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Consiglio Nazionale delle Ricerche
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ISTITUTO DI ELABORAZIONE
DELLA INFORMAZIONE

Pisa
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Titolo

**Aquisition of beliefs through
perception**

Daniela Musto and Kurt Konolige

Nota Interna B4-02

Gennaio 1992

Abstract

In this paper we present some current results of our ongoing project on the integration of perception and symbolic reasoning. The focus of the paper is on the formalization of perception and belief. We outline the basics of a formal theory of belief that is sensitive to the way in which beliefs are formed through perception. The process of formation of beliefs involves a form of inference that is defeasible. We represent this kind of inference by means of well-known techniques of non-monotonic reasoning. In addition, we provide an account of perception that is consistent with our intuition for how perception functions, i.e., causality.

1 Introduction

Intelligent agents acquire information about their environment by sensing the world around, and interpreting the sensory input to form beliefs about the environment. This interpretation process is called perception. Other forms of belief acquisition, like inductive generalization or communication with other agents, provide indirect ways of becoming aware of the surrounding environment. While there has been a great deal of work in AI on communication and belief, and on induction, learning, and belief revision, relatively little attention has been paid to the problem of describing the effects of sensing on beliefs. This is not because the problem is simple and has an obvious solution; on the contrary, the nature of perceiving is intrinsically complex, as it is testified by the iterated attempts of philosophers and cognitive scientists to provide a coherent and complete account. In particular, explaining how it is possible to acquire information about the physical world on the basis of sensing, that is, explaining the nature of the connection between the *appearance* of an object or situation and its *reality*, has long been a puzzling problem for any theory of perceiving.

The theory proposed by [Pollock 74] provides at least a partial solution to the problem of perception, and we draw from it. According to such a theory, perceiving that something is the case gives us a *logical*¹ presumption for assuming that what is perceived is really occurring in the physical world. Such a logical presumption leads us to acquire a belief, provided that we do not contemporarily hold additional information that constitutes a defeater for the logical presumption (see Section 2). Therefore perception is seen as a particular kind of defeasible inference.

¹The term *logical* is used as opposed to *contingent*.

This paper describes our attempt to formalize such a theory of perceiving within a theory of belief, and to integrate the formal account so derived with the commonsense intuition for how perception works, that is, with the causal nature of perception [Cox 85]. The focus of the paper is therefore on *normative* questions about what are the aspects of our perceptual experience that justify us in believing. At the same time, the present discussion provides a *descriptive* account of those aspects of our experience that make perception a source of evidence about the external world.

2 Modeling perception

The following example illustrates the crucial aspect of perceiving that must be taken into account by any formal account of perception and belief. Suppose that an agent S sees that a statue is red. Then, simply on the basis of the sensor information he acquires, S might come to have the belief that the statue actually is red. This, in practice, occurs whenever S does not hold any additional belief concerning the color of the statue and/or the condition of his observation. However, if S has also the information that, for example, there is a red light on the statue, then even though the statue appears red to him, he may be unwilling to believe that this is the case, knowing that a white statue would still appear red under a red light.

Therefore perceiving gives to the agent a *prima facie reason* [Pollock 74] for believing the content of its perception. However, because beliefs are not acquired in isolation, the agent holds the content of perception as a belief only if he does not believe something else that may constitute a *defeater* for the *prima facie* reason represented by perception. In particular, the agent may recognize the presence of such a defeater on the basis of its being aware of the relevant causal connections between perception and belief and of the beliefs he currently holds when he is perceiving (see Section 3).

This character of the perceptual process is summarized by the following principle:

Default Perceptual Rule *I normally believe in the content of my perceptions, unless I have reason to believe that there is something causing an abnormality in the perceptual process.*

The full formalization of this principle would involve understanding and representing the nature of causation, and in our preliminary work we have not attempted to do this. Rather, we have left causation as an informal

concept, and given a simple translation into a nonmonotonic logic of belief, autoepistemic logic [Moore 87].

3 A formal theory of perception and belief

A *perceptual attribute* is any property of a physical object or event which presence or absence can be detected directly by sensing. Examples of perceptual attributes are *spatial* attributes, like shape, size and location, and *non spatial* attributes, like color, temperature, texture, taste and weight. Attributes like "flammable" or "bachelor", whose presence or absence cannot be judged simply by sensing, cannot be included in the set of perceptual attributes.

Let us denote by α any statement concerning a perceptual attribute. In particular, α can be any *existential statement*, like "there is a blue fish" or any *attributive statement*, like "the fish is blue". And let us denote by $P\alpha$ the fact that the agent is perceiving α . Then by using epistemic concepts for representing defaults [Konolige 87, Konolige and Myers 89], the default perceptual rule of Section 2 can be expressed by the following logical statement:

$$P\alpha \wedge \neg def_{P\alpha \supset \alpha} \supset \alpha \quad (1)$$

where $def_{P\alpha \supset \alpha}$ represents the existence of defeaters for the implication $P\alpha \supset \alpha$.

