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**Relative Knowledge and Belief  
SKL Preferred Model Frames**

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Report LSI-94-10-R

 **UPC**  
Facultat d'informàtica  
de Barcelona - Biblioteca  
10 MAR. 1994

# Relatives Knowledge and Belief $SKL^{**}$ Preferred Model Frames

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## Abstract

The partial  $SKL^{**}$ -logic [2], based upon the three valued logic of Kleene [8], provides a flexible framework in defining, we hope in a suitable way, epistemic notions of Knowledge, Belief, Aposteriori Knowledge and the well related Potential Knowledge. Relations between these concepts are developed. The underling ideas in our definitions of knowledge and belief, are the same to those using the semantics of possible worlds [6], [5], but not jet the formalisation. Our definitions are constructive and recursive instead, and using the undefined truth value from  $SKL^{**}$ , it allows a not known or not believed status for a sentence.

**Keywords:** Relative Knowledge, Relative Belief, Entailment, Recursivity

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\* Scholarship of the Universidad Nacional Autónoma de México.

# 1 Introduction

## 1.1 Epistemic logics using the semantics of possible worlds

For knowledge and belief, the semantics of possible world has been attractive for its intuitive notion of making a discourse, not only of the *present* world but for any possible world [10]. The classical Kripke's possible worlds are sets of interpreted formulas, *i.e.* sets of formulas and an (arbitrary) associated interpretation. The worlds are related through an algebraical, usually reflexive, symmetric and/or transitive relation. If the true formulas in the actual world  $w_0$  are also true in a world  $w$ , this last world is said to be possible from  $w_0$  in the Kripkean model. However this is neither a fair constructive nor *causal* relation and does not capture, in a suitable way, the underlying intuition to be *possible* or *conceivable* from the actual world.

## 1.2 Logical omniscience and ideal reasoning

Many logics of knowledge and belief that have used the semantics of possible worlds [6], consider the knowledge in the actual world  $w_0$ , the true formulas in all the  $w_0$ -possible-worlds. If a formula  $\varphi$  is knowledge and  $\psi$  is a logical consequence of  $\varphi$ , then also this last formula is true in all the worlds in which  $\varphi$  does, and thus is knowledge too. So, all the logical consequences of the initial knowledge is knowledge. This topic, known as *logical omniscience* is unintuitive to modeling *real* knowledge (belief) agents [20], [13]. The logical omniscience agents should have unlimited time and informatic resources [17].

## 1.3 The semantics of possible worlds: a new proposal.

The basic idea of our approach is inspired by the metaphor of an agent who *conceives* (or imagines) worlds which are possible in (or compatible with) the existing world, by means of a well-defined iterative process. This requires the existence of a *causal* relation between the agent's existing world and the world that he is capable of conceiving of on the basis of that world. Furthermore, it requires that possible worlds not be static, but the result of a

dynamic process of creation and, therefore, dependent on the iterations which occur. In practice, these iterations will depend on the resources available. In accordance with the preceding, an agent's knowledge is conceptualised as a concept which is relative to the worlds which have been generated. This idea seems quite natural and adequately captures the intuition that knowledge is not static: it is being continually modified on the basis of experience. In relation to the reference world, the agent's knowledge in the  $n$ th iteration is constituted by those things which have been conceived of up to that iteration. The *potential* knowledge of the agent are those things which are realised in all of the worlds which are obtained when all of the iterations are made. In general, the total number of possible worlds can be finite or infinite. For example, an agent can construct worlds by choosing from amongst distinct options which are presented to him. He can choose between getting married ( $P$ ) and not getting married ( $\neg P$ ). If he gets married, he must choose to have children ( $Q$ ) or not to have them ( $\neg Q$ ). If he does not get married, he has the option of working ( $R$ ) or not ( $\neg R$ ), etc. . Each choice creates two new possible worlds for the world in which the choice is made. This procedure for constructing worlds is highly intuitive and constitutes quite a natural conceptual model of how we, as human beings, go about defining our lives by *choosing from amongst possible options*. This idea is in accordance with that expressed in [10], in which it is observed that statements in possible worlds must be possible in the present world or consistent with the statements of that world.

