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On the Use of Probability in Artificial Intelligence

The Metaphysical Character of the Non-Adequacy Claim

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Carlotta Piscopo and Mauro Birattari

IRIDIA, CoDE, Université Libre de Bruxelles, Brussels, Belgium

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Abstract

The treatment of uncertainty is a key problem in artificial intelligence. Nowadays, the field is split in two schools: a mainstream that adopts probabilistic methods and an alternative school that advocates the use of other approaches.

In this paper, we argue that this split is due to the lack of a philosophical analysis of what we call the *non-adequacy claim*, which is the main argument currently used by the alternative school against the adoption of probability in artificial intelligence. We analyze the *non-adequacy claim* and we argue that it has a strong metaphysical character and, as such, it should not be accepted as a conclusive argument against the adequacy of probability.

1 Introduction

In a recent paper, Antony Eagle (2005) argues that the concept of randomness, as presented in the current philosophical literature, is misleading and that this can entail serious consequences due to the central role that randomness plays in many scientific disciplines.

In this paper, we discuss the implications that the lack of an adequate definition of randomness had in the development of artificial intelligence. From the late 60's till the late 80's, the artificial intelligence community engaged in a vigorous and at times vitriolic debate about the nature of uncertainty and about the methods for its treatment. A part of the community considered probability as perfectly adequate for dealing with uncertainty. Another part of the community insisted instead on the inadequacy of the probabilistic framework and devoted itself to the development of alternative approaches including, for example, fuzzy sets theory (Zadeh, 1965), possibility theory (Zadeh, 1978; Dubois and Prade, 1987), Dempster-Shafer theory (Shafer, 1976), and the transferable belief model (Smets and Kennes, 1994). For a broad overview on the debate, see Shafer and Pearl (1990). As a result of this debate, the artificial intelligence community is nowadays split in two schools that develop along distinct research directions. This appears clearly from the fact that a significant amount of research works dealing with alternative methods are published in journals or conference proceedings that are entirely devoted to them. The fact that the debate on uncertainty in artificial intelligence reached its climax about 20 years ago, and that, since then, only few articles have been devoted to this debate, does not mean that a satisfactory definition of uncertainty, and of the related concept of randomness, has been achieved. Indeed, the very existence of the two communities should be seen as an evidence of the fact that some key issue on which these two communities diverge has not been properly addressed. Our thesis is that the key issue is what we call here the *non-adequacy claim*.

All the criticisms raised against the adoption of probability in artificial intelligence have been discussed at length in the literature and have been eventually confuted, typically by highlighting some technical fault. A systematic discussion has been proposed in the mid-80's by Peter Cheeseman (1985).[1] An exception is the *non-adequacy claim*, which concerns the status of randomness that is assumed within the probabilistic framework. This claim has been proposed in different formulations and can be summarized as follows:

> *Probability theory is not suitable to handle uncertainty in artificial intelligence because it has been developed to deal with intrinsically stochastic phenomena, while in artificial intelligence uncertainty has an epistemic nature.*

Contrary to most of the other criticisms moved against the use of probability in artificial intelligence, the *non-adequacy claim* has a marked philosophical character. Possibly for this reason, the *non-adequacy claim* does not lend itself to the kind of analyses that are customarily proposed in the technical literature. As a consequence, this claim has been so far overlooked.

The separation of the artificial intelligence community in two schools is now perceived as highly problematic: In their first editorial on *Fuzzy Sets and Systems*, the most representative journal of the alternative school, the current editors stress that establishing a common ground with the mainstream is one of their priorities (Dubois and Prade, 1999). This appears unfeasible unless the *non-adequacy claim* is properly addressed. By taking a philosophical outlook on the *non-adequacy claim*, we show that it has a strong metaphysical character and that, as such, it should not be accepted as a conclusive argument against the adequacy of probability.

2 The *non-adequacy claim*

In order to justify the introduction of fuzzy sets theory and of the Dempster-Shafer theory, their respective proponents, Lotfi Zadeh and Glenn Shafer, advanced each a version of what we called the *non-adequacy claim*. Both versions stand upon a dichotomy: Zadeh and Shafer assume that uncertainty has two distinct natures, a stochastic and an epistemic one. Although a dichotomic view of uncertainty is not new since uncertainty has been interpreted for centuries as *either* stochastic or epistemic, the point made by Zadeh and Shafer contains an element of novelty. Indeed, they state that *both* a stochastic and an epistemic uncertainty exist. They argue that these two kinds of uncertainty are distinct and of different nature. In particular, Zadeh and Shafer agree that the epistemic uncertainty does not have a stochastic nature. They conclude that the two kinds of uncertainty need to be handled with two distinct approaches: stochastic uncertainty needs to be handled by a stochastic method and epistemic uncertainty by a deterministic one.

