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Bayesian confusions surrounding simplicity and likelihood in perceptual organization

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ABSTRACT

In the study of perceptual organization, the Occamian simplicity principle (which promotes efficiency) and the Helmholtzian likelihood principle (which promotes veridicality) have been claimed to be equivalent. Proposed models of these principles may well yield similar outcomes (especially in everyday situations), but as argued here, claims that the principles are equivalent confused subjective probabilities (which are used in Bayesian models of the Occamian simplicity principle) and objective probabilities (which are needed in Bayesian models of the Helmholtzian likelihood principle). Furthermore, Occamian counterparts of Bayesian priors and conditionals have led to another confusion, which seems to have been triggered by a dual role of regularity in perception. This confusion is discussed by contrasting complete and incomplete Occamian approaches to perceptual organization.

1. Introduction

Bayes' rule (Bayes, 1763/1958) is a powerful mathematical tool to model all kinds of things in terms of probabilities. In this article, I discuss two separate sources of confusion related to Bayes' rule. One is the distinction between subjective and objective probabilities, and the other is the distinction between priors (or unconditionals) and conditionals (or likelihoods). I show that they have led to conflated lines of reasoning, and I show how unconflated lines of reasoning look like. I discuss these issues in the context of research on perceptual organization, which is the process by which the visual system structures incoming proximal stimuli into interpretations in terms of wholes and parts, that is, into hypotheses about the organization of the distal scenes. The issue of subjective versus objective probabilities is introduced in Section 2 and discussed in Section 3, and the issue of priors versus conditionals is introduced in Section 4 and discussed in Section 5.

2. Subjective versus objective probabilities

Imagine one wants to model the outcome of randomly selecting a letter in a randomly selected English text. To this end, one needs the objective (i.e., the actual, or the right) frequencies of occurrence of letters in English texts. For instance, in English, the most frequently occurring letter is E so that, objectively, E has the highest probability of being selected. Such objective probabilities also underlie the Morse Code and Shannon's (1948) classical information theory, for instance. Notice that these objective probabilities may not be suited to model the outcome of an experiment in which participants are asked to guess which letter is most likely to be selected. Participants invoke their own, subjective, ideas about frequencies of occurrence of letters and these may well disagree with the objective frequencies of occurrence. In other words, they use subjective probabilities, that is, probabilities which reflect a person's beliefs regarding the occurrence of things — irrespective of whether these beliefs are veridical (i.e., truthful).

By the same token, in perception research, one might test people to assess the probabilities that they give certain interpretations for certain proximal stimuli. This way, one might model the outcome of the human perceptual organization process in terms of the probabilities people assign subjectively to interpretations. Notice that these subjective probabilities primarily reflect how likely humans are to give certain interpretations, that is, they do not necessarily reflect how likely these interpretations are to agree with the actual distal scenes. To assess the latter, one would also need the actual frequencies of occurrence of distal scenes in the world. This distinction is crucial, for instance regarding amodal completion, that is, regarding the question of how the visual system deals with everyday scenes yielding proximal stimuli that may be interpreted as objects partly occluding themselves or others. After all, for such proximal stimuli, the

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visual system concludes to interpretations without knowing what the distal scenes actually comprise.

In many domains, including perception research, a problem is that the objective probabilities are unknown, if not unknowable. That is, despite suggestions (e.g., Brunswick, 1956), it seems impossible to establish objectively the frequencies of occurrence of distal scenes in the world. The point is that counting requires categorization and that any categorization of distal scenes is a subjective one (Hoffman, 1996). This fundamental problem may be exemplified by way of Bertrand's paradox (Bertrand, 1889). In Fig. 1, this paradox is illustrated for the question of what the probability is that a randomly picked outer-circle chord crosses the inner disk (see Fig. 1a). As illustrated in Fig. 1b,c, the chords can be categorized (or parameterized) in different ways — yielding different assessments of this probability. In this case, as well as in perceptual organization, one may have compelling arguments to choose a specific categorization, but the point is that it remains a subjective categorization which, therefore, yields subjective probabilities.

Hence, to be clear, by objective probabilities I mean probabilities reflecting the actual or right frequencies of occurrence of things in the world, and by subjective probabilities I mean any other choice of probabilities. For instance, however compelling they may be, not only probabilities based on intuition or on outcomes of perception experiments but also artificially designed probabilities (see next section) are subjective probabilities — simply because they do not necessarily agree with objective probabilities in the world.

Bayesian models, for instance, usually start from subjective probabilities. In some cases, this is simply because the very objective is to model subjective judgements, but in other cases, it is because the required objective probabilities are unknown. As said, also in perceptual organization, the objective probabilities are unknown. Yet, for the sake of the argument, let us assume that they can be established. I do not think this is possible, but as I discuss next, this assumption does underlie one of the principles that has been proposed to guide the perceptual organization process.

