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Modeling value-based reasoning for autonomous agents

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***Abstract*—The issue of decision-making and teleological reasoning of autonomous agents constitutes the current work topic for many researchers. The author of [1] presents a framework allowing for teleological reasoning with the use of values and the possibility of autonomous goal-setting by a device. In this paper we propose to extend this framework by a new manner of representation of the level of value promotion including the required modifications of the reasoning mechanism. The proposed model may become a formal foundation for the realization of the autonomous agent.**

I. Introduction

A DISTINCTIVE feature of modern technical devices is their increasing self-sufficiency. One may presume that in the future the user will only formulate the most rudimentary rules of how the device works, whereas the everyday aspects of system operation will be regulated completely autonomously. The most advanced types of such devices are e.g. self-driving vehicles, where the user merely sets the journey's destination and the vehicle develops the itinerary on its own and makes hundreds of traffic-related decisions.

In major decision-making models it is usually assumed that the purpose of system operation is to accomplish some state of affairs pre-declared by the user ([2], [3], [4], and many others). Many authors (including [1], [5]) believe, however, that increasingly complex devices must be endowed with the ability to not only find the best possible way to attain the state of affairs set by the user, but also the ability to set their own goals themselves; the model proposed in this paper is based on this assumption.

[1] presents a framework allowing for autonomous (based on values which should be promoted) goal-setting by a device. The model relies on the differentiation between several kinds of goals: abstract (that is, minimal levels to which values should be promoted) and material (that is, particular states of affairs which realize abstract goals).

The objective of this paper consists in proposing for the model from [1] a new method of the representation of the levels to which particular decision options promote various values as well as a modification of the reasoning mechanism allowing for autonomous setting and realization of goals. The proposed mechanism may serve as a formal foundation for the realization of the autonomous agent. We plan to attain our goal by introducing a numeric representation of the levels of value promotion. Such a method of representation of value levels (for single values as well as for value sets) will facilitate their comparison, leading to easier and quicker (searching orders' sets *O* and *OR* will not be necessary) reasoning. Additionally, for systems in which values are connected with the physical parameters of a device or the environment we propose a basic mechanism for automatic translation of physical units into the levels of promotion of values, allowing the possibility of its development and adjustment to evaluate other values difficult to measure, e.g. the degree of resemblance to the pattern, security level evaluation (such as in [6], [7], [8], [9]), etc. Our model was built on the basis of the framework of teleological reasoning from [1] (further referred to as the GVR model). Due to length limitations, the GVR model will not be presented in the paper. The detailed description and its discussion can be found in [1].

II. Numeric representation of the levels of value promotion by particular situations

The underlying objective of this paper is to propose a new semantics for the model described in [1], which would allow for a numeric representation of the levels to which given situations promote various values. This task consists of two main parts: first, a proposal and discussion of the numeric method of representation of the level to which given values are promoted; then the development of the mechanism of determining this level, of determining the cumulative evaluation of value sets, the mechanism of comparing them (equivalents of the *O* and *OR* relations), and discussion of the properties of the proposed semantics.

A. Numeric representation of levels to which various situations promote particular values

In the model presented in [1] the exemplary level to which a given value (e.g. v_i) is promoted by a given situation (e.g.

x_j) is presented as $v_i(x_j) \in V(X)$ (without a definition of the kind and range of values which can be taken). The relations between the levels to which a given value (v_i) is promoted by situations x_1 and x_2 are regulated by a partial order O_i. Our model assumes that $v_i(x_j)$ will be expressed with a number from the range $\langle 0;1)$, where $v_i(x_j) = 0$ means that a value v_i is not promoted by a situation x_j, a value $v_i(x_j) = 1$ means that a value v_i is promoted by x_j to the maximal possible level, though we assume that the accomplishment of the maximal fulfillment of the value is not possible – the value may be promoted very close to the maximal value, but cannot reach it. Such representation allows us to compare the levels to which the same value is promoted by various situations (order O will be a total order).

Assuming a numeric representation of the level of promotion of values one cannot miss the fact that not all values are equally important to each user. The simplest solution would be to assign some weight to each value (from the range $(0;1)$), though this proposition is a far cry from the way humans reason. In real decision-making, a person does not assign constant weights to various values. In most cases, the weight of a given value depends on the user's preferences, external factors, and the level to which the value is promoted.

