interpretation should be part of a decision theory because they do influence decision.

Thus, in order to develop one such theory one needs to identify rationales for defining the possibilities envisioned in a human mind and for developing judgments concerning them. Principles followed by the human mind when gathering information, conceiving possibilities and making decisions.

Silently, during the last decades various scholars working in different disciplines have made important steps in this direction. This article puts together various insights, developed independently of one another, pointing to one single principle, namely, that novel arrangements of the possibility set are explored by posing binary questions. By reporting and linking these insights to one another, it provides a map to researchers in an emerging field.

By connecting these streams to one another, it became clear that this emerging decision theory is questioning a basic feature of our idea of rationality — the independence of judgments of value (utility) from judgments of likelihood (probability), as it is expressed by the tale of the fox and the winegrapes. This implication has not been

realized by the scholars involved in this enterprise. Yet it is worth pursuing, for it has important consequences.

This article purports that attributing 'rationality' to utility maximization is a cultural artifact. In reality, foxes (and humans) may have good reasons to behave the way the story tells. Eventually, their actual decision procedures follow sensible guidelines that can be investigated and understood.

If these guidelines are sensible, they may not only be observed, but also prescribed. Thus, precisely because it questions the established idea of rationality, this emerging decision theory can aspire to both a descriptive and a normative status.

The rest of this paper is organized as follows. Section (2) exposes some theoretical principles that are supposed to guide the formation and destruction of possibilities in the human mind. Section (3) illustrates the main thread of this paper, namely, the idea that decision is made by opposing an alternative whose positive features are stressed to an alternative whose negative features are stressed — hence, the title "Either, Or". Section (4) reports on a computational model of this idea. Finally, section (5) concludes by discussing the descriptive and normative status of the decision principles outlined in the previous sections.

2   Guiding Principles

This section collects theoretical principles that may guide the construction of a decision theory where possibilities are conceived at the same time that beliefs are formed. My point of departure are a few statements made by the mathematician Glenn Shafer regarding the rationale for (*a*) conceiving novel possibilities, and (*b*) for merging or discarding possibilities. On the procedure for conceiving novel possibilities, biologist Peter Cariani has something to say, based on a re-interpretation of Gordon Pask's experiments in the System Science of the 1950s. On merging or discarding possibilities, the economist George Shackle first proposed that the human mind arrives at making a decision by contrasting an attractive alternative to a detestable one. As we shall see in the subsequent sections, a number of recent findings in experimental psychology confirmed this idea, and a connectionist computational model suggests a possible explanation.

Shafer has been the first scholar who drew attention on the entaglement between value judgments and likelihood judgments: "My point is that the process of formulating and adopting goals creates a dependence of value [utility] and belief [probability], simply because goals are more attractive when they are feasible." [1] [111]. This is just the same content as the tale of the fox and the grapes — the fox found the grapes more attractive when she thought that that reaching them was feasible — except that Shafer did not laugh at this feature of human nature.

Shafer's Evidence Theory [110], also known as "theory of belief functions", accepts that a decision-maker may be aware that the possibility set is not exhaustive [27]. This is achieved by forbidding the operation of complementation on the possibility set,

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[1]Shafer's theory is such that his "belief" cannot be equated to probability and his "value" cannot be equated to utility. Nevertheless, this is a first approximation that may help the reader understand Shafer's quotation.

so residual events cannot be defined. In order to stress the difference between the possibility set so modified and the one employed in Probability Theory, Shafer called the possibility set "frame of discernment". In the rest of this article, Shafer's usage will be followed.

Evidence Theory is concerned with the combination of empirical evidence stemming from different sources in the human mind (e.g., a judge evaluating testimonies, a manager evaluating scenarios, etc.). The bulk of the theory does not seek to explain how novel possibilities are conceived, or old possibilities are merged or discarded. However, in the last chapter of the 1976 book where Evidence Theory was first presented [110], Shafer speculated on a decision-maker who creatively builds the possibilities she envisions:

> Like any creative act, the act of constructing a frame of discernment does not lend itself to thorough analysis. But we can pick out two considerations that influence it: (1) we want our evidence to interact in an interesting way, and (2) we do not want it to exhibit too much internal conflict.
>
> Two items of evidence can always be said to interact, but they interact in an interesting way only if they jointly support a proposition more interesting than the propositions supported by either alone. (...) Since it depends on what we are interested in, any judgment as to whether our frame is successful in making our evidence interact in an interesting way is a subjective one. But since interesting interactions can always be destroyed by loosening relevant assumptions and thus enlarging our frame, it is clear that our desire for interesting interaction will incline us towards abridging or tightening our frame.
>
> Our desire to avoid excessive internal conflict in our evidence will have precisely the opposite effect: it will incline us towards enlarging or loosening our frame. For internal conflict is itself a form of interaction — the most extreme form of it. And it too tends to increase as the frame is tightened, decrease as it is loosened.
>
> Glenn Shafer, *A Mathematical Theory of Evidence* [110], Ch. XII.

In order to understand the above quotation it is in order to remark that Evidence Theory's frame of discernment has a cognitive flavor that is foreign to Probability Theory's possibility set. The frame of discernment is a mental representation of the empirical evidence available to the decision-maker. Empirical evidence is classified into mental categories, and these mental categories are the possibilities envisioned on the frame of discernment.

By "abridging or tightening the frame" Shafer meant sectioning the empirical evidence into finer mental categories in order to distinguish interesting details. The opposite strategy is that of "enlarging or loosening the frame", i.e., lumping empirical evidence into broader categories in order to oversee details that would contradict one another. A decision theory can be constructed if general principles are identified, upon which the cognitive processes that tighten or loosen the frame of discernment are identified.

In order to avoid possible misunderstandings with the economically-minded reader, it is worth to emphasize that looking for rationales for changing a frame of discernment has nothing to do with:

- Defining a cost function against which the number of possibilities would be traded. Although the cognitive processes whereby a frame of discernment is changed can be subsumed *ex post* by an objective function with a positive term representing the advantages of envisioning many possibilities and a negative term representing the mental effort that they require, by assuming *ex ante* the existence of one such function one would take as solved the problem that this article seeks to solve.

- Trading the number of possibilities considered by the decision-maker with the mistakes connected with choosing the "wrong" possibility. [2]. In fact, this is just another form of the cost function, where "mental costs" are exchanged for "making mistakes".

On the contrary, the following principles are relevant to the issue of tightening or loosening the frame of discernment:

Tightening the frame of discernment entails the creative act of conceiving novel possibilities. This is a difficult domain, for creativity cannot be formalized. However, even creative acts may follow a general scheme.