3. Perceptual organization

Perceptual organization is the process by which the visual system structures incoming proximal stimuli into interpretations in terms of wholes and parts. It is unclear exactly how it achieves this amazing feat, but a long-standing debate concerns the question of whether this process is guided by the Helmholtzian likelihood principle or by the Occamian simplicity principle (for an extensive review, see van der Helm, 2000).

The Helmholtzian likelihood principle, on the one hand, holds that, for a proximal stimulus, the visual system chooses the interpretation most likely to be true (von Helmholtz, 1909/1962). Feldman (2009), for instance, characterized this principle as follows:

> "*Choose the interpretation most likely to be true. The rationale behind this idea seems relatively self-evident, in that it is clearly desirable (say, from an evolutionary point of view) for an organism to achieve veridical percepts of the world.*" (p. 875)

Hence, models of this principle assume that the visual system has access to candidate interpretations as well as to their objective probabilities in the world.

The Occamian simplicity principle, on the other hand, holds that the visual system chooses the most simple interpretation, that is, the one that due to regularities can be defined by the least amount of information in terms of descriptive parameters. Hochberg and McAlister (1953) introduced this principle as follows (see also Attneave, 1954):

> "*The less the amount of information needed to define a given organization as compared to the other alternatives, the more likely that the figure will be so perceived.*" (p. 361)

To specify this further, they defined information loads (or complexities) by:

> "*The number of different items we must be given, in order to specify or reproduce a given pattern.*" (p. 361)

Hence, models of this principle need a formal coding language to describe and thereby categorize candidate interpretations, and a metric to quantify their complexities.

Notice that the Helmholtzian likelihood principle is about unconscious inference and holds that the visual system chooses the interpretation which objectively is most likely to be true, that is, not that it chooses the one which persons subjectively believe is most likely to be true. It is true that such subjective beliefs result from unconscious inference, but this is also what the Occamian simplicity principle implies, and the central question is which principle drives the unconscious inference leading to such subjective beliefs.

In this respect, the Helmholtzian likelihood principle is appealing because it suggests that the visual system is highly veridical in terms of the external world, and the Occamian simplicity principle is appealing because it suggests that the visual system is highly efficient in terms of internal resources. The debate between proponents of these two perceptual principles peaked in the 1980s (see, e.g., Boselie & Leeuwenberg's, 1986, reaction to Rock, 1983, and to Pomerantz & Kubovy, 1986; Sutherland's, 1988, reaction to Leeuwenberg & Boselie, 1988; Leeuwenberg, van der Helm, & van Lier's, 1994, reaction to Biederman, 1987). Later, Chater (1996) refueled the debate with an intriguing stance: he argued that the whole debate was misguided because, as he claimed, the two principles are formally equivalent. Though his proof of this claim has been refuted (van der Helm, 2000), this claim did find followers. Therefore, in the next subsections, I discuss this claim from a different and less technical angle. That is, I argue that it confused Bayesian approaches using subjective probabilities and Bayesian approaches using objective probabilities. To set the stage, I first give an overview of several issues and developments relevant to the simplicity versus likelihood debate in perception.

3.1. Simplicity versus likelihood

Most people will agree that some degree of veridicality is a prerequisite of the human perceptual organization process, simply because it has to guide us through the world. This does not mean that

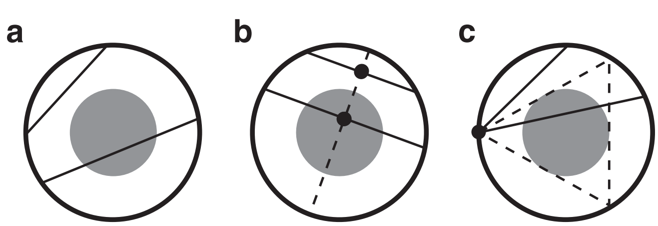

Fig. 1. Bertrand's paradox for chords (straight lines between two points on a circle). (a) Question: if the radius of the inner disk is half the radius of the outer circle, then what is the probability that a randomly picked outer-circle chord crosses the inner disk? (b) Answer 1: if chords orthogonal to a specific outer-circle diameter are taken to form a category then, within every category, half the chords cross the inner disk, so, picking such a chord has a probability of 0.50. (c) Answer 2: if chords starting at a specific outer-circle point are taken to form a category then, within every category, one-third of the chords cross the inner disk, so, picking such a chord has a probability of 0.33. Hence, the probability depends on how the chords are categorized.