Definition 1 (Function of the weight): Let $\Omega_i : v_i(x_j) \rightarrow \langle 0;1)$ be a function of the weight referring to a value v_i. We assume that every function of the weight in the range $\langle 0;1)$ will be a constant and increasing function (this assumption is indispensible for the preservation of the features of the GVR model). For every value $v_i \in V$ exists maximally one function Ω_i. Let Ω be a set of weights' functions.
By $vo_i(x_j) = \Omega_i(v_i(x_j))$ we will denote the level of promotion of a value v_i by situations x_j taking into account weight Ω_i. A value $vo_i(x_j)$ will denote the relative level to which a situation x_j promotes a value v_i. Let $VO(x) = \{vo_i(x_j) | vo_i(x_j) = \Omega_i(v_i(x_j)) \wedge v_i(x_j) \in V(X)\}$ be the set of all values vo_i in all situations.

The most basic kind of function Ω is a linear function $\Omega_i(v_i(x)) = a(v_i(x))$, where a is a constant from the range $(0;1\rangle$; it is, however, possible to define more complex functions which would better express the relative preferences between values.

B. Transition from physical values to the evaluation of the promotion level of particular values

The promotion levels of certain values that are considered in the model are measured in various different methods and posses their individual physical representation. This is because, each of them deals with another state of related but diverse events.

Definition 2 (function Φ): Let $\Phi_i : pv_i(x) \rightarrow \langle 0;1)$ be a function that normalizes the level of a physical value $pv_i(x)$ and transforms it into $v_i(x)$. Let Φ be the set of transformation functions. Our model can make use of several different transformation functions which can be additionally declared, depending on the nature of the values. Whenever we are unsure of how the transformation function should be defined for a particular case, we can chose the default form which is the following: In order to normalise the physical values we will use the following normalisation function: $v_i(x) = \Phi_1(pv_i(x)) = (pv_i(x) - min(pv_i))/(max(pv_i) + e_{pv_i} - min(pv_i))$ where:

- pv_i - is the actual level of the value from the set of physical values PV.
- x - is the situation that promotes the certain value.
- $min(pv_i)$ - is the minimal level of the value pv_i.
- $max(pv_i)$ - is the maximal level of the value pv_i.
- e_{pv_i} - is an arbitrarily small positive quantity.

The result of $\Phi_1(pv_i(x))$ is the level of the corresponding value $v_i(x)$. For values where higher levels indicate a worse state we inverse the result of the normalisation function: $1 - \Phi_1(pv_i(x))$. The derivative of function Φ_1 will always produce a positive number.

C. Cumulative evaluation of the level of promotion of a value set by a given situation

In the model discussed in [1] a given situation may promote various values to various extents. It is represented by set $V^Z(x_n)$, where V^Z is a subset (named Z) of value set V. By V^{x_n} we denote set of all values promoted by situation x_n. By $V^Z(x_n)$ we denote a set of estimations of the levels of promotion of values constituting set V^Z by a situation $x_n \in X$. If $V^Z = \{v_z, v_t\}$, then $V^Z(x_n) = \{v_z(x_n), v_t(x_n)\}$. The GVR model also introduces the order relation OR between promotion sets to which various values are promoted by various situations (def. 8 in [1]). Properties of the OR order are discussed In [1].

Since our model assumes that the grounds for evaluation are relative levels to which particular values are promoted by situations, in our model the correspondent of set $V(X)$ will be set $VO(X)$ and its subsets.

For the realization of value-based reasoning to be possible, it is indispensible to define the correspondent of order OR for the new semantics. Introducing the numeric representation of the level to which a given situation promotes a given value ($v_i(X_n)$) and the weight function Ω provides the possibility to develop a mechanism able to determine the cumulative evaluation of the promotion of a value set by a given situation.

Firstly, we assume that the cumulative evaluation of the level to which a given value set will be promoted by a given action will be a number from the range $\langle 0;1)$, where 0 is interpreted as the minimal level of promotion and 1 is interpreted as the maximal level of promotion (impossible to attain). Such a relation will anable the comparison of various situations, including those which promote different values.