In the 1950s, Gordon Pask built a series of electrochemical devices where an electrical current formed structures that were shaped by signals that the structures themselves detected, and that would be beneficial to their growth. Through interactions with the environment, these devices evolved an "interest" towards particular signals to which they would attach a meaning — that of being beneficial, or not. By means of these devices, Pask was able to evolve an ear and a receptor of magnetic fields, without any of these functions being planned by the experimenter. Such devices work if (1) they are sufficiently flexible and explorative to form a large number of structures, and if (2) some of these structures are enhanced by particular environmental signals [83] [16] [17] [18].

These conditions may be translated back into the domain of human decision-making, suggesting that in order for novel possibilities and novel meanings to be generated (1) a decision maker must be sufficiently flexible to apply available knowledge onto unchartered domains, and (2) the environment must provide a feedback that affects the decision-maker, either positively or negatively. If this feed-back is not strong enough, a new exploration must be undertaken.

Research in the economics of innovation has shown that firms make radical innovations by transposing old knowledge into new fields and subsequently reacting to the feed-backs provided by the new field of operations — e.g., by applying a technology that they already master on an entirely different class of products,

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[2]R. Heiner, the initiator of this reasoning, claimed that this circumstance would lead to "predictable" behavior. In reality, a behavior spanning a smaller possibility set may still be totally unpredictable if it is random. Heiner's conclusion is unjustified.

an entirely novel product may be conceived [81]. We may recognize the two conditions above, though since humans have the power to ignore environmental feed-backs we may split the second condition in two parts, obtaining as conditions for conceiving novel possibilities (1) a search procedure whereby novel hypotheses are explored, (2a) an environment that provides a feed-back, and (2b) a subject who accepts to change because of this feed-back.

Loosening the frame of discernment needs not be carried out up to a point where all distinctions are blurred and nothing is recognized. In general, loosening the frame of discernment means that the picture of reality is simplified until one possibility stands out as the best conceivable solution.

George Shackle, an economist who worked at a time when the theory of rational decision-making was still under development, outlined a decision theory that in its verbal statements anticipated the mathematical framework that would be set out by Shafer [25] [26]. Most interesting to us is the fact that, at the crucial point when a decision has to be made, Shackle assumed that an individual observes an *ascendancy function* that presents him the worst and the best conceivable hypotheses, "the extremes in the desirability-undesirability ordering" in his own wording [109].

Shackle explained "ascendancy" as "power of fascination". The "extremes in the desirability-undesirability ordering" were also called "focus elements", where "By (...) *focus-element* we mean an element (...) which has some special and extraordinary power to command and concentrate upon itself the decision maker's attention.". Shackle assumed that, for each hypothesis a decision-maker is able to entertain, (s)he is also able to think of a neutral reference point and, from there on, two "focus elements" with opposite values [109].

Shackle neither tested his theory, nor attempted to establish any link with theoretical or applied psychology. His decision theory, made of pure verbal statements, was forgotten in the light of the elegance and simplicity of the emerging theory of rational decision-making. Today, while the theory of rational decision-making is showing serious creeks, certain empirical findings in experimental psychology are pointing to the same path identified by Shackle out of personal introspection. This is the subject of § (3).

The above reasoning about tightening and loosening the frame of discernment might constitute the bulk of a new emerging decision theory. Decision-making would be viewed as composed by (*i*) a phase of exploration and invention of novel possibilities (tightening the frame of discernment), and (*ii*) a phase where the positive features of one alternative are emphasized and contrasted to a bad alternative (loosening the frame of discernment). Decision-making might be viewed as a process alternatively carrying out these two steps, back and forth as in figure (1).

All issues concerned with loosening the frame of discernment (focusing on one possibility) are easier to handle than issues on tightening the decision frame (adding a novel possibility). The ensuing § (3) and § (4) are concerned with focusing on one possibility in order to arrive at a decision. However, the issue of conceiving novel pos-
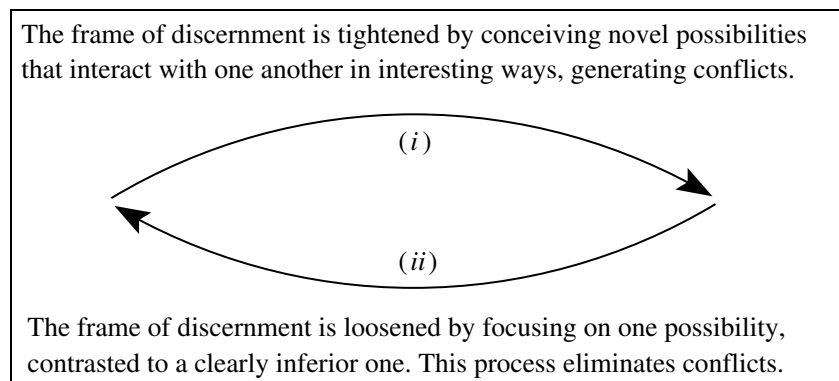
The frame of discernment is tightened by conceiving novel possibilities that interact with one another in interesting ways, generating conflicts.

(*i*)

(*ii*)

The frame of discernment is loosened by focusing on one possibility, contrasted to a clearly inferior one. This process eliminates conflicts.

Figure 1: Tightening (*i*) and loosening (*ii*) the frame of discernment. The frame of discernment is tightened out of a desire for interesting interactions, it is loosened out of a desire for coherence.

sibilities will be taken back in the final § (5), which deals with issues of descriptiveness and normativeness.

3   The Quest for Coherence

This section is concerned with theories and empirical findings that, subsequently and independently of Shackle, have described decision-making as focusing on one alternative whose positive features have been emphasized, eventually contrasted to an alternative whose negative features have been emphasized. In several settings it has been remarked that one alternative seems to attract the attention of decision-makers:

- In *pure coordination games* [104], players face a set of alternatives knowing that a positive payoff will only accrue to them if they all coordinate on the same choice. Most importantly pure coordination games are one-shot games so no learning can take place. For instance, two subjects may be shown a city map and asked, independently of one another, to select a meeting point. Or, subjects may be asked to select a positive integer.

  The astonishing fact about pure coordination games is that players succeed to make an agreement much more often than would be predicted by pure chance. The reason is that pure coordination games generally entail cues that suggest one alternative as more "salient" than others. For instance, subjects asked to select a meeting point generally opt for the railway station, whereas the majority of those asked to name a positive integer select the number 1.

- Consider a rather famous research project aiming at discovering "fast and frugal heuristics" that allow decision-makers to make good decisions with little effort [31]. Similarly to pure coordination games, this research discovered that many decisions are made by means of heuristics that order alternatives according to one

single, salient aspect. Perhaps the most striking finding of this research is that such simple heuristics let people make good decisions in many realistic decision settings, most of the time.

