Extending the Core Ontology on Decision Making according to Behavioral Economics

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Abstract. *Decisions are constantly made and some of them may be extremely critical. However, most decision makers are unaware that their decisions may be biased. We used Behavioral Economics as a foundation to propose an ontology that shows how decision makers' preferences are set and the situation in which they occur in an intuitive decision under risk and uncertainty. Our aim is that this ontology be used to improve their decisions by allowing them a better understanding of how they decide. In addition, this ontology can be used as part of a strategy to reduce biases.*

1. Introduction

Organizations' success depends on their decisions and decision-making processes are key to make good decisions (SIMON, 1997). An important part of human decision making processes is the use of intuition, i.e. not all decisions are taken rationally or based on logical reasoning. Intuition is supposed to help decision makers address complex problems, especially in risky and uncertain situations as in dynamic and turbulent environments and when little information is available (KAHNEMAN, 2011; VAN RIEL & HORVÁRTH, 2014). The Intuitive decision and its biases are studied by behavioral economics (BE) theory (descriptive theory) that is a theory about how decisions are made (KAHNEMAN, 2011) (THALER, 2015) (OVE HANSSON, 2005) (ARNOTT & GAO, 2019). An indication of the successful field's standing is that three Nobel Prizes have been awarded to BE (ARNOTT & GAO, 2019): to Herbert A. Simon in 1978, to Daniel Kahneman in 2002, and to Richard Thaler in 2017.

On the other hand, decisions can be negatively impacted by psychological biases, such as the ***loss aversion***, ***risk seeking*** and ***framing*** effects. Psychological biases, also known as cognitive biases, are systematic errors that recur predictably in particular circumstances, such as decision making under uncertainty. The errors resulting from a biased process prevent us from making sound decisions. Even when we have gathered abundant work experience and knowledge, we are still subject to those biases. Avoiding

bias is a challenge, and one of the reasons is that people are incapable of recognizing their own biases. Therefore, to improve decision making, it is important to better understand how these biases occur and how to reduce their negative consequences (KAHNEMAN, 2011).

In this sense, a considerable number of studies have been done in strategic decision making (e.g. KAHNEMAN et al., 2011; KAHNEMAN, 2011; BAZERMAN &MOORE, 2013; THALER & GANSER, 2015; CRISTOFARO, 2017; ABATECOLA et al., 2018; TSIPURSKY, 2019). Psychological and behavioral studies, for example, bounded rationality (SIMON, 1997), fast-and-frugal heuristics (GIGERENZER et al., 1999) and cognitive biases (TVERSKY & KAHNEMAN, 1974; KAHNEMAN, 2011) have suggested that there are contexts in which people consistently violate the axioms of utility theory based on the maximization of utility, but Cumulative Prospect Theory (CPT) can accommodate most of these violations (LEWANDOWSKI, 2017). CPT can predict and explain the ways in which people actually make decisions and may allow a better understanding of cognitive biases (KAHNEMAN, 2011) (FRENCH et al., 2009).

In this paper, we present an ontological analysis of the process of intuitive decision making according to CPT, and formalize it by means of a well-founded ontology. We build on the Core Ontology on Decision Making (GUIZZARDI et al., 2020) and consider the fourfold pattern of risk attitudes, one of the core achievements of CPT. This pattern models the following four behavior types: *risk aversion for gains* and *risk seeking for losses of medium and high probability*; *risk seeking for gains* and *risk aversion for losses of low probability*. The proposed ontology accounts for these four behavior types, allowing decision makers to understand how their preferences can be biased in comparison with rational decision making, and how such biases may occur.

The remainder of this paper is structured as follows. Section 2 presents Behavioral Economics and the Cumulative Prospect Theory. Section 3 shows the Core Ontology on Decision Making. Section 4 presents our proposed ontology, and Section 5 points to Related Work. Finally, Section 6 concludes this work.

2. Behavioral Economics

Behavioral Economics is a descriptive theory about how decisions are made. It shows our actual behavior and does not assume that people generally know what is best for them and make decisions consistent with it (THALER & GANSER, 2015), as the rational (normative) decision making theories do.