Zadeh and Shafer consider probability to be adequate to handle stochastic uncertainty, while they propose fuzzy sets theory and Dempster-Shafer theory, respectively, to handle epistemic uncertainty. According to them, whether one should adopt a probabilistic model or an alternative one in order to tackle a given problem depends on the nature of the problem itself: A problem is stochastic if the source of uncertainty can be traced back to an underlying physical random mechanism; conversely, a problem is epistemic, and therefore deterministic, if no underlying random mechanism can be spotted.

In this argument, we can isolate two main hypotheses. We name them *discrimination hypothesis* and *correspondence hypothesis*. On the one hand, the *discrimination hypothesis* assumes that it is possible to draw a sharp demarcation line between

[1] A more recent analysis has been proposed by C. Howson and P. Urbach (1993).

what is inherently stochastic and what is inherently deterministic. On the other hand, the *correspondence hypothesis* assumes that, in order to be adequate, a model has to match the inherent nature of the given problem.

Before proceeding to the analysis of the *non-adequacy claim*, let us briefly consider some passages of Zadeh's and Shafer's works in which this claim is advanced. Zadeh builds his analysis on the dichotomy *randomness/imprecision*. He argues that the *imprecision* that characterizes the natural language is not to be assimilated to randomness since it has an *intrinsically deterministic* nature. In his view, what differentiates imprecision from randomness is the fact that:

> *the source of imprecision is the absence of sharply defined criteria of class membership, rather than the presence of random variables*— (Zadeh, 1965, p. 339).

By adopting the term *presence*, Zadeh conveys the idea that a random variable is an entity that exists in Nature. If this entity can be spotted in the portion of reality we are observing, it is legitimate to adopt a probabilistic framework. Otherwise, fuzzy sets have to be employed.

An example can better clarify Zadeh's viewpoint. In the statement "John is tall", uncertainty comes from the fact that *tallness* is not sharply defined and is rather a *gradual* property (Bellman and Zadeh, 1970, p. 142). Zadeh handles the problem by reformulating the original statement as "John is a member of the class of tall people", and by introducing the concept of *degree of membership*: the higher the degree of membership of John into the class of tall people, the taller John is. On the contrary, in Zadeh's terminology, the statement "John will get married within a year" is *probabilistic* (Bellman and Zadeh, 1970, p. 142). Here, uncertainty stems solely from the fact that it is not known precisely when the event "marriage" will occur since this is somehow subject to chance. In this case, probability is the right apparatus.

Zadeh's justification of fuzzy sets theory stands entirely on the *discrimination* and on the *correspondence hypotheses*. Indeed, Zadeh takes for granted that we can always draw a sharp line of demarcation between different natures of uncertainty and consequently we can select the model that matches the case at hand. Coherently, he claims that fuzzy sets are the "natural way" (Zadeh, 1965, p. 339) for dealing with epistemic uncertainty since they are "completely nonstatistical in nature" (Zadeh, 1965, p. 340) as the problem they are intended to model.

Also Shafer's version of the *non-adequacy claim* stands on a dichotomy: the dichotomy *chance/belief*. Shafer introduces this dichotomy through an analysis of its historical evolution and argues that, for centuries, the concept of *belief* has been identified with that of *chance* and that these two concepts have been wrongly unified under the name of *probability* (Shafer, 1976, 1978). Shafer argues that this superposition is misleading, and that, while *chance* is an inherent property of a random experiment, *belief* is a personal opinion about the outcome of such an experiment. Since they do not necessarily coincide, it is a forcing fit to make beliefs "obey to all rules obeyed by chance" (Shafer, 1976, p. 9). Shafer claims that Bayesian probabilities are not adequate to deal with beliefs and he questions in particular the additivity axiom. He grounds his argumentation on the fact that this axiom entails that a belief on a hypothesis should be functionally related with the belief on its negation. This is criticized by Shafer who considers that evidence concerning an hypothesis does not necessarily extend to its negation.

The model proposed by Shafer goes under the name of Dempster-Shafer model (Shafer, 1976). It is an extension of the model developed in the 60's by Arthur Dempster (1967) but completely departs from the latter precisely in the fact that it does not postulate the third axiom of probability. Shafer does not provide any conclusive empirical evidence showing that modelling beliefs in probabilistic terms leads to contradictions. Instead, he grounds his rejection of the probabilistic approach on the philosophical argument that beliefs cannot be modelled as if they were chances since:

> *Chances* [...] *must be conceived as features of the world. They are not necessarily features of our knowledge or belief*—(Shafer, 1976, p. 16).

Shafer insists that handling beliefs as if they were chances is a contradiction in terms. Following this line of reasoning, he criticizes Laplace on his use of probability by saying that:

> *As a determinist he could not make philosophical sense of randomness*—(Shafer, 1976, p. 17).