The conceptual model presented can be formalised in such a way that the iterative procedure for generating possible worlds can be based on classical rules for the expansion of analytic tableaux [19]. At this paper we explain the case of a single agent with a modal epistemic language  $\mathcal{EL}$ , in the partial three valued logic SKL\*\*. The underground proof method is an extension of analytic tableaux.

Partial interpretation means *not necessarily complete* [1]. The partiality extreme cases, are given on one hand when any formula is not interpreted and on the other hand when all are interpreted. Whenever the interpretation is complete, the worlds are namely *complete* possible worlds, in other case *partial* possible worlds.

By considering worlds associated with partial interpretations related through a semantical *refinement* relation, is a more intuitive way making conceivable

or possible a world  $w$  from a given  $w_0$ . The refinement is made by interpreting a subset of undefined formulas in  $w_0$ .

If the actual world  $w_0$  is a set of formulas associated with a partial interpretation, we consider  $w$  possible or conceivable from  $w_0$  if the set of formulas in  $w_0$  is a subset of the one from  $w$  and the (partial) interpretation of  $w$  is a refinement from the interpretation of  $w_0$ .

By using both, partial interpretations and models, knowledge can be defined in accordance with the often real circumstance of incomplete actual information and limited resources. By the correspondence of worlds with partial interpretations, there is at most occasions partial knowledge. Whenever all the interpretation has been completed there is complete knowledge. But this is the minor case. The major one is the occurrence of partial knowledge, arising in the frequent situations with limited time and resources.

This paper is organized as follows, in section 2 is introduced a partial logic, namely the SKL\*\* [2]. From this logic we outline our epistemic definitions in section 3, and a partial logic of knowledge and belief is developed with an example in section 4. Finally at section 5 is discussed the suitable evolution of the work and the conclusions.

## 2 SKL\*\* Logic

In accordance with definitions of Langholm [12] for the Strong Kleene Logic, is defined the propositional language  $\mathcal{L}$ , consisting of a finite set of sentences  $\rho$  and the primitive connectives negation  $\neg$  and disjunction  $\vee$ . From these are defined the conjunction  $\wedge$  and implication  $\rightarrow$  connectives in the classical way.

In order to define the language of SKL\*\* logic is added to  $\mathcal{L}$  the *external negation* connective  $\sim$ , and from both negations are defined the nonprimitive connectives  $L = \neg \sim$  and  $M = \sim \neg$  [2].

The semantical definitions for disjunction and negation connectives in the Strong Kleene Logic are given in the Table 1 and 2, respectively. In the Table 2 are given the semantical definitions of  $\sim$ ,  $L$  and  $M$  in SKL\*\*.

$\varphi$	$\psi$	$\varphi \vee \psi$
T	T	T
T	F	T
T	U	T
F	T	T
F	F	F
F	U	U
U	T	T
U	F	U
U	U	U

Table 1

$\varphi$	$\sim \varphi$	$\neg \varphi$	$\neg \sim \varphi \equiv L\varphi$	$\sim \neg \varphi \equiv M\varphi$
T	F	F	T	T
U	T	U	F	T
F	T	T	F	F

Table 2

## 2.1 Partiality in $SKL^{**}$

Let  $\mathcal{F}$  be the set of  $\mathcal{L}$ -formulas and  $i$  a valuation function from  $\mathcal{F}$  to the  $\{T, F, U\}$  set. The interpretation of  $T, F, U$  is true, false and undetermined. So, the  $T$  and  $F$  are determined values. The so called Degree-of-information (partial) order between the elements of  $\{T, F, U\}$ , is defined by  $U \leq_i T, U \leq_i F$  and  $T, F$  are not comparable [2].

**Definition (Partial interpretation)**

A partial interpretation is a set  $I = I^T \cup I^F \cup I^U$ , so that  $I^T$  is the set of true formulas,  $I^F$  the set of false formulas and  $I^U$  the set of undefined formulas. When  $I^U$  is the empty set the interpretation is complete.

The informative order  $\leq_i$  is extended on the set of partial interpretation  $\Upsilon$ . Given an  $I, I' \in \Upsilon$ ,  $I \preceq_i I'$  is fulfilled if and only if  $I^T \subseteq I'^T$ ,  $I^F \subseteq I'^F$  and  $I^U \supseteq I'^U$ . The order  $\preceq_i$  is a partial one on  $\Upsilon$ .