One of the main foundations of BE is the dual process theory of human cognition. It reflects a fundamental distinction in human thinking known as System 1 (intuitive system) and System 2 (rational system), from the perspective of decision makers. Decision making can be described as a function of both Systems (KAHNEMAN, 2011). System 1 operates involuntarily, automatically, unconsciously, and quickly with little or no effort, and is also emotional, while system 2 operates voluntarily, consciously, and slowly with high effort (KAHNEMAN, 2011; KAHNEMAN & KLEIN, 2009). The latter is logical, based on controlled operations, and allocates attention to the effortful mental activities that demand it, including complex computations. System 2 can follow rules, compare objects on several attributes, and make deliberate choices between alternatives. On the other hand, System 1 does not have these capabilities. Systems 1 and 2 are both active whenever we are awake and operate in parallel and interactively

(KAHNEMAN, 2011; KAHNEMAN and KLEIN, 2009). In this Section, we present Cumulative Prospect Theory, which is the most famous theory of Behavioral Economics.

2.1. Cumulative Prospect Theory

CPT is a descriptive theory of decision making in risky and uncertain situations (TVERSKY & KAHNEMAN, 1992). It considers the fact that, in general, people tend to measure uncertainty and risk badly (SHARDA et al., 2014). To understand it, we here compare it to the Expected Utility (EU) theory, which is a rational decision making theory (FRENCH et al., 2009).

Expected Utility (EU) theory assumes that decision makers optimize by choosing the alternative with the highest Expected Utility among all the alternatives (FRENCH et al, 2009). The Expected Utility of an alternative is calculated by multiplying the value of each outcome by the probability of that occurring outcome and, lastly, summing those numbers (PALMER, 2016).

EU is the right way to make decisions while Cumulative Prospect Theory gives a good prediction of the actual choices people make (THALER, 2015). The EU theory and CPT predict differently the decision maker´s choice between Gamble A and Gamble B in the following example. Gamble A represents a sure loss of $1000, and Gamble B, 50% chance of losing $2500 or 50% chance of losing nothing. The EU of Gamble A is -$1000, and the EU for Gamble B is -$1250. According to EU, Gamble A would be selected as the final decision because s/he loses less (-$1000) than selecting the other option (-$1250). However, CPT argues the decision maker chooses Gamble B. The key to understanding this example is that CPT considers the notion of reference point and loss aversion in decision making, while EU does not. We show this example in detail in Section 4, but first we explain the main characteristics of Cumulative Prospect Theory.

CPT is based on the aforementioned dual process theory (KAHNEMAN, 2011; KAHNEMAN and KLEIN, 2009). The following three cognitive features, all operating characteristics of System 1 (Intuitive), are the foundation of CPT and are illustrated as the CPT value function in Figure 1: (i) **Reference dependence**: evaluation is relative to a neutral reference point. Outcomes that are better than the reference point are seen as gains, and are seen as losses when they are below the reference point. A reference point may be the status quo, but it can also be the outcome to which you feel entitled to, or the outcome you expect, or a goal in the future, for instance. In the aforementioned example, the reference point was "losing nothing" in the Gamble B. So, not achieving the goal is a loss. Receiving a bonus smaller than you expected is also a loss (KAHNEMAN, 2011). The reference point people use to compute gains and losses is their "beliefs . . . held in the recent past about outcomes (KŐSZEGI and RABIN 2006, 2007, 2009 apud BARBERIS, 2013)"; (ii) **Loss aversion**: a loss hurts more than an equivalent gain gives pleasure (THALER, 2015). We tend to avoid losses more strongly than to have gains (KAHNEMAN, 2011), that is why Gamble A is perceived as a loss. The thought of accepting the sure large loss is too painful. It has become the most powerful tool in the behavioral economist's arsenal (THALER, 2015); (iii) We feel **diminishing sensitivity** to gains and losses (THALER, 2015). We perceive the subjective difference between $1100 and $1200 as much smaller than the difference between $100 and $200 (KAHNEMAN, 2011).

