# An open problem in the logic of Knowing how.

## 1. Introduction

Since the publication of Hintikka's epoch making book *Knowledge and Belief. An Introduction to the logic of the Two Notion*s (Hintikka 1962, 2005), intensive research has been devoted to the formalization of "knowing that". The construction "knowing how" set off against "knowing that" by Ryle in *The Concept of Mind* (Ryle 1949) has not aroused the same interest. Yet it raises interesting philosophical issues of their own which deserve a careful scrutiny.

The study of "knowing that" has been a *shared concern* of philosophers, logicians, computer scientists and AI researchers. Inquiries into "knowing how", on the contrary have been conducted *independently* by philosophers and A.I. people and no attempt has been made, to my knowledge, to bring together these two approaches.

Ryle, to whom we owe the distinction between knowing how and knowing that, writes that "(t)here are certain parallelisms between knowing how and knowing that, as well as certain divergences (Ryle 1949, 29)". He takes however the distinction to be irreducible. His position has met with general but not unanimous agreement. In a recent paper, Jason Stanley and Timothy Williamson contest Ryle's irreducibility thesis and argue that knowledge how is simply a species of knowledge that (Stanley and Williamson 2001). They substantiate their claim by linguistic data obtained by a close scrutiny of the natural language construction "knowing how".

A third option is possible: one might claim that *some*, but not *all*, sorts of knowing how are reducible to knowing that. This third option was defended by Hintikka who distinguishes "a *skill-sense* of "knowing how" which is not reducible to "knowing that". "The skill sense of 'knowing how' ", Hintikka writes, "cannot be analyzed in terms of knowing that (...)". The other sense of 'knowing how' is comparable to the meaning of such locutions as 'knowing who', 'knowing when', etc., and can be reduced to the 'knowing that' construction in a parallel way (Hintikka, 1975, 14)". Hintikka's intermediate position was defended recently by independent arguments.

Let me open a quick parenthesis just to record some relevant data about the definition of "know how" to be found in dictionaries. Some monolingual American English dictionaries define "know-how" as "knowledge of how to do something smoothly and efficiently: expertise or ability to get something done with a minimum of wasted accumulated practical skill". In English, both the French locution "savoir-faire" and the English "know how" are

used. The first since 1811, the second since 1838! But they are not attributed exactly the same sense. "Savoir-faire" is defined as the "capacity for appropriate action; especially a polished sureness in social behavior: tact". Hence when used within the English language, "savoir-faire" comes close to the French locution "savoir-vivre". (I owe this to Professor H.G. Callaway)

I am not going to pursue these lexicographical considerations. Instead of revisiting the arguments put forward by philosophers to back up conceptual distinctions which are blurred or ignored by ordinary language, I will take a fresh start and bring the proposals made by A.I. logicians engaged in the formalization of *knowing how* to bear on the issue. At the end of Section 11, an open problem will be faced.

**2. The formalization of "knowing how" in the predicate calculus**

In "A Formal Theory of Knowledge and Action", Robert Moore spells out an integrated theory of knowledge and action formulated in the standard predicate calculus enriched with the metatheory of modal logic. To capture knowledge-how, Moore introduces a new object language operator **Can** which takes an agent *A*, and act *Act* and a state of affairs *P* as arguments. On Moore's reading, "**Can** (*A,Act, P*)" means that *A knows how* to achieve *P* by performing *Act* (Moore 1985).

It is worth observing that Moore implicitly commits himself to the reductionnist view of knowing how since he analyzes **Can** as a sort of propositional knowledge *de re* : "There is an action the result of which is known by the agent to lead to *P"*. (I owe this to Dr.P.Egré).

In "A First Theory of Planning, Knowledge and Action", Leora Morgenstern rejects the identification of knowing how with the ability to achieve a goal by performing an action. The concepts of *knowing how* to perform an action and *being able* to perform that action should be taken apart (Morgenstern 1986).

There is more to knowing how than mere ability. Most of the time performing an action requires not only ability, which is internal to the agent, but also the satisfaction of physical or social conditions, which are external to the agent.

The need for such a distinction is shown by this example: many people *know how* to hit the bull with a gun; you have to grasp a loaded gun, to aim at the target and pull the trigger. But only marksmen *are able* to hit the bull (The example if due to Robert Demolombe).

**3. The formalization of "knowing how" to perform an action.**

Leora Morgenstein's distinction between *ability* and *external conditions* was further elaborated in the A.I. research program which bears the name KARO (an acronym for "knowledge", "ability", "result", "opportunity"). B. van Linder, W. van der Hoek and J.-J.

