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Perception, memory, and imagination as propositional attitudes

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Abstract: Jaakko Hintikka started in 1969 the study of the logic of perception as a special case of his more general approach to propositional attitudes by means of the possible worlds semantics. His students and co-workers extended this study to the logic of memory and imagination. The key elements of this approach are the distinction between physical and perspectival cross-identification and the related two kinds of quantifiers, which allow a formulation of the syntax and semantics of various types of statements about perceiving, remembering and imagining. This paper surveys the main results of these logical investigations.

Keywords: Hintikka, cross-identification, epistemic logic, imagination, memory, perception, possible worlds semantics, propositional attitudes

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1. Introduction

After discovering model sets in 1955 and (simultaneously with Stig Kanger) the possible worlds semantics in 1957, Jaakko Hintikka published his pioneering work *Knowledge and Belief* in 1962. This study formulated, by using the framework of model sets (as partial descriptions of possible worlds), the fundamental ideas of epistemic and doxastic logic. In *Models for Modalities* (1969) Hintikka then generalized his approach from knowledge and belief to a general theory of propositional attitudes (see also [Hintikka, 1980]). This book includes an article "On the Logic of Perception" [Hintikka, 1969], where Hintikka proposes to analyze perceptual statements (with seeing, hearing, and feeling) within modal logic in a similar way as knowing and believing. This paper used as its tool the distinction between two ways of cross-identifying individuals in alternative possible worlds. In a subsequent article "Information, Causality, and the Logic

of Perception" [Hintikka, 1975a] Hintikka incorporated causal aspects to his logic of perception.

The logic of perception is an important part of Hintikka's legacy within intensional logic. It became an actively studied field in the 1970s and 1980s, with contributions (among others) by Robert Howell [Howell, 1972], Richmond Thomason [Thomason, 1973], John Bacon [Bacon, 1979], Jon Barwise [Barwise, 1981] and James Higginbotham [Higginbotham, 1983] — and from Finland Ilkka Niiniluoto [Niiniluoto, 1979; Niiniluoto, 1982] and Esa Saarinen [Saarinen, 1983]. But it is fair to say that, while epistemic and doxastic logics have become more and more popular within philosophical logic and artificial intelligence (see e.g. Hintikka [Hintikka, 2013] and the important collection edited by van Ditmarsch and Sandu [van Ditmarsch, Sandu, 2018]), the logic of perception has received relatively little attention (see, however, Rantala [Rantala, 2007] and Bourget [Bourget, 2017]). Apart from some scattered examples by Hintikka, the article by Aho and Niiniluoto [Aho, Niiniluoto, 1990] has remained the only systematic investigation of the logic of memory. On the other hand, the logic of imagination, introduced by Niiniluoto [Niiniluoto, 1983; Niiniluoto, 1985a; Niiniluoto, 1985b] along Hintikka's lines (see also [Aho, 1994]), has experienced a recent renaissance with several new contributions (see [Costa-Leite, 2010; Wansing, 2017; Berto, 2017]).

2. Hintikka on Propositional Attitudes

Let a be a person or agent (a proper name in language) and p a proposition (a factual statement in language). Then examples of *propositional attitudes*, which are relations between a and p, include

$$\begin{aligned} K_a p &= a \text{ knows that } p \\ B_a p &= a \text{ believes that } p \\ S_a p &= a \text{ sees that } p \\ R_a p &= a \text{ remembers that } p \\ I_a p &= a \text{ imagines that } p. \end{aligned}$$

According to Hintikka, a general truth condition for an attitude $\varnothing$ can be formulated as follows:

> Sentence 'a $\varnothing$s that p' is true in world w if and only if p is true in all possible worlds which are compatible with what a $\varnothing$s in world w.

Similarly,

> Sentence 'a $\varnothing$s that p' is false in world w if and only p is false in some possible world which is compatible with that a $\varnothing$s in world w.

Here the condition

w' is compatible with what a $\varnothing$s in w

defines an alternativeness relation for $\varnothing$ in the sense of possible worlds semantics. Thus, 'a $\varnothing$s that p' is true in w if and only if p is true in all $\varnothing$-alternatives of w.