Figure 1 shows the **psychological value**, yield to a decision maker, of gains and losses from a reference point, in the vertical axis. The monetary gains or losses of a decision are represented in the horizontal axis. The choice process of Cumulative Prospect Theory has two phases: framing and valuation. In the framing phase, the decision maker builds a mental representation of the problem, representing the acts, contingencies, and outcomes that are relevant to the decision. Then, in the valuation phase, s/he assesses the value of each prospect and chooses accordingly (TVERSKY & KAHNEMAN, 1992). One of the core achievements of CPT is the fourfold pattern of risk attitudes.
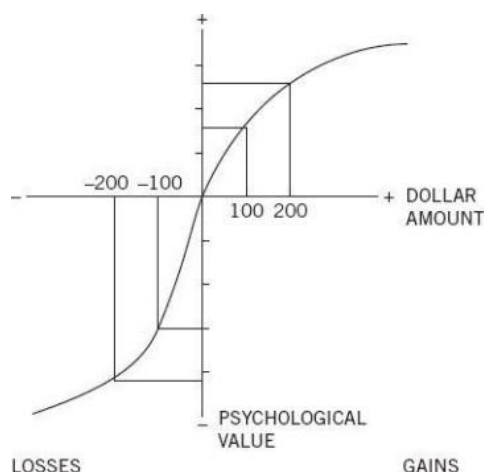

Figure 1. The form of the value function in CPT representing the psychological value of gains and losses – adapted from (KAHNEMAN 2011)

2.2. The fourfold pattern of risk attitudes

As already seen, according to CPT, "people attach values to gains and losses rather than to wealth, and the decision weights that they assign to outcomes are different from probabilities" (KAHNEMAN, 2011, p. 317). This is the basis to explain the distinctive pattern of decision makers' preferences presented in the fourfold pattern (Table 1) of risk attitudes as: *risk aversion for gains* and *risk seeking for losses of medium and high probability*; *risk seeking for gains* and *risk aversion for losses of low probability*. Decision makers are "risk seeking" if the gamble is preferred, and "risk averse" if the sure thing is preferred (KAHNEMAN, 2011).

In the top right cell, the pattern of decision makers' preference is **Risk seeking for losses of medium and high probability**. When they face very bad options, i.e. when offered a choice between a sure large loss and a gamble for a larger loss of medium and high probability, they hope to avoid the sure loss and become risk seeking. They reject the favorable settlement of losing $9,500 with certainty and choose 95% chance to lose $10,000. This was new and unexpected and is where many unfortunate human situations unfold. Decision makers tend to "accept a high probability of making things worse in exchange for a small hope of avoiding a large loss" (KAHNEMAN, 2011, p. 319).

In the top left cell, the pattern of decision makers' preference is **risk aversion for gains of medium and high probability**. When they face very good options, i.e. when offered a choice between a sure large gain and a gamble for a greater gain of medium and high probability, they fear disappointment and become risk averse. They accept the

unfavorable settlement of getting $9,500 with certainty, instead of 95% chance to get $10,000.

In the bottom left cell, the pattern of decision makers' preference is **risk seeking for gains of low probability**. When they face options like "5% chance to win $10,000" or "$500 with certainty", i.e. when offered a choice between a possible large gain of low probability and a small sure gain, they hope to get the large gain and become risk seeking. They reject the favorable settlement of getting $500 with certainty and choose a 5% chance to win $10,000. This effect explains why lotteries are popular.

In the bottom right cell, the pattern of decision makers' preference is **risk aversion for losses of low probability**. When they face options like "5% chance to lose $10,000" or "$500 with certainty", i.e. when offered a choice between a possible large loss of low probability and a small sure loss, they fear the large loss and become risk averse. They accept the unfavorable settlement of 100% chance to lose $500. Here is where insurance is bought because people are risk averse for losses of low probability and prefer paying much more for insurance than expected value.

	GAINS	LOSSES
HIGH PROBABILITY (Certainty effect)	"95% chance to **win** $10,000" or "$9,500 with certainty" Fear of disappointment. RISK AVERSE. Accept unfavorable settlement of 100% chance to obtain $9,500	"95% chance to **lose** $10,000" or "$9,500 with certainty" Hope to avoid loss. RISK SEEKING. Reject favorable settlement and choose 95% chance to lose $10,000
LOW PROBABILITY (Possibility effect)	"5% chance to **win** $10,000" or "$500 with certainty" Hope of large gain. RISK SEEKING. Reject favorable settlement and choose 5% chance to win $10,000	"5% chance to **lose** $10,000" or "$500 with certainty" Fear of large loss. RISK AVERSE. Accept unfavorable settlement of 100% chance to lose $500

Table 1. The fourfold pattern of risk attitudes. Adapted from Kahneman (2011).