Ch.Meyer worked out a multi-modal axiomatic system which is designed to deal formally with the notion of *Knowledge,* possessed by the agents, and their possible execution of actions.

Instead of taking belief, desire,and intention as primitive notions as it is the case in the well-known B.D.I. paradigm, Van Linder *et al.* adopt the following primitives:

(1) the epistemic operator K,

(2) the function symbol **r** which maps the triple made up of a given action $\alpha$, a given agent *i* and a given situation *s* either to the situation *s′* which results from the performing of $\alpha$, or to the empty set ($\varnothing$) if the action fails,

(3) the function symbol **c** which maps $< \alpha, i, s >$ to *true* (respectively *false* ) if agent *i* is able (is *not* able) to perform $\alpha$ in *s*.

(4) the dynamic modality $<do_i\ (\alpha_1)>$ whose meaning is given by the following clause:

Formula $<do_i\ (\alpha_1)>\varphi$ is true in model **M** and situation *s* if **r** applied to $<i, \alpha, s>$ results in *s′* and $\varphi$ is true in *s′*.

The dynamic modality $<do_i\ (\alpha_1)>$ is designed to capture *external opportunities.*

*Internal ability* of the agent is captured by the ability operator A which takes an action (simple or complex) as argument. It is worth stressing that in so far as Van Linder and his associates introduce a new primitive to capture ability they *ipso facto* reject the reducibility of knowing how to knowing that.

Combining opportunity with ability, Van Linder *et al.* define the notion of *practical possibility*: $\mathbf{PracPoss}_i\ (\alpha, \varphi) =_{Df} <do_i\ (\alpha)>\varphi \wedge \mathbf{A}_i\alpha$ and, finally "Can" is explicitly defined in this way: $\mathbf{Can}_i\ (\alpha,\varphi) =_{Df} \mathbf{K}_i\mathbf{PracPoss}_i(\alpha,\varphi)$. For those authors, being capable of producing result $\varphi$ by performing action $\alpha$ is tantamount to knowing that one has the practical possibility to produce $\varphi$ by $\alpha$. Not all capacities however are of that sort. Sometimes we know *how* to do something without knowing *that* we do. This is forcefully brought out by the short dialogue below (due to Mikaël Cozic):

A: Please do not let me alone with the baby. I do not know how to take care of very young children.

B: No! you perfectly well know how to take care of them but you do not know that you know.

**4. The formalization of knowing how to achieve a condition *p***

The relation which obtains between knowing how and knowing that can vary considerably. The system of modal logic just described captures one of these relations but by

no means all. Knowing how to drive and knowing how to empty a truck involve forms of knowing that. Moreover the second kind of 'knowing know' brings in something new which requires an adjustment of formalism.

In a recent essay on "Knowing how" M.P.Singh comes to grips with that issue. He observes an interesting peculiarity of knowing how understood as *knowing how to achieve a condition* (Singh 1999). For an agent to master that kind of knowing how it is required that as soon as the condition has been achieved, he or she knows that it is so, just to preclude his or her selecting again and again actions that are unnecessary to achieve *p* (Singh 1999).

For instance to empty a truck full of parcels, we need a program which involves a bounded iteration which stops as soon as the condition of truck emptiness has been achieved. All that we need is the *While loop* construct of dynamic logic together with the knowledge operator of epistemic logic. Formally the program reads as follows: <**While** K ¬Empty truck **do** move parcels out **endWhile**>.

**5. The formalization of knowing in the present *that* one will know *how* in the future**

Singh operates with two temporal quantifiers, namely **A** which means "in *all* the scenarios at the present moment" and **E** which means "in *some* of the scenarios at the present moment". On the top of that he introduces two dynamic operators made up of an agent symbol '*x*', an action symbol 'α' inside a dynamic modality and a formula symbol '*p*'. These operators are defined by the following clauses:

$x[\alpha]p$ holds on scenario *S* in moment *t* ⇔ if *x* performs α on *S* starting at *t* then *p* holds at some moment while α is being performed.

$x\langle\alpha\rangle p$ holds on scenario *S* in moment *t* ⇔ *x* performs α on *S* starting at *t* and *p* holds at some moment while α is being performed.