Immediate consequences of the truth condition for any attitude $\varnothing$ include

($\varnothing 1$) $\varnothing_a(A \to B) \to (\varnothing_a A \to \varnothing_a B)$

($\varnothing 2$) $\varnothing_a(A \& B) \equiv (\varnothing_a A \,\&\, \varnothing_a B)$

($\varnothing 3$) $\varnothing_a T$, if T is a tautology

($\varnothing 4$) $\varnothing_a A \to \varnothing_a(A \vee B)$.

When $\varnothing$ is replaced by K, B, S, R, or I, we obtain basic principles for these specific propositional attitudes. Besides these principles[Hintikka, 1962] argued that knowledge K (unlike belief B) satisfies the success condition

($K5$) $K_a A \to A$

and the KK-principle

($K6$) $K_a K_a A \equiv K_a A$.

Hintikka's truth definition for propositional attitudes leads to a problem which is called *logical omniscience* in epistemic logic: an agent knows all tautologies and all logical consequences of her knowledge. This is unrealistic, if knowledge is understood as an actual mental state of a person. Similar problems arise for "logical omniperception" (in watching an ice hockey match, do I see that Lionel Messi is playing or Lionel Messi is not playing?) or "logical omnimemory" (do I remember all logical and mathematical truths as Plato's slave boy in *Meno*?). One solution is to accept that we in fact know and see tautologies: when $S_a p$ means that according to the perceptions of a it is the case that p, then trivially a tautology T is true in the actual world and all of its S-alternatives. But there are also many other more technical solutions to logical omniscience. Hintikka himself proposed in 1975 the use of "impossible worlds", which were developed as "urn models" by Veikko Rantala [Rantala, 1982]. If one allows non-normal possible worlds, where ordinary laws of logic are not satisfied, then propositional attitudes do not satisfy closure conditions for logical

consequence. This proposal has been recently applied in the logic of imagination as "hyperintensionality" (see [Berto, 2017]). Hintikka also argued that one can use "small worlds", which need not include all possible individuals (like Lionel Messi), and the same restriction can be obtained by Barwise's "situations" [Barwise, 1981]. Fagin and Halpern proposed an "awareness logic" [Fagin, Halpern, 1985], where explicit knowledge concerns only such propositions about which the agent is aware, but this is a very strong restriction, since actual awareness need not satisfy even the closure condition for conjunctions (cf. ($\varnothing 2$)).

3. The Logic of Perception

Hintikka's proposal to treat *perception* as a propositional attitude ([Hintikka, 1969]) was inspired by Elizabeth Anscombe's thesis about the intensionality of perceptual ascriptions. It is also related to Edmund Husserl's phenomenological approach to intentionality as directness. At the same time this choice reflects Hintikka's "neo-Kantian" conviction that perception is thoroughly conceptual, always mediated by conceptual schemes. He even blames Husserl for assuming that in our sensuous experience there exists a non-conceptual ingredient or *hyle*, which is changed into an experience about an object by the act of *noesis* (see [Hintikka, 1975b, p. 198]). By the same argument, Hintikka would reject the idea of non-conceptual content in experience (see e.g. [Crane, 1992]). Perception differs from imagination by the fact that it involves causal interaction with external objects. With reference to the psychologist James Gibson's view of senses as information systems, Hintikka characterizes perception as a method of reaching information about the world.

The logic of perception can be understood as an attempt to develop an explicit semantics for sentences containing perceptual terms [Niiniluoto, 1982]. But the truth conditions of perceptual sentences provide also a formal syntax which exhibits the systematic interconnections between different grammatical constructions with perceptual terms. Just like epistemic logic shows how expressions like 'know who', 'know where', 'know when' etc. can be reduced to propositional 'know that'(see [Hintikka, 1962]), the logic of perception shows that 'seeing that' is the basic form of perceptual statements. In particular, the propositionality of perception is reflected in the result that all direct object *de re* constructions (about things or events) are reduced to sentences with seeing that. And, by the intensionality of perception, the truth conditions for statements of the form $S_a p$ have to refer to several alternative possible worlds of states of affairs at the same time.