For each of the cells of the fourfold pattern, systematic deviations from expected value are costly in the long run and this rule applies to both risk aversion and risk seeking (KAHNEMAN, 2011). However, most decision makers are unaware that their decisions are influenced by risk preferences as shown in the CPT, so they are likely to decide without realizing how it can bias their choice of action (FRENCH et al., 2009).

The true semantics of what is value and how the cognitive biases sometimes negatively affect decision making are sometimes not well understood. The semantic notions involving these concepts, and their relations with decision making can be better explored and represented, mainly by showing the differences between **intuitive** and **rational decision**.

3. The Core Ontology on Decision Making

Guizzardi et al. (2020) argue that for providing better support to decision making, it is paramount to understand, first of all, the nature of decisions and of the decision making process. For that, these authors propose the Core Ontology on Decision Making, founded on the Unified Foundational Ontology (UFO), on the ontology of Value Proposition

(SALES et al. 2017) and on the ontological analysis of Economic Preference (PORELLO & GUIZZARDI 2018)(PORELLO et al. 2020).

According to the ontology foundations, an agent termed VALUE BEHOLDER ascribes VALUE to VALUE OBJECTS or VALUE EXPERIENCES, the latter being past, present or future experiences of an agent (i.e., kinds of mental simulations, or mental models). Hence, VALUE OBJECT and VALUE EXPERIENCE are two types of VALUE BEARERS. The AGENT makes VALUE ASCRIPTIONS (i.e., assesses a VALUE BEARER) to assign it with VALUE. So, the AGENT starts simulating possible scenarios, e.g., imagining herself in experiences, in which she interacts with other AGENTS and OBJECTS. This is what Sales et al. (2017) call VALUE EXPERIENCE. In this sense, value is goal dependent, context dependent, uncertain, and subjective.

Furthermore, Guizzardi et al. (2020) defined an AGENT'S PREFERENCE by comparing the VALUE that the VALUE BEHOLDER assigns to two VALUE BEARERS, following Porello and Guizzardi (2018) and Porello et al. (2020). The preferred bearer is then called the PREFERRED VALUE BEARER, while the other DEPRECATED VALUE BEARER.

PREFERENCE is the truthmaker of the ternary "has preference" relation, the latter connecting a PREFERRED BEARER and the DEPRECATED BEARER (non-preferred bearer). PREFERENCE is a COMPLEX MODE, which aggregates two VALUE ASCRIPTIONS, each one associated to one of the VALUE BEARERS (GUIZZARDI et al., 2020). A VALUE ASCRIPTION is also a COMPLEX MODE associated to a VALUATION event, performed by the AGENT when ascribing value to the VALUE BEARER. Here, VALUE is an emerging quality that inheres in a VALUE ASCRIPTION that takes a magnitude in a given conceptual space (PORELLO and GUIZZARDI 2018) (GUIZZARDI et al., 2020).

Finally, a DECISION is associated with two ACTIONS, one that creates it, i.e., the DELIBERATION, and one that is associated with the decision result, the DECISION RESULTING ACTION. The DECISION RESULTING ACTION brings about a SITUATION termed CONSEQUENCE. By analysing the decision CONSEQUENCE, the AGENT develops other MENTAL MOMENTS (i.e. BELIEFS, DESIRES and INTENTIONS) that will then influence his future DECISIONS. CONSEQUENCE and DECISION RESULTING ACTION help in the cycle of assessing the result of the decision before taking the next one.

4. Proposed Ontology

In this paper, we extend the ontology of Guizzardi et al. (2020) by including **intuitive decision making** according to CPT and, consequently, we defined the concepts of INTUITION, REFERENCE POINT, COGNITIVE BIAS, LOSS AVERSION, GAIN, LOSS, RISK AVERSE, RISK SEEKING, PSYCHOLOGICAL VALUE ASCRIPTION and PSYCHOLOGICAL VALUE. CPT considers decisions *under risk and uncertainty*, and so does our proposed ontology.