Equipped with this formal apparatus, Singh offers an account of the link between knowing how and knowing that which is different from the link focused on by Van Linder and his associates. In Singh's system, Agent knows how to achieve the state of affairs *p* by performing action α if and only if either the state of affairs is known to obtain or there is an action α such that the agent knows *that* it is performed and he or she knows *how* to achieve *p* whenever α is being performed. Formally:

$$K_t\, p \vee V\, \alpha : K_t(\mathbf{E}\langle\alpha\rangle \text{true} \wedge \mathbf{A}\,[\alpha]K_h p)) \Leftrightarrow K_h p$$

**6. Is there a hidden structure which underlies and connects together these various forms of knoing how?**

Up to now I have briefly presented three rival formalizations of *knowing how* developed in A.I. circles. None of them supersedes the others. As a matter of fact each formalization provides an account of a *distinct concept* of knowing how. Each formalization illuminates different relationships which hold between *knowing that* and *knowing how*. The question arises whether it is possible to find a hidden order underlying this diversity. My answer is positive. I shall argue that there are as many kinds of knowing how as there are kinds of verbs in the infinitive mood which can occupy the position of X in "knowing how to X".

In *Linguistics in Philosophy,* Zeno Vendler distinguished four categories of verbs: verbs denoting states, activities, accomplishments and achievements. That classification rests upon the restrictions of time adverbials, tenses and logical entailments to which these verbs are subject. David Dowty, who adopted Vendler's classification, gives the following examples:

| *States* | *Activities* | *Accomplishments* | *Achievements* |
|---|---|---|---|
| Know | run | build | recognize |
| Believe | walk | make a chair | find |
| have | swim | recover from illness | die |

The Rylean contrast between knowing that and knowing how fits in with Vendler's taxonomy very well. It helps capture in one stroke all the varieties of knowing how which emerged when logicians tried to extend the formalization of knowing that to knowing how. Differences which had passed unnoticed were discovered by the A.I. researchers engaged in the formal reconstruction of practical reasoning. It became clear, for instance, that a formal rendering which suits "knowing how + accomplishment" is more demanding than a formal rendering of "knowing how + activity". It requires planning and use of a strategy enabling the agent to select the right move at each sage.

One might however object that Vendler's classification is not as neat as it should be. Even Dowty's examples seem to lie open to that criticism. For instance one might say that recovering from illness does not require a plan and that running involves, if not a *plan*, at least a *purpose* (arriving in time, escaping from a pursuer...). That objection however loses much of its weight if we stick to the *paradigm cases* of these four classes.

7. **Additional kinds of knowing how**.

However useful Vendler's classification may be as a guideline if we are after a taxonomy of knowing how, it should not be overstated. It gives us a good starting point but additional distinctions are needed. I shall examine two of them in this Section.

Singh observes that the knowing how to *achieve* a condition should be set off against another sort of knowing how, namely knowing how to *maintain* a condition. Providing a

pilot, whose aircraft is approaching the runway, with a landing plan is one thing. Supplying a travel agency with an on-line registration program which operates continuously is quite another thing. The first program necessarily requires a bounded number of steps. Not so for the program which keeps registration going on continuously.

Another kind of *knowing how* which has not been dealt with up to now is the competence exercised in speaking a natural language. What is at stake here is still another variety of knowing how which involves *rule directed behavior* as opposed to a *goal directed behavior*. The formalization of knowing how in terms of plan execution is of no avail. Moreover we must carefully distinguish between two kinds of linguistic rules: the rules learned at school in courses of *normative grammar* and a deeper layer of rules which make up what Chomsky calls *universal grammar*, namely the system of principles, "conditions and rules that are elements of all human languages not merely by accident but by necessity" if such there be.

Chomsky construes universal grammar as an *innate property* of the human mind which should be accounted for in terms of *human biology* (Chomsky 1976). If Chomsky is right on this, we can hardly expect much help from A.I. in the explanation of the second kind of linguistic competence. (On Wittgenstein's discussion of Rule-following, see Hintikka 1889).

**8. How to acquire knowledge. The notion of informative action.**

Within the field of A.I., a logical formalism has be worked out in which new logical tools can be found to analyze and formally represent intricate cases of knowing how such as, to mention an example which has become standard in the literature, the knowing-how instantiated in knowing how to open a safe. This logical formalism which bears the name of "Situation Calculus" goes back to "Some philosophical problems from the standpoint of Artificial Intelligence", a paper co-authored by John McCarthy and P.J.Hayes and published in 1969.

Among others things, Situation calculus provides the formal language and the axioms we need to analyze how *informative actions* such as sensing, observing, reading etc. produce knowledge sates. The new developments of that formalism build upon Robert Moore's monograph "A formal Theory of Knowledge and Action" which I shall briefly present here as it lays down in a very intuitive way the main insight which lies behind the "knowledge axiom" of the recentversion of the Situation Calculus.

Moore drew a distinction between (1) *informative actions* like *sensing* or *reading* which enable us to know the truth value of propositions and (2) *ordinary actions* like *removing* or *burning* which change the physical state of the world. In his unified theory of

knowledge and action, both knowledge and action are modeled by accessibility relations albeit by different accessibility relations. Informative actions - the only ones that concern us here - lead from a given state of knowledge *w* to another one *w'* in which knowledge has increased. This kind of shift can be modeled in a diagram.