- Marketing research has found out that consumer choice can be eased if only a few product attributes are made salient [47] [64] [82] [45] [12] [44]. Apparently, purchase is induced by manipulating the saliency of a few, or just one, product attribute(s), rather than overall quality along several attributes. By doing so, decision becomes a binary choice, or a short sequence of binary choices.

Coordination in pure coordination games is generally explained by ascribing saliency either to features of the decision problem, such as the fact that the railway station is a place where people meet or that 1 is the first positive integer. Likewise, the efficiency of simple, one-aspect heuristics is generally ascribed to features of the decision problem. Note also that the very fact that marketers seek to manipulate saliency implies that, similarly to the above explanations, saliency is understood as exogenous to the decision-maker.

My point is that binary choice is common not only because world experiences come in binary form as the aforementioned justifications imply, but also because human reasoning proceeds by framing decision problems as binary alternatives. On many occasions, saliency may be constructed by the decision-maker in order to simplify the decision problem until one option stands out as the only reasonable one.

The binary choices in the above examples may also be interpreted as deriving from an innate human tendency to isolate one best alternative, rather than from objective features of the decision problem. One may claim that railway stations would not be chosen so often if humans would consider them along with main squares, old bridges and city councils as possible meeting points. Or, that the number 1 would not be chosen so often if, say, humans would start by considering all ten single-digit numbers. A similar reasoning holds for heuristics, which do not necessarily need to focus on one salient aspect in order to be fast. In all these cases, the prominence of one salient feature could be ascribed to human interpretation at least as much as to objective features of the decision problem. And the fact that marketers frame consumers' decision problems as binary choices may simply mean that they know human nature.

Likewise, we have seen that the preference reversals examined in § (1) can be explained by assuming that decision-makers frame their decision problem around the probability to win if they are asked to play the game, whereas they frame their decision problem around the possible gains if they are asked to sell their lottery ticket. In this case, the saliency of the probability to win and the saliency of the possible gains are clearly constructed by the decision-maker herself [119] [76] [6]. And decision-makers construct the saliency of only one feature at a time, either the probability to win or the possible gains.

Empirical research has highlighted that decision-makers are eager to utilize even trivial cues to draw sophisticated inferences and attribute causality to salient factors, and that they do so without awareness (see [136] for a review of early studies). In particular, decision-makers have been shown to routinely construct reasons to justify their choices to others and to themselves, both before and after a decision is made [57]

[112]. Post-decisional justification of decisions is undisputed in psychology, but pre-decisional construction of reasons in order to make a choice upsets our certainties on rationality.

Nevertheless, an increasingly wide stream of empirical research is sheding light on pre-decisional biases. Apparently, decision-makers focus quite early on one single alternative, spending the remaining time before decision emphasizing its positive aspects while denigrating the remaining alternatives [130] [65] [66] [24] [77] [7] [143] [21] [144] [146] [99] [135] [100] [120] [101] [102] [117] [90] [62] [116] [36]. This is extremely interesting, because it accords with Shackle's intuition that decision-making takes place through binary choices between one "best" and one "worst" alternative (see § 2). However, in Shackle's account it was not clear that two alternatives are "the best" and "the worst" in the sense that the human mind constructs them as such.

The above empirical evidence has been collected in conjunction with theory development. Indeed, several psychologists have included bolstering the advantages of one promising alternative and the disadvantages of all other alternatives among the processes occurring during decision-making. Let us examine these theories in time order.

Mills' Choice Certainty Theory (CCT, 1968) stated that, if decision-makers are completely uncertain about which alternative is best, then information favoring any of the alternatives will increase their certainty. However, if they are somewhat certain that one alternative is best, then they will prefer information favoring that alternative [69].

CCT is important, because for the first time a decision theory admitted that the evaluation of alternatives could be distorted in order to arrive at a decision. By comparison, its contemporary theory of cognitive dissonance stressed that the evaluation of alternatives could be distorted after a decision is made in order to minimize regret, but not before decision [14]. However, note that CCT considered the distortion of evaluation a consequence of biased information gathering, rather than a genuine psychic process. So CCT did admit a pre-decisional distortion of evaluation, but actually not a pre-decisional distortion of preferences.

Janis and Mann's Conflict Theory (CT, 1977) of decision-making focuses on decisions involving profound, eventually destructive consequences for a decision-maker [49]. According to CT, if a decision-maker faces serious risks both in the case she changes her course of action and in the case she does not, and if she has no hope to find a better solution, then a state of "defensive avoidance" of decisions ensues. This can take the form of procrastinating decision, or of shifting responsibility, or of bolstering the positive aspects of the least objectionable alternative. Figure (2) illustrates the conditions leading to defensive avoidance in CT.

Janis and Mann specified under which conditions a decision-maker would resort to defensive avoidance, and under which conditions defensive avoidance would take the form of changing preferences. It is a real endogenous process of preference change, triggered by specific psychic conditions. However, according to CT only in a few special occasions the positive aspects of the least objectionable alternative would be bolstered. CT did not take this as a main ingredient of decision-making.

Kuhl's Theory of Action Control (TAC, 1982) postulates that an individual may find himself in one of two different moods [54] [55]. In the mood labeled "state orientation" an individual is excessively focused on his past, present or future state so he cannot attend to any action plan which may bring about a change. On the contrary, in the
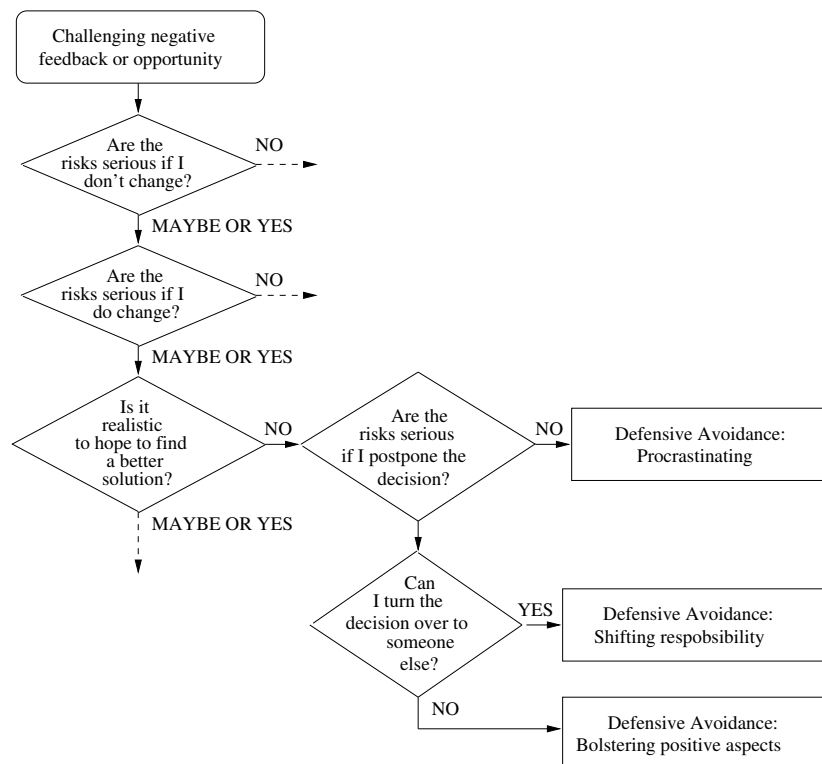
Figure 2: The conditions leading to defensive avoidance according to CT, after [49] ©The Free Press. Dotted arrows represent parts of the flowchart not included in this picture.