EU theory (aforementioned on Section 2.1) is based on elementary rules (axioms) of rationality (KAHNEMAN, 2011) and it represents *value* as final states of wealth

(FRENCH et al., 2009). In this sense, *value* (or *use value*) is a composition of benefits (which emerge from goal satisfaction), and sacrifices (which emerge from goal dissatisfaction) (LANNING & MICHAELS, 1998). This is the value considered in the ontology of Guizzardi et al. (2020), which allows one to determine what are the alternatives (value bearers) to be chosen from, how they are valued, what are the applied criteria, who can execute the action resulting from the decision, and so on. In our proposed ontology, we call this *value* as RATIONAL VALUE to make the difference with PSYCHOLOGICAL VALUE explicit.

According to CPT, people attach values to gains and losses rather than to wealth (KAHNEMAN, 2011). Depending on how a decision maker frames the decision problem (mental representation of the problem), she represents the value of the possible outcomes that may occur as *gains* and *losses* from a **reference point**. To account for PSYCHOLOGICAL VALUE, our ontology reuses the concepts proposed by Guizzardi et al. (2020), but specializes them from VALUE ASCRIPTION to RATIONAL VALUE ASCRIPTION and PSYCHOLOGICAL VALUE ASCRIPTION, from VALUE ASCRIPTION COMPONENT to RATIONAL VALUE ASCRIPTION COMPONENT and PSYCHOLOGICAL VALUE ASCRIPTION COMPONENT, from VALUE COMPONENT to RATIONAL VALUE COMPONENT and PSYCHOLOGICAL VALUE COMPONENT.

Suppose that an AGENT **A** is in a given SITUATION **S₁**, i.e., her actual state of affairs. Suppose that **S₁** does not satisfy **A's** INTENTIONS (GOALS). Thus, **A** desires a different SITUATION **S₂**. Given her PREFERENCES and resources (including capacities) and the context surrounding **S₁** (such as risk and uncertainty, quantity of available information, time and pressure to make the decision), **A** can decide to self-commit to a particular way of pursuing her GOALS. Agent **A** does that by **deliberately assessing her options** (rational decision making) or by **using intuition** (intuitive decision making) to form a new INTENTION[1] according to the dual process theory explained in Section 2. In other words, an INTENTION can result from an **intuitive or rational decision making process** (KAHNEMAN, 2011).

Figure 2 shows that an AGENT performs a CHOICE between alternatives due to a certain (motivating) INTENTION. Choice is a critical step of decision making in which "the actual decision and the commitment to follow a certain course of action are made" (SHARDA et al., 2014, p. 85).

The Choice is performed by DELIBERATION and/or by performing an INTUITIVE CHOICE. These sub-classes of Choice are not disjoint. An INTUITIVE CHOICE applies an INTUITION (reasons intuitively) which, in turn, creates a new INTENTION termed a DECISION (as the result from the decision making process). In other words, a DECISION is an INTENTION created by a DELIBERATION or by an INTUITIVE CHOICE. An INTUITIVE CHOICE can be influenced by COGNITIVE BIASES, such as loss aversion. As an INTENTION, that DECISION can eventually be manifested by performing another ACTION termed a DECISION RESULTING ACTION, whose resulting situation is termed a CONSEQUENCE. If that is a successful

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[1] Remember that according to the foundation ontology we adopt (i.e. UFO), a GOAL is a propositional content of an INTENTION. And an INTENTION is adopted by an agent having in mind a particularly aimed SITUATION.

action, a CONSEQUENCE satisfies the PROPOSITIONAL CONTENT (GOAL) of the original DECISION (GUIZZARDI et al., 2020).
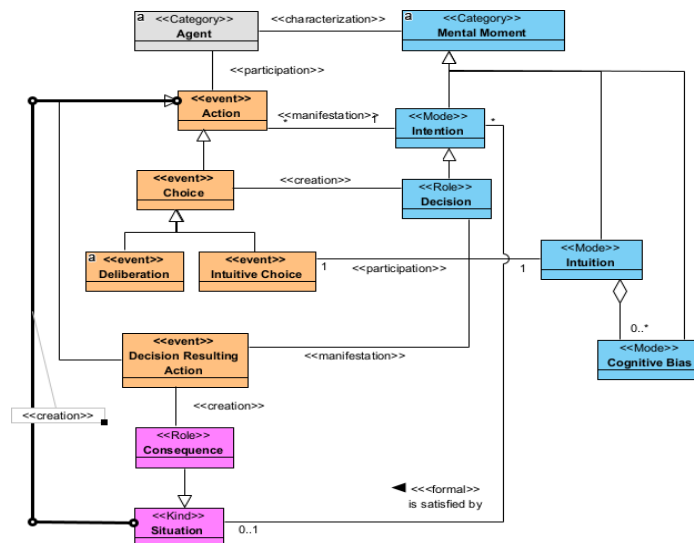