Let : *E* be an event consisting of the performance of an informative action which lets the agent *know whether* P is true. Moore uses the accessibility relation $R :_E$ (represented by vertical arrows in the diagram) to model the informative action and the accessibility relation $K:_A$ (represented by the horizontal arrows) to model the epistemic state of agent A respectively *before* and *after* the informative action. The effect produced by the informative action is depicted in the diagram below:

$w_2$ ( P ) → ( P ) $w_3$

⇑ ⇑

$w_1$ ( ) → ( ) $w_4$

. Initially agent A belongs to world $w_1$ and considers $w_4$ as compatible with what he or she knows in $w_1$ . Thanks to the informative action, represented by a vertical arrow, agent A jumps into world $w_2$ in which *P* is true, and where agent A considers world $w_3$ as compatible with what he or she knows in $w_2$ . As *P* is also true in $w_3$. *P* is true in all the worlds which have turned out to be epistemically accessible *after* action has been performed.

**9. Situation Calculus**

The situation calculus is designed to represent properties and relations which may change with time ("fluents"). For that purpose, situational variables or constants are appended to predicates as in "temperature (*x*,*s*)". To capture the situation which results from the performance of an action α, the function symbol (**do**(α,s)) is used.

We have already seen that, as opposed to ordinary physical actions, informative actions, or to use Reiter's terminology, "information producing actions", such as sensing or observing normally do not. This peculiarity is captured in the Situation Calculus by axioms called "no Side-Effects Assumptions for knowledge producing action". There are still other kinds of axioms which should not detain us here: frame axioms, action precondition axioms etc. (Reiter, 2001).

Hence when we move from the standard predicate calculus to the situation calculus, the *deductive power* of the system as much as the *expressivity* of the language, increases. One particular axiom of the Situation calculus deserves special attention: the "knowledge axiom"

which serves to characterize the state of knowledge which results from the performance of an *information producing action*.

Expressed in natural language, it reads as follows:

Situation *s″* is compatible with what agent A knows in the situation produced by observing *whether q* in situation *s* [formally "K( *s″* , *do* (*sense q*, *s*))" ]

if and only if

(1) There is a situation *s′* such that *s″* is identical with observing *whether q* in situation s ′ ,

(2) What agent A knows in *s* is compatible with what he or she knows in *s* ′ ,

(3) Q is true in *s* if and only if Q is true in *s* ′ .

Formally the axiom is rendered thus:

K( *s″* , *do* (*sense q*, *s*)) ≡

(1) ∃s′*s″* = *do* (*sense q*, *s′*)

(2) ∧ K (*s′* , *s*)

(3) ∧ Q*s*≡Q*s* ′

Let me quote Scherl's and Levesque's illuminating reading of the axiom: "the idea here is that in moving from *s* to do(*sense q*,s), the agent not only knows that the action *sense q* has been performed (since every accessible situation results from the *do* function and the *sense* action, but also the truth value of the predicate 'Q' " ( Scherl and Levesque 2003, 12).

With the apparatus of the Situation Calculus, we easily prove the validity of inferences which are beyond the reach of the expressive and deductive power of the standard predicate calculus. For instance we can prove that the following causal relation obtains between the knowledge producing action denoted by "sensing *whether q*" and the epistemic state expressed by " Agent A knows whether Q": *after sensing whether q*, *A knows whether Q*.

Beside using axioms and rules of the predicate calculus with equality the proof of that theorem requires not only the above "knowledge axiom" but also two instances of the following *no Side-Effects Assumption for knowledge producing actions*:

Q(do *sense q*,*s*) ≡ Q(*s*).

**10. Application of the Situation calculus to a paradigm case of knowing how**

The opening of a safe can be used as a testbed for assessing the relative merits of the rival formalizations of knowing how that are available in the literature. This example of knowing how nicely brings out the interplay between various kinds of knowledge. Knowing how to open a safe involves (a) *knowing how* to dial a combination on the safe, (b) *knowing*

*which* combination to dial, and this amounts to (c) *knowing that* a given sequences of letters or figures is the combination of the safe under consideration.

Knowing which combination opens a given safe often requires an informative action such as reading the combination of the safe on a piece of paper. Hence an appropriate form of the "knowledge axiom" is likely to enter the picture, something like: "after reading the information contained in the paper, the agent knows the combination of the safe". We also need a no *Side-Effects Assumption for knowledge producing action* which stipulates that reading a message does not alter it.