The following formal structure taked from [2], it provides a suitable framework in our intended definitions.

**Definition (Model Frame)**

A model frame is a order pair  $\mathcal{M} = \langle \Upsilon, I \rangle$ , where  $\Upsilon$  is a (nonempty) set of interpretations and  $I \in \Upsilon$  is the actual interpretation (*situation*). For any  $I' \in \Upsilon$ , we assume that  $I \preceq_i I'$ .

Notice that the initial interpretation  $I$  remaining fix through the successive extension, constitutes an invariant and characterizes the model frame. The following definition of satisfaction is relative to a given model frame. This relativity is welcome in our intend of encourage the point of view considering knowledge and belief relative to actual information and context. So, the relativity at defining the capabilities of inference is imported from SKL\*\*.

**Definition (Satisfaction)**

An interpretation  $I \in \Upsilon$  in the model frame  $\mathcal{M}$  satisfies a sentence  $\varphi \in \mathcal{L}$ ,  $I \models_{\mathcal{M}} \varphi$ , if and only if  $I(\varphi) = T$ . Is said that the frame satisfies  $\varphi$ ,  $\mathcal{M} \models \varphi$ , if every  $I \in \Upsilon$  satisfies  $\varphi$ . For a set  $\Gamma$  such that any sentence of  $\Gamma$  is satisfied by  $\mathcal{M}$ , is said that the frame  $\mathcal{M}$  satisfies  $\Gamma$ ,  $\mathcal{M} \models \Gamma$

## 3 Knowledge and Belief in SKL\*\*

### 3.1 Context Relativity

At this section are defined the notions of knowledge, belief and some related notions. In SKL\*\*, definitions of satisfaction and entaliment are relative to

a given model frame  $\mathcal{M}$ . This relativity is maintained in our epistemic definitions: we propose that there is not *absolute* knowledge or belief, instead both are relative to the actual information and context.

A related point of view has been apologised by Konolige [9], who defines agents of belief so that the set of agent's beliefs is the closed deduction from a initial set of premises and local (particular agent's) and effective inference rules. The Konolige's work is situated at the so called sentential approach [5].

More recently, Giunchiglia et al. [4] have defined non-omniscient context-based reasoning agents. They define the non-omniscience of agents of belief depending of several kinds of incompleteness: language or basic facts or axioms or inference's rules, etc. The relatives agents' belief are defined from any one of these incompleteness. They contrast this agents respect the saturated or omniscient agents defined by possessing complete information and inference rules.

One of the more recent McCarthy's proposal [16] is intended with the formalization of contexts, defined through sets of information from which are derived sentences. Each context can be embedded in other one and conversely, each context is constituted by several contexts. McCarthy suggests some basic operations between contexts and provides motivations for its develop. In a cognitive sense he suggests consider the individual mental states as *outer* contexts which provides the reasons (*pedegrees*) of each actual (*inner*) individual believe.

### 3.2 Knowledge $K$

The propositional language  $\mathcal{L}$  is extended by adding the modal operators of Knowledge  $K$ , Belief  $B$ , Potential Knowledge  $K_p$ , and A posteriori Knowledge  $K_{aps}$ . The language extended with these modal operators is called  $\mathcal{EL}$  by epistemic language.

In some of the following definitions we take  $I'$  being a *direct succesor* of  $I$ . A direct succesor of  $I$  is a partial interpretation  $I'$  such that for any  $I''$ ,  $I \prec I'' \preceq I'$  then  $I'' = I'$ . In the satisfaction relation  $I \models_{\mathcal{M}} \varphi$ , whenever is clear the model frame  $\mathcal{M}$  the subindex is ommited.

**Definition**



**Definition**

A formula  $\varphi$  is knowledge in the model frame  $\mathcal{M}$ ,  $I \models_{\mathcal{M}} K(\varphi)$  if and only if,

- 1)  $I \models_{\mathcal{M}} L(\varphi)$  or
- 2)  $I \models_{\mathcal{M}} M(\varphi)$  and  $I' \models_{\mathcal{M}} L(\varphi), \forall I'$ .