Let ϕ_α denote the presence of abnormal conditions in perceiving that α . Note that an abnormal condition may be either *personal*, i.e. a fact about the agent (like "I'm wearing rose-colored glasses") or *unpersonal*, i.e. a fact about the specific object or event perceived or about the general circumstances (like "The statue is illuminated by a red light"). Assume that the agent is aware of the normal causation rule concerning the perception that α (see (2) below), and, possibly, of the existence of a specific corresponding abnormal condition (say, $\theta_{\alpha,i}$). Then the agent is aware of the following causal rules [Konolige 91]:

$$\alpha \wedge \neg \phi_\alpha \rightarrow P\alpha \quad (2)$$

$$\theta_{\alpha,i} \rightarrow \phi_\alpha \quad (3)$$

Here the arrow represents a causal statement, so the first expression could be read as " α , in the absence of defeaters for α , causes the perception of α ."

Such causal rules can be mapped into ordinary material implications, as follows (for brevity, we omit the proof):

1. Each abnormal condition rule $\theta_{\alpha,i} \rightarrow \phi_{\alpha}$ corresponds to the implication $\theta_{\alpha,i} \supset \phi_{\alpha}$
2. the normal causation rule $\alpha \wedge \neg\phi_{\alpha} \rightarrow P\alpha$ corresponds to the following set of implications:
 - (a) $P\alpha \wedge \neg def_{P\alpha \supset \alpha} \supset \alpha$
 - (b) $\neg\alpha \supset def_{P\alpha \supset \alpha}$
 - (c) $\phi_{\alpha} \supset def_{P\alpha \supset \alpha}$

The previous rules show that there are essentially two kinds of defeaters for the implication $P\alpha \supset \alpha$: the belief that $\neg\alpha$, and the belief that there are abnormal conditions in perceiving α (i.e., ϕ_{α}). The first is a *type I* defeater (in fact, it directly contradicts the conclusion of the statement (1)), whereas the second is a *type II* defeater, because it represents a reason for believing that $\neg(P\alpha \supset \alpha)$ without directly contradicting the conclusion α [Pollock 74].

Finally, we need the assumption that in the absence of other information, the normal conditions of perception hold and that no defeaters arise. We can express this in autoepistemic logic by:

$$\neg L\phi_{\alpha} \supset \neg\phi_{\alpha} \quad (4)$$

$$\neg Ldef_{P\alpha \supset \alpha} \supset \neg def_{P\alpha \supset \alpha} \quad (5)$$

To summarize, a logical theory modeling the acquisition of the belief that α by perceiving that α is defined by the following axioms:

1. $P\alpha \wedge \neg def_{P\alpha \supset \alpha} \supset \alpha$
2. $\neg Ldef_{P\alpha \supset \alpha} \supset \neg def_{P\alpha \supset \alpha}$
3. $\neg\alpha \supset def_{P\alpha \supset \alpha}$
4. $\phi_{\alpha} \supset def_{P\alpha \supset \alpha}$
5. $\neg L\phi_{\alpha} \supset \neg\phi_{\alpha}$
6. $\theta_{\alpha,1} \supset \phi_{\alpha}$
7. ...
8. $\theta_{\alpha,n} \supset \phi_{\alpha}$

4 Conflicts

There is always the possibility that different sources of information will be in conflict, e.g., memory and perception; or even that the perceptual process itself will give rise to information that tends to be contradictory. We have formulated the following sets of formal defeat rules to implement the default perceptual rule given in the second section.

- (a) There is a default assumption that $\neg\alpha$, while we perceive α . For example, the agent holds the statement $\neg L\alpha \supset \neg\alpha$ (e.g., "normally the fishes are not blue"). In this case, differently from the case in which $\neg\alpha$ is a categorical belief (i.e., it is an incorrigible justified belief instead of a prima facie justified one), the default assumption that $\neg\alpha$ is not a sufficient reason to deny the acquisition of α by (1)²
- (b) There is a default assumption that β , where β asserts an abnormal condition for observing that α , at the same time that we perceive α . Suppose, for example, that the agent holds a statement like $\neg L\neg\beta \supset \beta$ (e.g., "normally the light is blue"), together with the following causal rule: $\beta \rightarrow \phi_\alpha$. In this case, even if β is only a default assumption, it becomes a reason to deny the acquisition of α by (1) (in particular, β represents a type II defeater for (1)).³
- (c) As in the case (b), β is a default assumption that asserts an abnormal condition for observing that α at the same time that we perceive α , but in this case β is generated by a current perception (that is, $P\beta$ holds). In this case, $P\beta$ becomes a reason to deny the acquisition of α by (1) (the opposite, clearly, is not true, that is $P\alpha$ cannot be a reason to deny the acquisition of β , because of the content of the causal rules).

These rules take care of the key cases in which defaults will conflict and the causal structure of the perceptual process can be used to adjudicate them.

²Note that this property holds also in the case in which α asserts the presence of an abnormal condition for perceiving some other property (e.g., α is the sentence "there is a blue filter"). Thus perceiving a blue filter dominates the default assumption that normally there are not blue filters, as well as perceiving that there is no blue filter dominates the default assumption that normally there are blue filters.

³Note that it is immediately obvious that β is a type II defeater for (1) only when β is a categorical belief.

5 Concluding Remarks

This paper represents an attempt to develop a formal theory of belief that is sensitive to the way in which beliefs are formed through perception. The formalization uses the autoepistemic logic of [Moore 87] to represent the causal and default connections between belief and perception. The framework we have presented models a rational perceiving agent that, under the appropriate conditions, augments his beliefs on the basis of his perceptions. However, we have not considered the problem of revising already-held beliefs on the basis of perceptions; we are currently investigating the extension of this approach to include belief revision.

References

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