We expect of a logic for *knowing how* that it provide us with the formal tools needed to reconstruct practical reasonings in which this kind of knowledge is displayed. Here is an example adapted from Reiter (2001, 300-302).

(1) Precondition axiom for *dial*(*combo*(*x*)):

*Poss*(*dialCombo*(*x*),*s*) ≡ **KRef**(*combo*(*x*),*s*).

Substitute '*Sf*' to '*x*' and '$S_0$' to '*s*').

Applying appropriate instances of both the *knowledge axiom* and the *no Side-Effect Assumption* for reading, we can derive :

(2) Agent A knows the reference of the information on the paper after reading the paper.

Formally: **KRef**(*info*(*Ppr*),*do*(*read*(*Ppr*),$S_0$).

(3) Assuming that :

**Knows** (*info*(*Ppr*) = *combo*(*Sf*), $S_0$ ),

we obtain:

(4) Agent A knows the reference of the combination of the safe after reading the paper.

Formally: **KRef** (*combo*(*Sf*), *do*(*read*(*Ppr*),$S_0$).

From (1) and (4), we get:

(5) *Poss*(*dialCombo*(*Sf*),*s*), *do*(*read*(*Ppr*),$S_0$).

The trickiest step consists in proving (2). Formula (2) can be reformulated as (a)

(a). $\exists x \ \forall s''$. K (*s''*, do (read *z* , s)) $\supset$ *x* =info( *z*, *s''*)

in which 'knowing *who*/knowing *what*' has been reduced to 'knowing *that*'. The method was introduced by Hintikka and adopted by Reiter.

The proof of (a) is made easier if we assume the following lemma (which can be treated as a true empirical premise) saying: "*z* contains some information( is not blank)"

(b) $\exists$ *x* (*x* = info(*z*,*s*))

The proof that lemma (b) entails (a) is an exercise in the predicate calculus with equality *enriched with* the "knowledge axiom" and the no-side effects assumption.

**11. Can the situation calculus be reduced to Modal Logic?**

There is a well-known "standard translation" due to Johan van Benthem which recursively turns formulas belonging to modal logic into formulas of the predicate calculus. The possibility of such a translation rests upon the fact that there is no mathematical difference between models for interpreting propositional modal logics and models of the predicate calculus. As Patrick Blackburn, Maarten de Rijke and Yde Venema observe, this should *not* come as a surprise "since there is no mathematical distinction between modal and first-order models - both modal and first-order models are simply relational structures" (Blackburn, de Rijke, Venema, 2000,85).

In "Situation Calculus as Hybrid Logic: First Steps", Patrick Blackburn, Jaap Kamps and Maarten Marx pushed the matter further and showed that quantified hybrid logic, QHL, is able to express situation calculus formulas *often in a more natural and a more concise way than situation calculus itself*.

As far as the expressive power of situation calculus and quantified hybrid logic is concerned, we should agree with their claim. But consideration of *expressive power* alone does not settle the question of the reducibility of Situation Calculus to Hybrid logic. One has also to take the *deductive power* of these logics into account.

Situation Calculus contains new axioms. The "axiom of knowledge" is one of these new axioms which plays a crucial role in formalizing complex forms of knowing how. But, as Scherl and Levesque observed (Scherl and Levesque 2003). it seems that there is no representation of that axiom in modal logic of knowledge.

Hence the question whether Situation calculus is more than a notational variant of quantified modal logic and whether it offers resources which cannot be found in the other formalisms available today remains an open problem. (See Demolombe 2003).

**12. Beyond individual knowing how**

Let us take stock. Analytic philosophers contributed a lot to the clarification of the conceptual distinction between knowing that and knowing how. The question was raised by several authors whether knowing how could not be reduced to knowing that in the same way as knowing who has been reduced to knowing that by Hintikka. Arguments for and against the reducibility thesis have been put forward. They were philosophical or linguistic.

Meanwhile, A.I.logicians worked out formal systems meant to offer an epistemic logic of knowing how comparable with the epistemic logic for knowing that. In the spirit of the

sort of *formal philosophy* advocated by Vincent Hendricks, I showed that the findings of A.I. logicians are relevant for the philosophers who deal with the conceptual analysis of these two forms of knowing and give us new insights.

At the end it was argued that Situation calculus occupies a privileged position in the range of formalisms designed to investigate the logic of knowing how.

I only dealt with *individual knowing how*. The more interesting and difficult problems arise however in connection with *multi-agent systems* (On this see Tuomela and Sandu 1994). A whole monograph was devoted to this topic more than ten years ago (Singh 1994). This important topic has to be left for another occasion.

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