In 1) whenever the sentence  $\varphi$  is true at  $I$ , we can say that  $\varphi$  is *apriori* knowledge meanwhile the case 2) could be said the **Aposteriori Knowledge**  $K_{aps}(\varphi)$ . Accordign the context may be of interest the distinction. It is noted that the second condition subsumes the first one but not conversely. Thus, there are knowledge sentences  $K(\varphi)$  that could be said factual *aposteriori* knowledge in  $I$ , regarding that  $\varphi$  is undefined at  $I$  but  $L(\varphi)$  is satisfied at each  $I'$  (see fig. 3.1). They are considered knowledge in  $I$  too, although it has been *get on* latter.

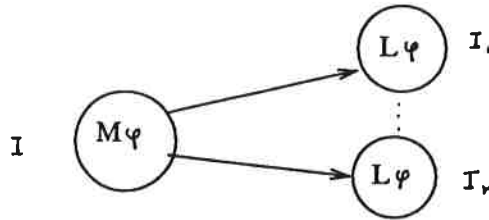


Figure 1: Aposteriori Knowledge

Thus, eventually accepting the distinction between *apriori* and *aposteriori* knowledge, the knowledge could be consider the *summa* of both them. The formal distinction is of interest by philosophical or epistemical approach. In a context, the well known true sentences are the *apriori* knowledge. The true sentences arising at every possible world (situation) is the *aposteriori* knowledge. Inside our work the set of *apriori* knowledge sentences, is the initial true information.

There is some kind of defaults about we have special interest. They are the true sentences at all the direct sucesors of  $I$  except at only one of them. This are default sentences (or beliefs) that may be consider *nearly* knowledge. We emphasize them in the next subsection and analize its relation with the remaining default sentences.

### 3.3 Default, Belief and Potential Knowledge

Regard that the knowledge sentence  $K_{aps}(\varphi)$ , is a very *aposteriori* (factual) knowledge in  $I$  whenever both sentences  $M(\varphi)$  and  $\neg L(\varphi)$  are satisfied in  $I$ . The same condition must be satisfied by potential knowledge and belief. That means that  $\varphi$  is really undefield at  $I$ . Whenever is true (or false) at the minimal interpretation of a model frame, it is *apriori* knowledge.

**Definitions**

**Belief  $B$**

$I \models B(\varphi)$  iff  $I \models M(\varphi)$ ,  $\exists I', I' \models L(\varphi)$  and  $\forall I', I' \models M(\varphi)$  (see fig. 3.2).

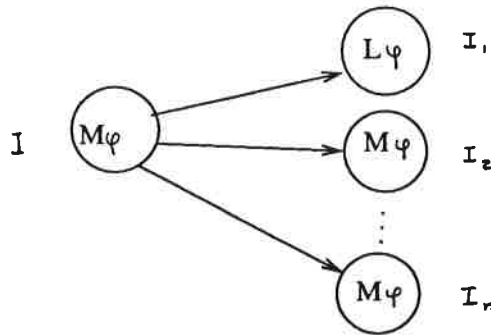


Figure 2: Beleif

**Potential Knowledge  $K_p$**

$I \models K_p(\varphi)$  if and only if the following three conditions are satisfied.

- 1)  $I \models M(\varphi)$ ,
- 2) Exists a direct succesor  $J$  of  $I$ , such that  $J \models \neg L(\varphi)$
- 3)  $\forall I', I' \neq J, I' \models L(\varphi)$  (see fig. 3.3).

Formally, the definition of belief corresponds with default sentences from SKL\*\*. The interpretation in epistemic context is very intuitive: a default conclusion, by its own character of *provisional*, it seems natural be consider belief. Conversely, a belief may be consider a default conclusion.

Now, we establishe the following relations between the above definitions. An interesting point is the condition that determine when potential knowledge turns up knowledge.  $K_p(\varphi)$  turns up  $K(\varphi)$  in  $I$ , when in the interpretation  $I'$ , such that  $\varphi$  is undefield,  $\varphi$  turns up *aposteriori* knowledge  $K_{aps}(\varphi)$ . This is established in the following proposition.