The contradiction Shafer sees derives only from the assumption that a model is justified by its perfect correspondence to the nature of the object it refers to. Coherently with this assumption, adopting a probabilistic framework amounts to assume that randomness is an entity existing in Nature, which clearly could not be accepted by a determinist like Laplace.

We maintain that the reason why Zadeh and Shafer claim that probability is not adequate to treat epistemic uncertainty has to be searched in their interpretation of randomness. In the following, we show that their interpretation entails a metaphysical drift. Indeed, both the *demarcation* and the *correspondence hypotheses* have a marked metaphysical character.

Within the *demarcation hypothesis*, Zadeh and Shafer adopt a *naturalistic* interpretation of randomness. In their argumentation, the demarcation between stochastic and deterministic phenomena is presented as something that is in the nature of things: whether a phenomenon is stochastic or deterministic can be simply assessed by direct observation. In reality, such a natural demarcation cannot be drawn on the basis of empirical data. Indeed, empirical data is always finite and, on the basis of a finite sequence of observations, it is not possible to state in absolute terms whether an observed mechanism is stochastic or deterministic. At most, a *conventional demarcation* can be defined. In the literature, different conventional criteria have been proposed including a characterization of randomness in terms of complexity of the sequence of observations (Kolmogorov, 1963) and an operational definition of randomness based on a number of empirical tests (Martin-Löf, 1966; Marsaglia, 1995). It is in the nature of these criteria to provide conclusions that cannot be taken as absolutely certain. In this sense, the *demarcation hypothesis* is metaphysical.

As far as the *correspondence hypothesis* is concerned, it is to be observed that this hypothesis contradicts the scientific praxis. Indeed, the adoption of probability in clearly non-stochastic contexts is a standard scientific procedure. Consider, for instance, nonlinear deterministic systems that present a chaotic behavior.[2] Despite their deterministic nature, these systems are described and studied with tools such as Markov models and Monte Carlo methods, which were originally developed for stochastic processes. As an example, consider (pseudo-)random number generators commonly used in computer programming. Although these generators are perfectly deterministic, the sequences of numbers they produce pass a variety of tests of randomness and the fact that they look as random is indeed their *raison d'être*. If one had to adopt the *correspondence hypothesis*, these sequences of numbers, being intrinsically deterministic, could not be described in probabilistic terms and could not therefore serve their purpose of being used in computer programs as a source of randomness.

[2]It is worth to point out here that the issue we have raised above against the *demarcation hypothesis* is not relevant in this context. Indeed, we are concerned here with a mathematical system: the fact that it is deterministic can be stated on the basis of a formal analysis and does not need to be assessed empirically.

In some sense, the *correspondence hypothesis* is an *a priori* criterion for assessing the adequacy of a model: It is only the nature of the problem at hand that decides whether a model is adequate or not. This clearly contrasts with the widely accepted scientific practice that prescribes that models should be empirically validated and therefore accepted on the basis of an *a posteriori* criterion. The shift of the focus from an *a posteriori* criterion for the assessment of a model to an *a priori* one, definitely characterizes the *correspondence hypothesis* as metaphysical.

The metaphysical glow that pervades the whole *non-adequacy claim* is in our view what prevented Zadeh and Shafer from recognizing that the adoption of probabilistic models to deal with epistemic uncertainty stands simply on a *working hypothesis*: observations of a deterministic but (partially) unknown phenomenon can be seen *as if* they were produced stochastically. Though fictitious, this hypothesis finds its justification in the fact that it allows one to formulate predictions that are eventually empirically validated. Whether this working hypothesis should be adopted or rejected ultimately depends only on its usefulness in the specific application at hand and can be decided only on the basis of an empirical evaluation.

By pointing out the metaphysical character of the *non-adequacy claim*, we do not mean to exclude it *tout court*. Although we deem it an invalid argument against the use of probability, we do not exclude that this claim could have a *regulative* role and, for example, be used as a guideline for the development of new techniques for handling uncertainty. Nonetheless, these techniques will have to be evaluated for their ability to produce satisfactory predictions: Metaphysical elements should not play any role in their evaluation.

3 Conclusion

The tangible effect of the lack of a philosophical analysis of the *non-adequacy claim* is that the introduction of alternative methods has been mistaken by part of the artificial intelligence community for a "paradigm shift" (Blair, 1999). On the other hand, another part of the community kept working within the probabilistic approach, since they felt that no unsolvable anomaly had been actually highlighted in the probabilistic framework.

The problem is that nowadays an alternative framework exists, to which a considerable amount of theoretical and experimental work has been devoted. The situation is rather atypical: a 40-year old framework, which is considered by some as a new paradigm, co-exists with a well-founded 400-year old one. Notwithstanding many efforts to reconcile these two frameworks, they keep developing along distinct research directions.

In this paper, we argued that this situation should be ascribed to a metaphysical quarrel and, as such, it could be solved only by taking a philosophical perspective.

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