mood labeled "action orientation" an individual seeks to implement an action plan and focuses simultaneously on the present state, a desired future state, the discrepancy between them and action alternatives which may turn the present state into the desired state.

According to TAC, action orientation should be protected against tendencies towards state orientation. TAC points to three mechanisms to keep an action orientation going: 1) Quick termination of action-oriented decision-making in order to shield it from state-oriented alternatives; 2) Selective attention to information that is relevant to an action-oriented decision; 3) Emotional arousal of an action-oriented alternative. Note that (2) is akin to pre-decisional bias as in CTT, whereas (3) implies a true change of preferences as in CT.

The real novelty about TAC is that preference modification is no longer considered a wrong way of reasoning, but rather a good means to achieve and maintain a desirable orientation. Preferences are not inadvertently "distorted", but willingly modified.

However, the open breakthrough comes with Montgomery's Search for Dominance Structure Theory (SDS, 1983) [71] [72] [73] [79], where emphasizing the positive aspects of one alternative while denigrating the other alternatives is the essential step of decision-making. SDS claims that, even without additional information, decision-makers engage in a search for a coherent framing of available alternatives at the end of which one of them stands out as the best one, whereas all other alternatives are depicted in their worst aspects. SDS claims also that the "best" alternative is generally selected quite early in the decision process, well before a decision is made. According to SDS, most of the time employed in decision-making goes in constructing a justification for an alternative that is actually chosen on other grounds.

SDS provides a crude description of the processes employed by a decision-maker. Figure (3) reports their flowchart.

The distinctive block of SDS is the one where preferences are modified in order to make one alternative dominate the others (Dominance Structuring). This block includes bolstering the positive features of one alternative, de-emphasizing the positive features of all other alternatives, canceling alternatives from the frame of discernment, and collapsing distinct alternatives into one broad alternative. If these operations are carried out with sufficient skill on a sufficiently differentiated initial set of alternatives, a decision-maker ends up contemplating one "good" alternative that has a number of attractive features with one "bad" alternative that may actually lump together several alternatives whose interesting features have been de-emphasized.

SDS may illustrate a search for dominance as a pure mental construction, or an interactive process that includes a search for better information. In this second case, decision is reached after a series of steps where the frame of discernment is alternatively tightened and loosened.

SDS ascribes to decision-makers the ability to apply the dominance structuring operations to an alternative that is different from the one that was initially preferred. Furthermore, SDS contemplates the possibility of postponing decision as well as that of not making any decision at all.

Affect and emotions are known to play an important role in the formation of preferences [89]. SDS understands their role as facilitators of the process of construction of a dominant structure [52].
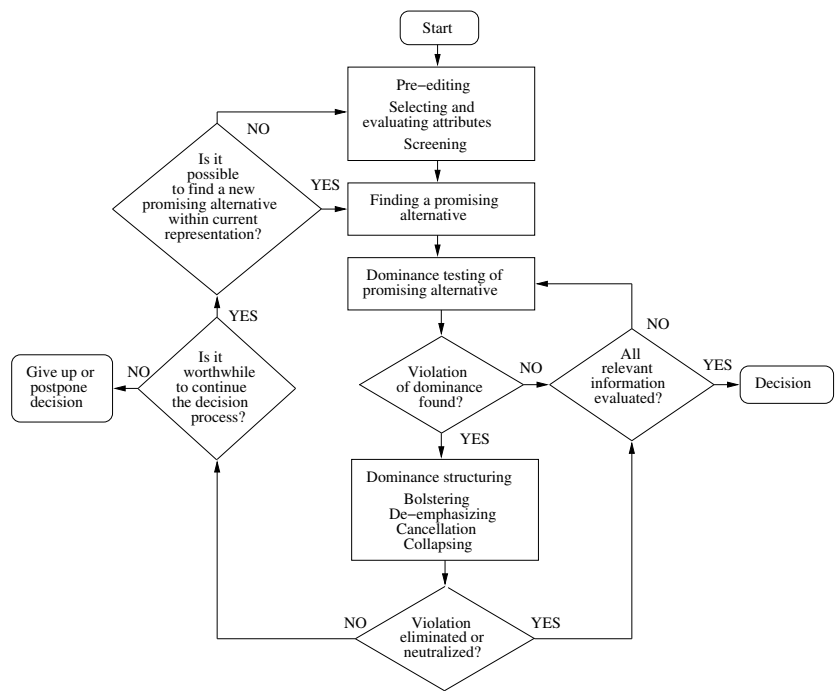
Figure 3: The flowchart of SDS, after [72] ©John Wiley & Sons and [79] ©Lawrence Erlbaum Associates.

Svenson's Differentiation-Consolidation Theory (DC, 1992) [131] [132] [133] is quite similar to SDS. According to Svenson himself [135], the main difference is that DC takes account of post-decisional re-evaluation of alternatives (consolidation) besides pre-decisional evaluation (differentiation), whereas SDS, at least in its first version, did not include post-decisional re-evaluation. However, post-decisional re-evaluation of alternatives, i.e., a bias to confirm the goodness of any choice that has been made, was known and accepted by the theory of cognitive dissonance long before the empirical studies that stimulated these theories were carried out [14].

In a sense, DC may be understood as an attempt to bridge between SDS and a compatible aspect of an otherwise radically different theory (the theory of cognitive dissonance, which concerns post-decisional re-evaluation of alternatives, assumes rational decision-making). However, there is empirical evidence claiming that the desire for coherence (by means of pre-decisional differentiation) is a much stronger motivation for decision-making than the desire to avoid post-decisional regret (by means of post-decisional consolidation) [145].