Perception is usually understood as a species of knowledge, even though errors of observation are common (illusions, hallucinations). Evolutionary arguments suggest that human perception is relatively reliable in ordinary cir-

cumstances. Some early attempts to develop logics of perception imitated epistemic logic. For example, Richmond Thomason [Thomason, 1973] assumed that seeing satisfies the success condition

$(S5)$ $S_aA \to A$

and John Bacon [Bacon, 1979] suggested an SS-principle

$(S6)$ $S_aS_aA \equiv S_aA$

But Hintikka realized that it is better to start from a weaker interpretation, where S_ap means something like 'it appears to a that p', 'it looks to a that p' or 'a seems to see that p'. In this sense, the S-operator does not satisfy the success condition $S5$, so that it belongs to the same group of propositional attitudes as belief. A stronger notion of veridical seeing ${}^*S$, which satisfies the success principle ${}^*S_ap \longrightarrow p$, can be obtained from the weaker S by adding conditions which are sufficient to guarantee the truth of the perceived p. It is also interesting to investigate the interplay of the operators K and S [Hintikka, 1975a; Niiniluoto, 1979].

Similar remarks apply the notion of *memory* [Aho, Niiniluoto, 1990]. As a propositional attitude, memory is more complex than perception, since 'a remembers that p' allows for many temporal alternatives, where p may be an eternal, past tense, present tense, or future tense sentence. For example, 'I remember that $5 + 6 = 11$', 'I remember that Jaakko was lecturing on information in 1967', 'I remember that today is my daughter's birthday', and 'I remember that tomorrow is my wife's birthday'. Again memory is relatively reliable, but mistakes are common. So in the logic of memory one should start from a weak interpretation of R, which does not satisfy the success principle

$(R5)$ $R_aA \to A$,

but a strong notion of remembering ${}^*R$ can be obtained by adding conditions so that ${}^*R_aA \to A$ is satisfied. At least for the strong notion we have the principle that ${}^*R_ap$ at t implies $(Et' < t)S_ap$ at t', i.e. reliable memories are based on earlier perceptions. Instead of the RR-thesis $(R6)$ it is plausible to assume that $K_aR_aA \equiv R_aA$.

For *imagination*, which a mental faculty of creating fictional worlds, it is even more straightforward to observe that the principle $I_aA \to A$ is not valid [Niiniluoto, 1983; Niiniluoto, 1985a]. Still, it would be too strong to assume an anti-success principle $I_aA \to \neg A$, since our imagination may be accidentally true. It can be debated whether it is possible to imagine physically impossible or logically contradictory states of affairs (see [Niiniluoto,

1985b; Costa-Leite, 2010; Berto, 2017]). Berto, whose dialetheism accepts the conceivability of real contradictions, gives an affirmative answer to this question. In order to emphasize imagination as an activity, Wansing analyses imagination by combining a neighbourhood semantics with a modal logic of agency [Wansing, 2017].

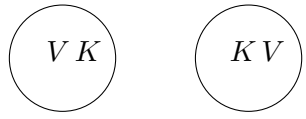
4. Quantifiers and Propositional Attitudes

The expressive force of Hintikka's treatment of propositional attitudes is seen only when we move from propositional logic to a framework with existential and universal quantifiers. This requires a solution to the problem of quantifying into an intensional context, i.e. a method of identifying the same individual in different possible worlds. In Hintikka's approach, identified individuals constitute *world lines*, which as intensional entities serve as interpretations of quantified variables (cf. [Tulenheimo, 2017]). The *cross-identification* of individuals can be achieved by two different method: *physical* (descriptive) world lines rely on physical properties of individuals, such as their permanent public attributes and spatio-temporal continuity, while *perspectival* world lines depend on the role of individuals in the agent's perspective. In the case of perception, the perspectival method identifies those individuals who play the same role in the visual field of the percipient (cf. [Rantala, 2007]). These two methods of cross-identification are correlated with two different quantifiers: the physical existence quantifier is denoted by (Ex) and the perspectival by $(\exists x)$. Then the truth conditions for quantified sentences with the S-operator can be formulated as follows:

1. $(Ex)S_aA(x)$ is true at world w if and only if there is a physical world line f which picks out an individual in each S-alternative w' of w such that $f(w')$ satisfies $A(x)$ at w';

2. $(\exists x)S_aA(x)$ is true at world w if and only if there is a perspectival world line f which picks out an individual in each S-alternative w' of w such that $f(w')$ satisfies $A(x)$ at w'.

