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Paired structures in knowledge representation

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A B S T R A C T

In this position paper we propose a consistent and unifying view to all those basic knowledge representation models that are based on the existence of two somehow opposite fuzzy concepts. A number of these basic models can be found in fuzzy logic and multi-valued logic literature. Here it is claimed that it is the semantic relationship between two *paired concepts* what determines the emergence of different types of neutrality, namely *indeterminacy, ambivalence* and *conflict*, widely used under different frameworks (possibly under different names). It will be shown the potential relevance of *paired structures*, generated from two paired concepts together with their associated neutrality, all of them to be modeled as fuzzy sets. In this way, paired structures can be viewed as a standard basic model from which different models arise. This unifying view should therefore allow a deeper analysis of the relationships between several existing knowledge representation formalisms, providing a basis from which more expressive models can be later developed.

1. Introduction

Recent advances in Psychology and Neurology are providing relevant results for the development of decision making models. The human brain has specifically and successfully evolved to manage complex, uncertain, incomplete, and even apparently inconsistent information. For example, neurologists have shown that the part of the brain taking care of making up the last decision is different to the part of the brain in charge of the previous rational analysis of alternatives, being the first part associated with *emotions* (see, e.g., [6,7]). A number of similar results within neurology (see, e.g. [41,52,82]) suggest that the activation of different areas of the brain, associated with both cognition and emotion, participate in our decision processes through the continuous interplay among different networks (namely the valuation network, the control network and the memory system), each one following their own set of rules (see, e.g., [59,60]). Among other key achievements, it has been recently shown the key role that concept representation plays in our knowledge process (see, e.g., [10,39]), along with the fact that the human brain manages positive information in a different way than negative information. This observation suggests some kind of *bipolarity* in the way that our brain handles information (see, e.g., [17,18]). Positive and negative affects are not processed in the same region of the brain, as they are generated by clearly different neural processes [61].

The importance of bipolar reasoning in human activity was emphasized by Osgood et al. in 1957 [54] (see also [38,71]). These authors proposed a semantic theory based on the Semantic Differential (SD) scale for evaluating the meaning of concepts. This theory became very popular for measuring attitudes in a practical way, where individuals are asked to use the SD scale to evaluate if a given object is perceived as being *positive, neutral* or *negative*.

Nonetheless, it becomes evident that by using the SD scale, objects cannot be evaluated as being *positive* and *negative* at the same time, and its neutral value can hardly be understood as a proper representation of *neutrality*. From this perspective, there are certain attitudes that seem to escape the linear logic of such a scale, but still require proper representation. This led to some critiques (see, e.g., [18,27,38]), stating that the SD scale does not consider other relevant attitudes arising from the inherent tension among opposite-like concepts, like for example *ambivalence*. Hence,

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a modified SD scale was proposed (see, e.g., [38]), consisting of two unipolar scales joined together by their minimal element, allowing the simultaneous measurement of positive and negative evaluations.

The relevance of this discussion can be well positioned and illustrated by different works in multicriteria decision making and decision theory (see e.g. [36,37,81]). There, the SD scale, or *unipolar bivariate model* [22,36], has been widely applied, and further developed into more complex scales. These scales are grouped together under a general (somewhat oversimplifying) category of *bipolar univariate models* (for some examples on *opposite-based* decision modeling see again [36], but also [31,78]).

Moreover, it can be stated that our internal decision making process is of a complex nature, implying previous differentiated knowledge acquisition and representation processes (see, e.g., [48,49]), quite often based upon multi-criteria arguments. In fact, the linear logic behind the SD scale does not allow representing the natural complexity we perceive from reality. Hence, once such a complexity is acknowledged, our mathematical modeling must continuously balance precision and simplicity, just as our brain looks for relevant but at the same time manageable information.

But whenever an objective measure for a concept is not available, it will be difficult to manipulate such a concept in an isolated manner. Most surely, immediately related concepts need to be taken into account. Generally speaking, understanding concepts by means of two *opposite concepts*, implies that we can capture the tension between both opposites. In some way, such simultaneous opposite views are unavoidable to start understanding the world, and indeed we need more complex knowledge representation structures to manage more than two views.

From our standpoint, most concepts cannot be properly understood in an isolated way. Addressing two different views seems to be the basic model to start with (although some concepts might need more than one surrounding concept in order to understand its limits). A number of quite similar fuzzy models focusing on the existence of two opposite concepts can be found in the literature, somehow offering a confusing view that we pretend to unify and explain within the unique umbrella of *paired fuzzy sets* and *paired structures*. We cannot understand certain concepts without understanding their opposite concepts. Pairs of predicates that will constitute paired concepts are, for example, *tall/short, fat/slim, big/small, cheap/expensive* or *good/bad* (see e.g. [63]).