Slightly after the wave of empirical research that suggested the above theories, a parallel wave of empirical research started, that focused on group decision-making. Jurors have been shown to arrive at a verdict by creating consensus rather than by compromise [84] [85] [86] [87] [88] [80], which means that group decision-making is by no means a trade-off between individual preferences as the theory of rational decision-making assumes. Group decision-making may rather follow the same pattern as individual decision-making, with a group behaving somehow similarly to one single mind. Jurors deciding on guilt or innocence , as well as boards of managers deciding whether a risky investment should be made [108], have been shown to identify quite early a preferred alternative. Tentatively, one may hypothesize that the theories that explain individual decision-making apply to group decision-making as well.

This is makes for a sharp and notable distinction with the theory of rational decision-making. In fact, the theory of rational decision-making is designed for one single individual so it is not obvious that it can be applied to groups or organizations. In order to pass from individual to group decision-making, assumptions on power structures and interacting procedures must be made so preferences can be aggregated, and in some cases — such as Arrow's paradox — no rational collective decision can be made even if individuals are supposed to be rational. On the contrary, the above studies suggest a pattern for group decision that is quite similar to individual decision. Through confrontation and discussion, a coherent picture of reality is elaborated where, in the end, one option stands out as the one sensible thing to do.

Finally, the above theories of decision-making suggest a simple explanation of "groupthink", i.e., the tendency of groups to fixate on a wrong course of action, isolating themselves from potentially disturbing information [48]. In fact, the alternative whose positive aspects are emphasized by the group may simply not be the best one. Indeed, the empirical evidence testifies that while the group as a whole follows the typical pattern of emphasizing the positive aspects of one alternative and the negative aspects of all other alternatives, its members may have a much weaker drive to preference differentiation as group members than as single individuals [13] [70]. So the drive to consensus that makes the above theories applicable to groups may also be responsible of groupthink.

4 Parallel Constraint Satisfaction Networks

Parallel constraint satisfaction networks (CSNs) [98] are neural networks characterized by:

- Excitatory and inhibitory connections;

- Feedbacks between neurons.

Neurons represent possibilities, or concepts, or propositions. Connections represent inferences: an excitatory connection from neuron A to neuron B means "A implies B", whereas an inhibitory connection from neuron A to neuron B means "A implies $\neg$ B".

Let a_i denote the activation (the output) of neuron i, with $a_i \in \Re$. Let $w_{ij} \in \Re$ denote the weight by which neuron i multiplies the input arriving from neuron j.

The net excitatory input to neuron i is:

$$enet_i = \sum_j w_{ij}a_j \qquad if \ \ w_{ij}a_j \geq 0 \tag{1}$$

The net inhibitory input to neuron i is:

$$enet_i = \sum_j w_{ij}a_j \qquad if \ \ w_{ij}a_j < 0 \tag{2}$$

At each time step, the activation of neuron i is increased by its excitatory inputs and decreased by its inhibitory inputs:

$$\Delta a_i = enet_i(a_{max} - a_i) + inet_i(a_i - a_{min}) \tag{3}$$

where, in general, $a_{max} = 1$ and $a_{min} = -1$.

Feedbacks between neurons make the network maximize consonance C:

$$C = \sum_i \sum_j w_{ij}a_ia_j \tag{4}$$

or, equivalently, minimize energy $E = -C$.

Consonance maximization means that those neurons are strengthened, that represent possibilities, concepts or propositions that are coherent with one another. Thus, constraint satisfaction networks can be used to model any cognitive process characterized by search for coherence [43] [137]. Notable applications of CSNs are the elaboration of scientific theories, understood as the arrangement of empirical findings in a network of coherent causal relations, the evaluation of guilt or innocence in a trial, understood as fitting testimonies in a coherent frame, and the *Gestalt* idea that the human mind may shift among alternative interpretations of reality.

CSNs have also been used to model post-decisional re-evaluation as in the theory of cognitive dissonance (see § (3)). But most intersting to us is that CSNs can be used to model pre-decisional emphatization of the positive aspects of one alternative at the same time that the negative aspects of its competitors are stressed [114] [118]. In particular, some of the empirical examples mentioned in § (3) as instances of

decision-making by emphatization of the positive aspects of one alternative, have been reproduced by means of a CSN [42] [63].

On the whole, CSNs implement quite well the decision theories expounded in § (3). Indeed, an experimenter working with CSNs wrote the following lines without any acquaintance with those theories, and yet reaching strikingly similar conclusions:

> Coherence-based reasoning posits that the mind shuns cognitively complex and difficult decision tasks by reconstructing them into easy ones, yielding strong, confident conclusions. The research reveals an unconscious transformation of the way decisions are mentally represented, ultimately leading to a seemingly straightforward choice between a compelling alternative and a weak one.
> Simon, [113]: 513

CSNs can also reproduce the preference reversals mentioned in § (1) [15]. In fact, a CSN can either reinforce the choice induced by looking at prizes, or the choice induced by looking at the probability to win. So CSNs support the interpretation of preference reversals presented in § (3), where preference reversals were ascribed to construction of saliency of either the probability to win or the possible gains [119] [76] [6].

Some researchers have also emphasized the ability of CSNs to provide story-like descriptions of reality, much like humans actually do [91]. This is extremely important, because it supports the idea that decision-making occurs once a coherent narrative has been constructed. In § (5) it will be shown that narrative construction is the basis for ascribing a normative value to the emergent decision theory outlined in this article.

A clear limitation of CSNs is that they work with given possibilities, given concepts, or given propositions. CSNs can reproduce the arrangement of possibilities and concepts, not their arousal. In terms of Shafer's theoretical guiding principles mentioned in § (2), CSNs give us a hint of the processes by which the frame of discernment loosened, but say nothing on the procedures by which it may eventually be tightened. In order to include this feature it has been proposed that CSN represent unconscious arrangement of available possibilities and concepts, whereas a conscious process running in parallel would care about the search and elaboration of novel ones [35] [34]. This is obviously a very important research direction, but still at the stage of wishful thinking for the time being.

As the reader may remark by looking at the references of this article, CSNs generated the most recent contributions to the emerging decision theory described herein. Their attractiveness stems from the fact that they provide a simple explanation of the mechanisms that may generate certain puzzling findings. The next step would be to have CSNs that are detailed enough to reproduce decision-making in the complex settings of the real world.

5   Towards a Descriptive and Normative Theory

The theory of rational decision-making has been inundated with criticisms based on empirical evidence that this is not the way people actually make decisions. Its proponents have objected that, in fact, the theory of rational decision-making is not meant to

be a faithful description of what people actually do, but rather a prescription of what they should do [103]. It is a normative theory, not a descriptive theory. Indeed, since the time of the story of the fox and the winegrapes, the purpose of having an idea of "rationality" is that of telling people how they should make their decisions. Whether people actually conform to rationality principles or do not, this is an empirical question that does not affect our idea of rationality.