For example, assume that I meet on the road two familiar brothers, Ville and Kalle, but I am not able to recognize who is who of them. The worlds compatible with by perception are two:



Then the perspectival world line picks out the brother on the left side, i.e. V and K, while the physical word line identifies Kalle (resp. Ville) in the two alternative worlds.

According to the causal theory of perception, sense experience is normally caused by external objects and events in the real world. Hintikka (see [Hintikka, 1975a]) complemented his logic of perception by requiring that perspectival world lines are extended to the actual world by means of a *causal* connection. For example, the line connecting the brother on the left is continued to the individual who in the actual world has caused the observation. Memory involves typically two causal processes: first learning that p by perception and then maintaining this memory content in the mind over time. Due to their temporal dimension, the world lines for memory are more complex, since they may pick out temporally extended individuals from possible world histories (see [Aho, Niiniluoto, 1990]).

With this machinery, we can formalize a variety of different epistemic and perceptual statements (see [Niiniluoto, 1982]). Examples of sentences with a direct reference to the object of perception include the following:

$(\exists x)K_a(x = b)$	a knows b
$(\exists x)S_a(x = b)$	a sees b
$(\exists x)(x = b \,\&\, S_a(\exists x)(y = x))$	a looks at b

The sentence 'a sees b' is intensional in the sense that the object b may be misidentified or a mere illusion. But instead 'a looks at b' implies that $(\exists x)(x = b)$, i.e. b exists. The construction of seeing as, which was important to Ludwig Wittgenstein, has a natural formalization (see [Howell, 1972]):

$(\exists x)(x = b \,\&\, S_a(x = c))$	a sees b as c
$(\exists x)(x = b \,\&\, S_aFx)$	a sees b as an F

Additional examples with a physical quantifier include

$(Ex)K_a(x = b)$	knows who b is
$(Ex)S_a(x = b)$	a sees who b is

Besides perceiving things and states of affair, one may speak about perceiving events, when we allow quantifiers to range over events (or world-line connecting events in alternative possible worlds). For example, we may distinguish between

S_a(Esa runs)	a sees that Esa runs
$(\exists e)(e =$ Esa's running $\& S_a(\exists x)(x = e))$	a sees Esa run

(see [Niiniluoto, 1982]). The former sentence is intensional, so that I can be mistaken by the observed person or his activity. The latter sentence 'I see Esa run' is known in English as "naked infinitive". Jon Barwise (see [Barwise, 1981]) proposed in his situation semantics that the sentence 'I see Esa run' is true, if there is a situation which I see and which supports the truth of the sentence 'Esa runs'. Seeing a situation is a purely extensional relation for Barwise. Thus, such extensional perceptual statements are associated with a success condition: if I see Esa run, then Esa runs. This holds also of the Hintikka style formalization, which implies that $(\exists e)(e = \text{Esa's run})$. In the same way, the statement 'I see the birch tree blowing in the wind' can be formalized by the formula

$$(\exists e)(e = \text{the tree is blowing in the wind } \& S_a(\exists x)(x = e)).$$

Here Barwise's extensional success condition is satisfied, but the problem of his situation semantics is its inability to treat the intensionality of perception (cf. [Saarinen, 1983; Higginbotham, 1983; Niiniluoto, 1985a; Niiniluoto, 1985b]).

In Hintikka's formalism, one may distinguish the epistemologically important cases ([Niiniluoto, 1979]):

$(\exists x)(x = b \,\&\, Fx \,\&\, S_aFx)$	veridical perception
$(\exists x)(\sim Fx \,\&\, S_aFx)$	visual illusion
$(\exists x)(S_aFx) \,\&\, \sim (\exists x)((Ey)(y = x) \,\&\, S_aFx)$	visual hallucination

As an example of hallucination, in the morning after a heavy party I may see a pink elephant on the wall (F), but the associated perspectival world line cannot be extended to the actual world. The sentence

$$(\exists x)(S_aFx \,\&\, K_a \sim Fx)$$

expresses a conscious illusion: it seems to me that the oar is bent in the water, even though I know that this is not really the case. Hence, illusions need not always be mistaken beliefs, as many theories of perception claim.