Definition 3 (function Θ): Let $\Theta : VO^Z(x) \rightarrow \langle 0;1)$ be a function returning the cumulative evaluation of the level to which a situation x promotes a value set V^Z. If:

- $V^Z = \{v_1\}$ then $\Theta(VO^Z(x)) = vo_1(x)$
- $V^Z = \{v_1, v_2\}$, then $\Theta(VO^Z(x)) = vo_1(x) + vo_2(x) - vo_1(x)vo_2(x)$
- $V^Z = \{v_1, v_2, v_3\}$, then the value returned by function Θ is determined in the following manner: first, we

determine $\Theta(VO^{vo_1,vo_2}(x)$ for $V^{vo_1,vo_2} = \{vo_1, vo_2\}$, then we determine $\Theta(VO^Z(x)) = \Theta(V^{vo_1,vo_2}(x)) + vo_3(x) - \Theta(VO^{vo_1,vo_2}(x))vo_3(x)$

- In case of a higher number of values in set V^Z the cumulative value $\Theta(VO^Z(x))$ is determined analogously to the previous case.

Properties of function Θ: (1) The value returned by function Θ is independent of the order in which particular values from V^Z are reviewed. (2) Function Θ is monotonic (here as monotonic we understand not only its being non-increasing, but also the fact that adding a new value which promotes a given situation increases the cumulative evaluation $\Theta(VO^Z(x))$. As we have already noticed, values must not be treated equally (they are not all equally important), and therefore we proposed a set of weight functions Ω. On the basis of that, we assume that in our model the equivalent of order OR will be order ORO:

Definition 4 (Value-extent-weight preference): A total order $ORO = (\trianglerighteq; 2^{VO(X)})$ represents a preference relation between various values, their weight functions and various sets of situations. We assume that $\Theta(VO^Z(x_n)) \geq \Theta(VO^Y(x_m)) \Rightarrow VO^Z(x_n) \trianglerighteq VO^Y(x_m)$

III. Goals

The four kinds of goals defined in [1] remain the same. The only changes are caused by the fact that the level of promotion of values expressed in numbers, and therefore the threshold values: ($v_n min(ga)$ and $v_n min(gua)$) will also be numbers from the range $\langle 0; 1)$. These values may be declared directly by the user or determined from function Φ and the minimal values of particular physical values declared by the user.

IV. Inference rules

The author of [1] introduces a number of the so-called argumentation schemes (in this work they will be treated as defeasible inference rules) allowing for the realization of value-based and teleological reasoning. Due to the length limitations, in this paper we will only present a model of three of them. A full model will be introduced in future works.

Below are presented three mechanisms from [1] which have been adapted to our reasoning model with a numeric representation of the level of value promotion (the names will correspond to the mechanisms from [1]):

AS2 **Generalized practical reasoning:** If in circumstances s_m performing an action a_t is preferred to remaining in s_m and $as_{t,m} \in AS$, then an action a_t should be performed:

$$\frac{\gamma(s_m) = 1 \quad as_{t,m} \in AS \quad VO^{as_{t,m}}(as_{t,m}) \trianglerighteq VO^{s_m}(s_m)}{\varepsilon(as_{t,m})}$$

In the above example, relation gg from [1] (def. 9) is expressed by means of order ORO ($\trianglerighteq$) which takes into consideration the weight function.

AS3 **Reasoning with abstract goals:** If in the current circumstances s_m achieving an abstract goal ga_k is possible by a material goal gm_l and gm_l is an action at performed in s_m, then a goal gm_l becomes the practical goal gp:

$$\frac{ga_k \quad \gamma(s_m) = 1 \quad gm_l = as_{t,m} \quad sat(gm_l, ga_k)}{gp = gm_l}$$

Interestingly, predicate $sat(gm_l, ga_k)$ (see: def. **??**) requires a determination (for goal ga_k) of the minimal levels to which particular vales should be fulfilled $v_i min(ga_k)$).

AS5 **Goal-driven practical reasoning:** In the current circumstances s_m, in order to achieve the practical goal gp, an action a_t should be performed:

$$\frac{\gamma(s_m) = 1 \quad gp = as_{t,m}}{\varepsilon(as_{t,m})}$$

V. Argumentation framework

Since no argumentation framework on which to build the model has been pre assumed, we have to adapt a simple ad-hoc model from [1]. The model is presented in an informal way, the fully fledged formal model of the argumentation framework will appear in a future works:

- We assume that arguments are constructed on the basis of inference rules.
- There are two kinds of attack: undermining, which is an attack on the premise of the inference rule, and rebuttal, which is an attack on the conclusion of the inference rule.
- An attack on the premise occurs when there exists an argument whose conclusion is the negation of the premise.
- An attack on the conclusion of argument $arg1$ occurs if: (1) There exists an argument whose conclusion is the negation of the conclusion of $arg1$, or (2) $arg1$ concludes that $\varepsilon(as_{t,m})$ and there exists argument $arg2$ which concludes $\varepsilon(as_{z,m})$, where $a_t \neq a_z$, or (3) $arg1$ concludes that $gp = as_{t,m}$ and there exists argument $arg2$ which concludes that $gp = as_{z,m}$, where $a_t \neq a_z$.
- We assume a partial ordering between arguments where if $arg1 > arg2$, then it means that $arg1$ is stronger than $arg2$.
- We assume that the basic grounds for determining order ($>$) between arguments is the inference rule on the basis of which the argument is constructed. We assume that $AS5 > AS3$, $AS5 > AS2$, and $AS3 > AS2$, meaning that if arguments $arg1$ and $arg2$ are in conflict and if $arg1$ is built on the basis of $AS3$ and arg is built on the basis of $AS2$, then $arg1 > arg2$.
- Argument $arg1$ defeats argument $arg2$ when argument $arg1$ undermines argument $arg2$ or argument $arg1$ rebuts argument $arg2$ and $arg2 \not> arg2$.
- Reasoning about priorities: we assume that priorities between arguments built on the basis of the same inference rule, depend on values whose application the argument promotes.
  - If both arguments ($arg1$ and $arg2$) are built on the basis of inference rule $AS2$, argument $arg1$ attacks argument $arg2$ (or vice versa), the conclusion of

$arg1$ is $\varepsilon(x_1)$, the conclusion of $arg2$ is $\varepsilon(x_1)$, and $\Theta(VO^{x_1}(x_1)) > \Theta(VO^{x_2}(x_2))$, then $arg1 > arg2$.
   - If both arguments ($arg1$ and $arg2$) are built on the basis of inference rule $AS3$, argument $arg1$ attacks argument $arg2$ (or vice versa), the conclusion of $arg1$ is $gp = gm_l$, where $gm_l = x_1$, the conclusion of $arg2$ is $\varepsilon(x_1)gp = gm_k$, where $gm_k = x_2$, and $\Theta(VO^{x_1}(x_1)) > \Theta(VO^{x_2}(x_2))$, then $arg1 > arg2$.
- If one of the arguments concludes that $\varepsilon(as_{t,m})$ and the argument is not defeated, it brings about performing action $as_{t,m}$.
- If one of the undefeated arguments concludes that $\not\varepsilon(as_{t,m})$, it results that action $as_{t,m}$ cannot be performed and $as_{t,m}$ is excluded from set AS.
- If the argument excluding $as_{t,m}$ from set AS is defeated, then $as_{t,m} \in AS$.
- Argument $arg1$ is not defeated if it is not attacked by any argument or all arguments which attack $arg1$ are defeated.

Generally speaking, the argumentation framework used in the example is based on a simplified version of the ASPIC+ argumentation framework [10].

VI. Conclusions

The framework included in [1] allows for the modeling of reasoning in autonomous systems. Regretfully, its practical implementation requires a declaration of a large number of orders describing relations between levels to which various situations promote various values and sets of values. With real decision-making problems, the declaration of such a high number of orderings is very challenging and can only be feasible in the case of a situation with relatively small sets of values and actions which are possible to perform. The main objective of our work is to propose modifications of the framework from [1] which would allow a facilitated implementation of the decision-making systems for autonomous agents.

While making a decision, a person intuitively evaluates available decision options, dividing them into better and worse ones (like it was presented in [1] and other works), but does not attach any numeric values to them. This paper introduces a modified approach, where the level to which particular situations promote various values is represented as a number from the range $\langle 0;1)$. Though unlike a typical human approach, we believe it is much more natural for all kinds of technical devices. The proper definition of function Φ allows for automatic evaluation of not only simple values (like the ones used in the example), but also more complex ones, e.g. degree of resemblance to the pattern (image, sound, etc.) or the level of risk evaluation. The modification we propose allows for a substantial reduction of the number of orderings (declarations of O and OR will not be necessary) because the level to which particular values are promoted can be easily compared; moreover, the lack of necessity to search large order sets may significantly accelerate the decision-making process. The proposed mechanism of determining the cumulative evaluation of particular situations (decision options), joined by the weight functions, makes it possible to compare complex situations promoting various values to various levels.

Further work on the model will proceed in several directions: (1) development of a full argumentation model for our framework, (2) discussion of our model's formal properties (e.g. basing on one of the available proofcheckers [11]), (3) discussion of the issue of decision-making in a legally-regulated environment, including an analysis of various reasoning mechanisms ([12], [13]), conflict resolution ([14], [15]), interpretation ([16], 1[17]), and other.

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