Throughout the previous sections, different streams of thought have been linked to one another pointing to something like an embryo of a new decision theory, one where judgments about the likelihood of events (probability) are not disjoined from judgments about their desirability (utility). The case for this decision theory was made in terms of its stronger descriptive power with respect to the theory of rational decision-making. This is quite acceptable for the theory of rational decision-making, since it does not attack what it really stands for, namely, its power as a normative theory. However, in the conclusion I would like to speculate whether this embryonic decision theory may have a normative value as well.

The principles, schemes and models mentioned in the previous sections pictured decision-making as a process oscillating between tightening and loosening the frame of discernment, where the final part of the loosening cycle consists of focusing one one single alternative by contrasting it to a clearly inferior counterpart. This process does not consist of applying preferences to given alternatives as the theory of rational decision-making assumes, but rather of constructing preferences and conceiving alternatives such that they are coherent with one another. Human minds are viewed as coherence-seeking machines that make use of available information in order to construct a plausible interpretation of reality, be it scientific theories or social roles. By drawing causal relationships and eliminating inconsistencies a decision-maker tells herself a story that explains why certain facts are the way they are and why certain people did what they did. This story, a founding story that suggests a decision-maker what it is appropriate to do, is called a narrative.

The construction of a narrative may require that issues that do not fit into the picture are ignored, downplayed or forgotten. It may require that opinions are changed even dramatically, and yet their purporters candidly claim that they have always been coherent, or that they have been coherent if their story is seen from a particular point of view. Albeit disturbing for our idea of rationality, the extent and easiness with which human beings distort previous experiences is proven by a number of experiments. It has been shown that it is easy to induce the subjects of psychological experiments to change opinion while they are still convinced to have been coherent throughout the whole experiment [8] [9] [11] [10] [97]. Experiments have shown that people construct coherent narratives of their past, and that they remember past events to the extent that they fit these narratives [38] [92] [30] [93] [149] [96]. Other experiments have shown how they may eventually change their interpretation of the past and construct a new narrative if new evidence must be accommodated [38] [95] [94] [20]. Human beings are ready to lie to themselves in order to build coherent narratives.

This attitude is puzzling, because distorting reality in order to construct a coherent narrative is at odds with our idea of rationality. It is what the fox did, and we are laughing at it since at least three thousand years. So either human nature is inherently irrational, or our idea of rationality is incorrect. Having a narrative may be so important

for human decision-making, that nearly any price is worth it.

According to March, re-inventing the past is a crucial ability that enables decision-makers to conceive new goals and figure out a strategy in an uncertain future [19] [68]. Later, a similar argument has been made by Weick [147] [148] under the label of "sensemaking". Essentially, these authors suggest that in order to make decisions in the face of an uncertain future it is good to have a narrative that explains the past as if previous decisions had been made along a coherent line. This line guides the decision-maker into the future, providing a rationale for action even if certainties are very few.

In business, politics and other fields, narratives may constitute the bulk of strategies. Lane and Maxfield have made a years-long field observation of the elaboration and modification of the narrative of a Silicon Valley firm [56]. This study is very clear in making us understand that narratives are useful precisely because they provide a guidance in the face of an uncertain future, and that their usefulness is not impaired by the fact that their coherence is based on an arbitrary interpretation of reality (see Appendix D).

So here comes a straightforward argument for normativeness. If seeking coherence has the purpose of constructing a narrative, and if narratives are useful, then the decision theory outlined throughout the previous sections should be regarded as rational, and openly prescribed.

Let us compare the normativeness of this emerging decision theory with the normativeness of the theory of rational decision. The following passage by Glenn Shafer is illuminating in this respect:

> Just what are the assumptions with empirical content that underlie Savage's argument for the normativeness of subjective expected utility? There are at least two. First, the assumption that a person always has well-defined preferences in those settings where the postulates are applied. Second, the assumption that a setting can be found that permits a disentanglement of belief [probability] and value [utility]. [3]
> Glenn Shafer, [111]

This passage suggests that different decision theories might be normative, depending on the setting to which they should be applied. Utility maximization might be normative whenever preferences are defined for the whole possibility set and, furthermore, utility can be evaluated independently of probability. This is certainly the case of playing dice, but it is not the case of decision-makers facing a future whose possibilities are only partially known, so that not all preferences can be conceived. In this second case, it is rational first to tighten the frame of discernment, e.g. enriching it by means of a sort of brainstorming, then to construct a narrative that isolates one possibility that is liked and likely at the same time, loosening the frame of discernment.

What should we think of the fox, at the end of this discussion? The issue is whether the future is known, or not. If the jumping capabilities of the fox are fixed and accurately measured by its attempts to reach the grapes, then the fox should update her

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[3]As in a previous quotation, it is fair to remember that Shafer's "belief" and "value" cannot be equated to probability and utility, respectively. Nevertheless, it is a rough approximation that may help understanding.

evaluation of the probability to reach the grapes, accepting the fact that it cannot reach them. On the contrary, if its jumping capabilities depend to a large extent on mood, wind, nutrition and other imponderable factors, then it is better for the fox to convince itself that the grapes were sour. By doing so, it will try again next time.

It is due to conclude with a warning on the decision theory outlined hitherto. In fact, recognition of the usefulness of narratives may easily be turned into an invitation to build and believe whatever narrative, no matter how awkward, crazy and senseless it is. Narratives are useful because they make us act, but not every action is right. It is obvious that issuing prescriptions and guidelines is a major task for this emerging decision theory to gain practical normativeness.

A Ellsberg's Paradox and Sub-Additive Probabilities

Suppose that a decision-maker is placed in front of two urns, henceforth denoted A and B. The decision-maker is informed that urn A entails white and black balls in equal proportion, e.g., urn A may contain 10 white balls and 10 black balls. Regarding urn B, the decision-maker knows just that it entails white and black balls. Suppose to ask the decision-maker to evaluate the probability to extract a white ball from urn A and the probability to extract a white ball from urn B.

Since urn A entails white and black balls in equal proportions, the probability to extract a white ball from urn A is 0.5. On the contrary, nothing is known regarding the proportion of white to black balls in urn B. In cases like this, the so-called "principle of insufficient reason" — i.e. the fact that there is no reason to think otherwise — suggests to imagine that also urn B entails white and black balls in equal proportions. Thus, also in this case the probability to extract a white ball is assessed at 0.5. And yet, something is not in order: intuitively, urn B should be characterized by a greater uncertainty than urn A!

Ellsberg's paradox actually deals with the size of the sample on which probabilities are evaluated. In fact, Ellsberg's paradox places two extreme situations aside.