By combining perceptual and epistemic operators further interesting cases are obtained (see [Niiniluoto, 1979]):

$(\exists x)(x = b \,\&\, S_a(\exists y)(y = x) \,\&\, B_a(x = c))$	a visually holds b as c
$(\exists x)(x = b \,\&\, S_a(\exists y)(y = x) \,\&\, K_a(\exists y)(y = x))$	a notices b
$(\exists x)(S_a(\exists y)(y = x) \,\&\, K_a(x = b))$	a recognizes b

For similar reasons perception may fail in many ways: don't look at, don't see, don't notice, don't recognize.

Corresponding formulations for memory (e.g. 'I remember you', 'I remember Jaakko lecturing', 'I am reminiscing about her', 'I remember who this girl

is') and imagination (e.g. 'I am imagining about my friend', 'I imagine her as Anna Karenina', 'I imagine that Esa is running') can be given by the two kinds of quantifiers combined with the operators R_a and I_a (see [Aho, Niiniluoto, 1990; Niiniluoto, 1985b]). It is also easy to formulate sentences for remembering when, where, what, and who. But a complete formalization of memory statements should be combined with temporal logic: the statement 'I remember Esa as a young student' is directed to a person living now, but 'Jaakko remembers Gödel' should not entail that Gödel exists now.

An interesting special feature of memory and imagination is self-identification. Memories of past event are personal in the sense that the agent has to be able to place himself or herself in the remembered scene. If I remember that Jaakko was lecturing in 1967, I have to identify myself as a person in the audience. David Lewis (see [Lewis, 1979]) has called such epistemic abilities *de se* attitudes. More generally, contexts involving *de se* attitudes may involve interplay of physical and perspectival identification.

5. Concluding Remarks

The logic of perception is mainly interesting for epistemology and philosophy of language, but it may have potential applications with the psychology of perception and cognitive neuroscience. Hintikka himself was excited by the fact that his philosophical distinction between the physical and perspectival methods of cross-identification has a counterpart within neuroscience: the what- and where-systems of visual perception [Vaina, 1990] and the semantic and episodic memory [Tulving, 1972] (see [Hintikka, 1990; Hintikka, Symons, 2003]). But while the neuroscientists have postulated two different kinds of visual perception or memory, Hintikka's system is more economical, as it assumes only one perceptual operator (seeing that) or memory operator (remembering that).

Given the strong emphasis on the concept-laden nature of perception and memory, one may ask whether the Hintikka-type of approach is applicable to animals and children before they have learnt a symbolic language. One possibility is that the logic of perception is a third-person analysis of perceptual processes independently whether the agent has linguistic abilities. But Hintikka's own discussion seems to assume that the framework describes perceptual experiences of actual subjects. Then one might surmise that the physical cross-identification is not yet successful for a creature on the pre-linguistic level, as this presupposes mastery of temporal and spatial concepts and the objective distinction between "you" and "me". Perspectival cross-identification is simpler, as it allows a dog to "know" its master or a child to "know" her mother. The formula 'a looks at b' presupposes only that a is able to see b as an existing object separate from its environment, which is possible already in the pre-conceptual

level of consciousness. But here it is somewhat perplexing that Tulving argues that animals possess the semantic memory but lack the episodic memory (see [Tulving, 1972]). Perhaps such animal abilities should be formalized by statements involving remember-how in analogy with know-how.

Similar question arise, if the logic of perception and the logic of memory are applied to theories and practices of artificial intelligence, such as pattern recognition and machine learning. There the human agent is replaced by a robot or a self-regulating computer program, which does not have intentional mentality or *de se* attitudes. Still, such machines can be taught to be in causal interaction with their environment, to store perceptual data and to use them in recognition and inference.

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