Figure 2. Deliberation, Intuition and Decision

The next figure (Figure 3) illustrates how the RATIONAL and INTUITIVE DECISIONS are made and how the concepts of VALUE and PREFERENCE are related. Consider a SITUATION in which an AGENT must decide between two alternatives A and B. Each alternative is a VALUE BEARER (either a VALUE OBJECT or a VALUE EXPERIENCE). When an AGENT decides something, she can decide rationally or intuitively (KAHNEMAN, 2011) (KORNYSHOVA and DENECKERE, 2012). During the decision making process, she takes into consideration her own PREFERENCES regarding two possible VALUE BEARERS.

Let us now consider in more detail what happens when an agent makes a decision. When s/he decides **rationally** (i.e., performs a **DELIBERATION**) or **intuitively** (e.g., performs an **INTUITIVE CHOICE**). DELIBERATION (GUIZZARDI et al., 2020) and INTUITIVE CHOICE are manifestations of that agent's PREFERENCES over two VALUE BEARERS.

Based on the dual process theory explained in Section 2, the VALUE ASCRIPTION[2] can be PSYCHOLOGICAL or RATIONAL. If the AGENT deliberately assesses her/his options, then s/he is using System 2, i.e. s/he is reasoning logically (a DELIBERATION is hence happening). This results in a RATIONAL VALUE ASCRIPTION (RVA). On the other hand, if the AGENT uses her/his intuition to decide, then s/he is using System 1, i.e. intuitive thinking. So, it is a PSYCHOLOGICAL VALUE ASCRIPTION (PVA). Note that Systems 1 and 2 operate in parallel and interactively (KAHNEMAN, 2011; KAHNEMAN & KLEIN, 2009). To account for both systems, we incorporated the notion of a PVA in addition to a RVA, as described in the following paragraphs.

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[2] According to Kahneman (2011), in an intuitive decision making there is psychological value and in a rational decision making there is a "value", that we renamed here to "rational value".

Each RATIONAL VALUE ASCRIPTION is composed of several smaller "comparisons" (or "judgements"), named RATIONAL VALUE ASCRIPTION (RVA) COMPONENTS, which aggregate an INTENTION and INTRINSIC MOMENTS that are taken into consideration by the AGENT when ascribing VALUE to a VALUE BEARER. Each RVA COMPONENT is in its turn associated to a RATIONAL VALUE COMPONENT, defined as either a BENEFIT or a SACRIFICE.

Each PSYCHOLOGICAL VALUE ASCRIPTION is composed of several smaller "comparisons" (or "judgements"), named PSYCHOLOGICAL VALUE ASCRIPTION (PVA) COMPONENTS, which aggregate an INTENTION and INTRINSIC MOMENTS that are taken into consideration by the AGENT when ascribing VALUE to a VALUE BEARER. Each PVA COMPONENT is in its turn associated to a PSYCHOLOGICAL VALUE COMPONENT, defined as either a GAIN or a LOSS according to a REFERENCE POINT, which is ontologically a BELIEF. A reference point is highly determined by the objective status quo, but is also affected by social and expectations comparisons. When an employee receives a smaller raise than everyone else in the office, s/he experiences this objective improvement as a loss. Moreover, the PSYCHOLOGICAL VALUE COMPONENTS are influenced by the COGNITIVE BIASES, such as LOSS AVERSION, that is the DESIRE to avoid losses. For example, in many decisions, decision makers must choose between retaining the status quo and accepting an alternative to it. Because losses loom larger than gains, they tend to be biased in favor of keeping the status quo, considering the status quo as the reference point (KAHNEMAN, 2011).

It is important to note that when instantiating this ontology for a particular decision making case, we may not be able to account for all involved PSYCHOLOGICAL VALUE ASCRIPTION COMPONENTS because PVA is done by the intuitive thinking, which is unconscious and holistic. On the other hand, all the RATIONAL VALUE ASCRIPTION COMPONENTS should always be represented, because RVA is done by logical reasoning, which is conscious.