In the case of urn A, since we know that it entails white and black balls in equal proportions we are able to compute probability with infinite precision. It is just like extracting a ball (and replacing it afterwards) infinite times. We are measuring probability on a sample of infinite size.

In the case of urn B, lack of knowledge on the proportion of white to black balls is equivalent to estimating the probability of extracting a white ball prior to any extraction. It means that the probability must be measured on a sample of size zero. We guess its value at 0.5, but the reliability of our estimate is very low.

The frequentist interpretation of Probability Theory suggests to represent uncertainty by means of two magnitudes. The first one is probability whilst the second one is sample size. In general, the size of the sample is expressed by a *precision indicator*.

The subjectivist interpretation of Probability Theory represents uncertainty by means of one magnitude: probability. The problem highlighted by Ellsberg's paradox is dealt in this case by the theory of sub-additive probabilities.

While according to classical probability theory the sum of the probabilities of an exhaustive set of events must be equal to 1, according to the theory of sub-additive

	Consequence 1	**Consequence 2**	**Consequence 3**
Alternative A	receive $ 2,500 with prob. 0.33	receive $ 2,400 with prob. 0.66	receive nothing with prob. 0.01
Alternative B	receive $ 2,400 with prob. 1.00		

Table 1: The first choice in Allais' experiment.

probabilities this holds only if probabilities are measured on a sample of infinite size. In all other cases the probabilities take values such that their sum is smaller than 1.

Let us consider the following example: We are playing dice in a clandestine gambling room. Since we fear that we are playing with an unfair die, we may not assign probability $1/6$ to each face, but rather less, e.g. $1/8$. Thus, the sum of the probabilities of all faces is $6 \times 1/8 = 3/4$, which is smaller than 1. Subsequently, if we have a possibility to throw the die several times — i.e. if we can increase the size of our sample — we may find out that the die is unfair in the sense that, e.g., face "2" comes out with probability 1/3 while the other faces come out with probability 2/15. The sum of all these probabilities is $5 \times 2/15 + 1/3 = 2/3 + 1/3 = 1$.

Let us return to Ellsberg's paradox. In the case of urn A, the probability to extract a white ball is 0.5 and the probability to draw a black ball is 0.5. The sum of these probabilities is 1. In the case of urn B, the decision-maker may judge that the probability to extract a white ball is, for instance, 0.4, and that the probability of extracting a black ball is also 0.4. The sum of these probabilities is 0.8, but this does not constitute a problem for the theory.

B   Allais' Paradox and Prospect Theory

Allaiss paradox results from the following experiment. A subject is asked to choose between the alternatives A and B reported on the rows of table (1). It is empirically observed that most people choose alternative (B).

Subsequently, the same subjects are confronted with the alternatives C and D reported on the rows of table (2). It is empirically observed that most people choose alternative (C).

Let us now examine the expected utilities of two pairs of alternatives (A,B) and (C,D). Preferring (B) to (A) means that $u(2,400) > 0.33 \times u(2,500) + 0.66 \times u(2,400)$, which can be written as $0.34 \times u(2,400) > 0.33 \times u(2,500)$. Unfortunately, preferring (C) to (D) implies the opposite, i.e. that $0.33 \times u(2,500) > 0.34 \times u(2,400)$. So it turns out that most people do not behave rationally.

Allais' paradox is due to the presence of a tiny probability of not obtaining anything in alternative (A). Thus, it is due to aversion to risk.

	Consequence 1	**Consequence 2**
Alternative C	receive $ 2,500 with probability 0.33	receive nothing with probability 0.67
Alternative D	receive $ 2,400 with probability 0.34	receive nothing with probability 0.66

Table 2: The second choice in Allais' experiment.

It is possible to introduce non-linear transformations of utilities and probabilities in order to balance risk aversion. The transformed utilities and probabilities satisfy expected utility maximization. This extension of the theory of rational decision-making is called Prospect Theory.

A prospect is a set of pairs $\{(c_1, p_1), (c_2, p_2), \ldots\}$, where c_j is a consequence that will obtain with probability p_j. As a preliminary step, prospects with identical consequences are summed, dominated prospects are eliminated and riskless components are ignored.

Prospects Theory prescribes that the utilities and the probabilities of the above prospects be transformed according to the following rules:

1. Utility is transformed by means of a non-linear function $v = f(u)$ such that $f'(u) > 0$ and $f''(u) < 0$ for $u > 0$, $f'(u) > 0$ and $f''(u) > 0$ for $u < 0$, with $\mid f''(u) \mid_{u<0} > \mid f''(u) \mid_{u>0}$.

2. Probabilities p are transformed into "weights" w by means of a non-linear function $w = g(p)$ such that $g(0) = 0$ and $g(1) = 1$ but $\exists \overline{p} \in (0,1)$ such that $\forall p < \overline{p}$ it is $g(p) \geq p$ and $\forall p > \overline{p}$ it is $g(p) \leq p$.

3. Weights w are transformed into coefficients q by means of the following rules:

$$
\begin{array}{llll}
q_{-h}^{-} & = & w^{-}(p_{-h}) & \text{for} \quad j = -h \\
q_i^{-} & = & w^{-}(p_{-h}+\ldots+p_i) - w^{-}(p_{-h}+\ldots+p_{i-1}) & \text{for} \quad -h < j \leq 0 \\
q_i^{+} & = & w^{+}(p_i+\ldots+p_k) - w^{+}(p_{i+1}+\ldots+p_k) & \text{for} \quad 0 \leq j < k \\
q_k^{+} & = & w^{+}(p_k) & \text{for} \quad j = k
\end{array}
$$

where w^{-} and q^{-} refer to prospects with negative utility, denoted with an index $j \in [-h, 0]$, whereas w^{+} and q^{+} refer to prospects with positive utility, denoted with an index $j \in [0, k]$.

The v and q obtained at the end of this procedure can be used much like utilities and probabilities, respectively. Prospect Theory succeeds to eliminate the inconsistencies highlighted by Allais' paradox, but it does not explain why it works. It should be called a heuristic, rather than a theory.

C   Preference Reversal in Slovic's Paradox

Let us consider a series of bets with different characteristics. For instance, a series of bets on different horses, or playing on a series of different slot machines, or a series of unfair dice different from one another. The game consists of choosing to bet on a specific horse, choosing to play on a specific slot machine or selecting a specific die to throw. In other words, the game consists of choosing one bet out of a series of bets.

In order to simplify matters, let us consider series composed by two bets. More specifically, let us consider the four pairs of bets in table (3.

For any pair of bets, subjects are asked to select either bet A or bet B. On average, the number of subjects who prefer A to B is slightly greater than the number of subjects who prefer B to A.