The point of departure of this paper can be found in the above considerations, together with the bipolar approach proposed by Dubois and Prade in several papers (see [22–24]). Among other things, Dubois and Prade proposed a classification of bipolar models in three types of bipolarity that indeed shows similarities with our proposal below, but also essential differences: our approach, as it will be seen, follows from a constructive view of what we call *paired structures*, by focusing on how the semantic tension between two opposites generates certain *types of neutrality* (see [62] for a previous attempt). In this sense we emphasize the key role of certain neutralities in our knowledge representation models, as pointed out by Atanassov [4], Smarandache [70] and others. But notice that our notion of *neutrality* should not be confused with the *neutral* value in a traditional sense (see [22,–24,36,54], among others). Instead, we will stress the existence of different kinds of *neutrality* that emerge (in the sense of [11]) from the semantic relation between two opposite concepts (and notice also that we refer to a neutral category that does not entail linearity between opposites). Such a constructive view establishes an alternative to Dubois–Prade's approach, providing a distinction of those models based on opposites different from their types of bipolarity. Moreover, the term *paired concepts* we propose instead is not subject to be confused with the term bipolarity in the sense of a psychological disorder.

Therefore, our alternative for modeling basic knowledge representation is based on *paired concepts*, which will naturally lead to *paired structures*. A paired structure is defined by a pair of opposite concepts plus their associated neutralities and the relationships between these elements. Such a basic structure stands as a primary foundation from where further valuation scales and learning processes can be developed. As a consequence, it can be understood as a first stage for more complex and meaningful evaluation structures, where non-neutralities are allowed besides the original two opposites. This *paired* approach has already led to a specific model for preference representation (see [32]), a particular case whose general framework should be found in this paper.

Let us remark that this paper is not about formal logic or its interpretation. It rather deals with knowledge and natural language representation by means of logical tools.

In order to illustrate our position, this paper is organized as follows: in the next section we shall present a general example from where our discussion will evolve. Our proposal will be formalized in Section 3, restricted to our definition of opposite concepts. From this definition we shall formalize what we understand by *paired fuzzy sets* and *paired structures*. We shall expose the types of neutrality that rise from *paired fuzzy sets*, and that will produce different *paired structures*. Section 4 is devoted to compare our proposal with some related existing models. A discussion in Section 5 shows a standard procedure for building paired structures, and a final Section 6 is devoted to discuss some open key issues for future research.

2. Preliminary example: on the representation and measurement of size

Let us try to illustrate our view through a classical well-known example.

The meaning of the notion *size* of a person can be modeled in terms of predicates defining an evaluation scale. The structure of such a scale highly depends on how *size* is perceived, and particularly on whether it is viewed as a 1-dimensional or multi-dimensional characteristic. For example, in case *size* is understood as *size* = *height*, the verification of its occurrence can be evaluated within a linear scale. Let us examine more in detail this meaning of *size* = *height*.

Although we all know that *height* is measurable in the real line, we should realize that we usually do not try to measure the height of each person we meet with a value in the real line. Instead of saying "Paula's height looks around 1′90 m", most people will talk about Paula as a *tall* person, i.e., in terms of the *tallness* concept, which can be regarded as a fuzzy context-dependent concept [85]. Indeed, a person's *height* is usually judged in terms of the predicates *tall* and *short*, which constitute semantic references or landmarks for the evaluation of such a notion. We hardly use the notion of a person's *height* without the landmarks provided by the opposites *tall* and *short*, or any other equivalent pair of opposite predicates.

If our concept of *tallness* were crisp, the sentence "Paula is *tall*" would have a direct translation on the evaluation scale in terms of *height*: for example, "Paula is *tall*" if and only if "Paula's height is at least 1′70 m". As soon as we have this crisp definition, the concept of being *non-tall* is automatically created by the classical crisp negation: "Paula is *non-tall*" if and only if "Paula's height is less than 1′70 m". That is, *tallness* is associated with the interval $[1'70,\infty)$ meanwhile *non-tallness* is associated with the interval $(0,1'70)$. In order to generate such paired predicates (*tall* and *non-tall*), we simply need to assume the existence of the crisp negation: a person x within a community X belongs to the set of *tall* people if and only if the height $h(x)$ of such a person is greater than or equal to 1′70. And a person x within the community X belongs to