As seen before, the core premise of conventional economic theory is that people choose by optimizing (THALER, 2015). Hence, considering a RATIONAL VALUE ASCRIPTION, a VALUE BEARER is preferred in a has preference relation if and only if the value magnitude of its RATIONAL VALUE ASCRIPTION bearer is greater than the one of the compared alternatives (GUIZZARDI et al., 2020). However, the PSYCHOLOGICAL VALUE ASCRIPTION works differently. As shown by CPT, a VALUE BEARER that is preferred in a RVA may be the deprecated in a PVA because the PSYCHOLOGICAL VALUE is represented as **gains and losses from a reference point** rather than as final states of wealth, as assumed by EU theory (FRENCH et al, 2009). This will set the PREFERENCE mode for most of the decision makers as RISK SEEKING PREFERENCE or RISK AVERSE PREFERENCE. They tend to be risk averse for gains and risk seeking for losses of medium and high probability; risk seeking for gains and risk aversion for losses of low probability (KAHNEMAN, 2011).

To facilitate the understanding of the concepts and as a preliminary evaluation of the proposed ontology, Figure 4 illustrates a possible instantiation of a situation.

Suppose the example in which someone named Fred needs to make a choice between Gamble A (a sure loss of $1000) and Gamble B (50% chance of losing $2500 and 50% chance of losing nothing). The Expected Utility (EU) of Gamble A is -$1000,
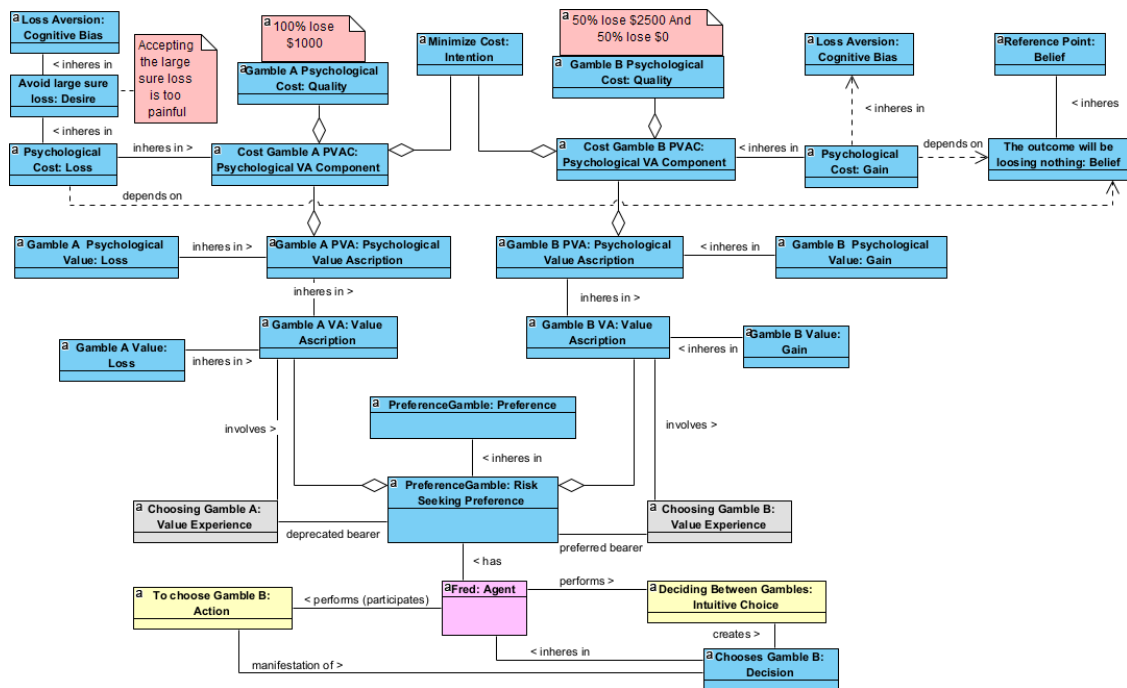
and the EU for Gamble B is -$1250. The EU is calculated by the probability multiplied with the expected win/loss. The EU theory says that people tend to choose Gamble A, because it has the highest Expected Utility. However, CPT shows that most people select Gamble B, despite having the lower Expected Utility. We explain how it happens as follows.