At this point, a different game is played. Subjects are asked to imagine that they own a lottery ticket for each bet, and that they have a possibility to sell it. That is, they can either wait for the outcome of each bet, where they may win or loose with a certain probability, or they can sell the ticket. In order to compare the willingness to play to the willingness to sell the ticket, subjects are asked to fix a minimum selling price for each bet.

In general, it is empirically observed that most people ask a higher price for bets B than for bets A.

However, for each pair of bets, bet A has the same expected (utility) value than bet B. Thus, according to the theory of rational decision, decision-makers should be indifferent between A and B.

On the contrary, subjects have a slight preference for A if they are asked to play one of the two bets but they definitely prefer B if they are asked to fix a selling price. This behavior is clearly at odds with the theory of rational decision.

The distinguishing feature of bets A is that the first consequence has a much higher probability than the second one. Thus, one assumes that it is the difference of probability values that orientates decision-making.

The distinguishing feature of bets B is that the first consequence concerns a much larger amount of money than the second one. Probabilities, on the contrary, are sometimes very similar, sometimes very different from one another. Thus, one assumes that it is the difference of money values that orientates decision-making.

If subjects are asked to play the bets their attention is caught by probabilities, so either they are indifferent or they prefer A. If subjects are asked to sell lottery tickets their attention is caught by money values, so they prefer B.

Slovic's paradox shows that preferences change if the decision-maker focuses on the probability of a consequence or, rather, on its utility (here, money value). This means that human beings are unable to evaluate probabilities and utilities independently from one another. We laugh at the fox who says that the grapes are sour, but we behave in precisely that way.

PAIR OF BETS   I

	Consequence 1	Consequence 2
Bet A$_I$	win $ 4.00 with probability 0.99	loose $ 1.00 with probability 0.01
Bet B$_I$	win $ 16.00 with probability 0.33	loose $ 2.00 with probability 0.67

PAIR OF BETS   II

	Consequence 1	Consequence 2
Bet A$_{II}$	win $ 3.00 with probability 0.95	loose $ 2.00 with probability 0.05
Bet B$_{II}$	win $ 6.50 with probability 0.50	loose $ 1.00 with probability 0.50

PAIR OF BETS   III

	Consequence 1	Consequence 2
Bet A$_{III}$	win $ 2.00 with probability 0.80	loose $ 1.00 with probability 0.20
Bet B$_{III}$	win $ 9.00 with probability 0.20	loose $ 0.50 with probability 0.80

PAIR OF BETS   IV

	Consequence 1	Consequence 2
Bet A$_{IV}$	win $ 4.00 with probability 0.80	loose $ 0.50 with probability 0.20
Bet B$_{IV}$	win $ 40.00 with probability 0.10	loose $ 1.00 with probability 0.90

Table 3: Slovic's experiment.

D Reconstructing the Past at *Echelon*

The following case study was carried out by Lane and Maxfield [56]. It shows that distorting reality and reconstructing the past can be a good and useful thing.

In 1990, *Echelon*, a Silicon Valley company, launched *LonWorks*, an innovative technology for distributed control. Previously, control was centralized into one main processing unit. With *LonWorks*, each electrotechnical device is endowed with a microprocessor and can communicate with all other devices, so all device control each other. Distributed control is more resilient than centralized control, and easily implements modular architectures to which additional devices can be added.

Distributed control is particularly suited to the automation of office spaces in large buildings, post-Fordist productive plants, as well as any setting where a large number of heterogeneous devices must coordinate their operations while retaining some flexibility. Thus, in its early days *Echelon* focused on partnerships with large producers of the devices to be automated, e.g., a producer in the field of heating and air conditioning was offered a possibility to integrate a microchip in their devices, as well on lifts, doors and windows in order to integrate all controls in a large building, from lighting to heating to theft protection.

With some disappointment, *Echelon* had to recognize that the *LonWorks* technology was not exploited in its full potentialities. In fact, each large producer was specialized in one tiny sector so it had neither the power nor the capability to implement *LonWorks* on all devices. For instance, a producer in the field of heating and air conditioning found it difficult to install *LonWorks* on doors, windows, lights and lifts, for the automation of these devices was covered by other firms. Indeed, the difficulty was that *Echelon* was attempting to create a new market — one may call it a market for automation — in a marketplace that was covered by producers of several physical devices at a time.

Echelon was conscious of the enormous difficulties connected with the creation of a new market. Nevertheless, it deemed that long-term relations with a few specialized producers would pay in the long run. *Echelon* had a narrative, saying that large specialized producers would slowly but persistently adopt and impose *LonWorks*. Consequently, it invested all of its resources in these relations.

By 1994, *Echelon* was loosing confidence in this narrative. *Echelon* started to approach large system integrators of ICT, such as *Olivetti* and *Ameritech*. However, the crucial move was that of hiring a person for this job, who did not come from Silicon Valley as all other executives did. Through this employee, *Echelon* approached smaller companies, that integrated devices from different producers. Some people at *Echelon* conceived the idea of embedding *LonWorks* in a box that could be attached to any electrotechnical device, of whatever producer.

Scholars of technological innovation know how difficult it is for visionary employees to convince their boss of the value of their idea. In the case of *Echelon* the CEO embraced enthusiastically the new idea, because it appeared to fit with his previous experience.

Echelon's CEO had been the successful entrepreneur of a small firm that exploited digital technologies to produce PBX (private branch exchange) systems with innovative features. This firm had been able to displace giants such as *AT&T* by providing small

independent installers with a superior product. When this CEO met small independent integrators of electromechanical devices, he mapped the new idea onto his previous experience.

In 1996, and within a few months, *Echelon* changed its narrative. *Echelon* presented itself as a provider of an innovative microchip for independent system integrators, a microchip that could be installed on any electrotechnical device, of whatever producer.

Most importantly, *Echelon* told itself that it had always pursued this strategy. Nobody in the firm seemed to be aware that the firm's strategy had changed. According to the narrative that they had developed, they had always done what they were doing.

Moreover, when faced with evidence that the firm had adopted a different strategy, management wished that the final publication by Lane and Maxfield would not stress this aspect (Lane: personal communication). This makes sense, for according to our idea of rationality narratives should reflect "objective information", and decision-makers should stick to it. Thus, management did not want to appear irrational.

However, the case of *Echelon* highlights that constructing a narrative by re-interpreting the past may be good and useful for decision-makers. In fact, the reported case reveals that by re-interpreting its mission *Echelon* was able to direct its investments. If the future is uncertain, as it is often the case, interpreting the past in order to find a direction for the future is a sensible activity.

Rather, the trouble is with our idea of rationality. Since re-interpreting the past is regarded as irrational, then it must be done in secrecy. In reality, if re-interpreting the past has positive effects, then it should be prescribed.

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