Figure 3. Deliberation, Intuition, Value and Preference

Fred starts evaluating these two alternatives, thus ascribing value (VALUE ASCRIPTION) to each alternative. The VALUE ASCRIPTION can be PSYCHOLOGICAL (PSYCHOLOGICAL VALUE ASCRIPTION) or RATIONAL (RATIONAL VALUE ASCRIPTION). Each VALUE ASCRIPTION may be composed by one or more components. In this example, we only consider one component (Cost).

For instance, illustrating rational decision, Fred may rationally value Gamble A as -$1000 while Gamble B is valued as -$1250, according to the EU theory (RATIONAL VALUE ASCRIPTION). There are BENEFITS and SACRIFICES inhering in each of these RATIONAL VALUE ASCRIPTION COMPONENTS, for instance, Gamble B is a SACRIFICE and Gamble A is a lower sacrifice that we represent here as a BENEFIT just to simplify the understanding. So, Fred chooses Gamble A, the PREFERRED BEARER, while Gamble B is the DEPRECATED ONE.

On the other hand, Fred may intuitively value Gamble A as a LOSS and Gamble B as a GAIN, according to CPT (see Figure 4). These PSYCHOLOGICAL VALUES are represented as gains and losses from a REFERENCE POINT that set the PREFERENCE mode for RISK SEEKING PREFERENCE because the alternatives were *losses of medium and high probability*. In this context, as stated by CPT, decision makers hope to avoid the sure loss and become risk seeking by choosing the riskier alternative with high chance to lose even more. The thought of accepting the large sure loss (Gamble A) is too painful for Fred. This is the effect of loss aversion. He has the desire to avoid the large sure loss and he believes the outcome of Gamble B will be losing nothing. His reference point is to lose nothing.

Figure 4. Instantiation of the PVA and its related concepts, illustrating how an intuitive decision is taken

Figure 4 shows that Fred chooses Gamble B, the PREFERRED BEARER, while Gamble A is the DEPRECATED ONE. Based on his set PREFERENCE (RISK SEEKING PREFERENCE), Fred uses INTUITION to decide between Gambles, which leads to the creation of the "Chooses Gamble B DECISION". And finally, Fred chooses "Gamble B DECISION RESULTING ACTION".

5. Related Work

In the literature review, we found no ontology representing the fourfold pattern of risk attitudes of the CPT. However, we found a few proposals of ontologies (KORNYSHOVA and DENECKERE, 2010; NOWARA, 2017) that consider intuitive decision making, which are the source of cognitive biases and risk preferences, but they do not consider the cognitive biases neither the risk preferences.

Brodaric and Neuhaus (2020) provided a conceptual and formal foundation for an ontology of beliefs, desires, and intentions, and discussed how their theory can be extended to some major philosophical accounts of desires, and cognitive biases such as wishful thinking. However, the cognitive biases concerned by Tversky and Kahneman (1974) stem from the reliance on judgmental heuristics and are not attributable to motivational effects such as wishful thinking or the distortion of judgments by payoffs and penalties.

So, to the best of our knowledge, there are no ontologies considering relevant concepts to model the fourfold pattern of risk attitudes of the CPT for decision making under uncertainty.

6. Conclusion

Our proposed ontology makes explicit what is involved in a decision making whether it is a rational or intuitive decision. Our main contribution is considering intuitive decision making under risk and uncertainty. Most decision makers are unaware that they use reference points, so they are likely to decide "without realizing how it can bias their choice of action" (FRENCH et al, 2009, p. 38). Our proposed ontology allows the decision maker to improve his decision making by understanding how his preferences are influenced by his reference point and cognitive biases in an intuitive decision. It can be achieved by improving the understanding of the risk preferences and the situation in which they occur. Future work includes the evaluation of the ontology w.r.t. its completeness and perceived usefulness. Moreover, the ontology may be used as part of a strategy to reduce the biases, and contribute to improving the development of Decision Support Systems (DSS) considering intuitive decision making. This may allow a joint decision making between human and DSS that can ultimately help human decision makers reach better decisions (TINTAREV et al., 2016) by allowing them to understand how their preferences can be biased in comparison with rational decision making, and how such biases may occur.

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