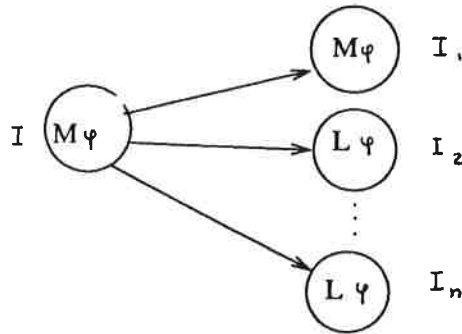


Figure 3: Potential Knowledge

**Proposition**

The  $I \models K_p(\varphi)$  turns up  $I \models K(\varphi)$  if and only if  $I' \models K_{aps}(\varphi)$ ,

**Demonstration**

$I' \models K_{aps}(\varphi)$ , thus  $I' \models L(\varphi)$ . So  $I' \models K(\varphi)$ .

From the unfulfillment of the hipotesis of  $K_{aps}$ , it follows that if eventually any sucesor (direct or indirect) of  $I'$  satisfies  $\neg\varphi$ , then  $\varphi$  fails to be knowledge at  $I$  in this model frame. The arising of this fail —that could be interpreted as the refutation in the model frame  $\mathcal{M}$  of  $\varphi$  — may suggest the change of model frame, or the suitable reception of the refutation against a *virtual* or *presumable* knowledge up to this step.

The semantical definitions of  $\mathcal{EL}$ -sentences involving the operators  $K, K_{aps}, K_p$  and  $B$ , and the distinction between them and the object or  $\mathcal{L}$ -sentences, makes to deal with situations such that a  $\mathcal{L}$ -sentence  $\varphi$ , can be argument of a  $\mathcal{EL}$ -sentence satisfied by an interpretation that satisfy  $\neg\varphi$  also. This is an advantage attending the situation described in the previous paragraph: if some potential knowledge sentence not turns up knowledge and this fact not disable the framework, the distinction between the two kinds of sentences let it be dealing with this incompatibility. The following is an obvious result.

**Proposition**

If  $I \models K_p(\varphi)$ , then  $I \models B(\varphi)$

### 3.4 Recursivity and fulfillment of epistemic conditions

The definition of knowledge and potential knowledge are recursive: they appeal the satisfaction of the argument in all, or at most in except one, of its direct successors to deliver if the argument sentence is knowledge or potential knowledge. Each successor repeat the process. The same process is accomplished by belief. Whenever the conditions are satisfied stops the process and is established if the sentence is knowledge, potential knowledge (a special case of belief) or belief. This is a constructive process, because the status of any sentence is determined up to the conditions are fulfilled. Never is determined without accomplished the punctual conditions.

By other hand, is very useful that any operator can be applied to any sentence of a (direct or indirect) successor of  $I$ . So that, for example, from  $K_{aps}(\varphi)$  it may be established  $L(\varphi)$  at any successor of  $I$ . Related to local reasoning may be of interest the case of belief respect the successor  $I'$  satisfying  $L(\varphi)$ , so that it implies  $K(\varphi)$  in  $I'$ . That means that it is a local knowledge, although this is not the case at everywhere.

## 4 Epistemic Entailment

To obtain the information that can follows from a initial given one, we are intended with the intuitive idea of fairly *what follows from what*. Its formalisation, the so called *entailment*, has been major realized by Shoham [18] and Makinson [14]. Entailment provides a suitable framework in modeling the getting conclusions from incomplete or imprecise information. The frequent situations involving incomplete information can be consider situations involving the minimal (actual) information from which it must be set up conclusions. At this sense it constitutes a formalism dealing with the presumeble human mental act of jumping to conclusions from the minimal plausible information and can be consider a semantical generalisation of McCarthy's Circumscription [15] and of Hintikka's Model Minimization [7]. The preferential entailment criteria given by Doherty [2] is adapted in our epistemic intend.

### Preferred Model Frames

Suppose  $\mathcal{M} = \langle \Upsilon, I \rangle$ , and  $\mathcal{M}' = \langle \Upsilon', I' \rangle$ , are two model frames satisfying a

set of premises  $\Gamma$ .  $\mathcal{M}$  is said to be preferred to  $\mathcal{M}'$  if and only if it is fulfilled any of the following conditions:

- 1) Satisfy the sentences in  $\Gamma$  using the minimal amount of information
- 2) If  $I = I'$  prefer the frame that satisfy the minimal number of constraints defined by epistemic sentences
- 3) If  $I = I'$  and the number of epistemic constraints are the same, is preferred the maximal number of interpretations.

#### Preferential entailment

Let  $\Gamma, \Psi$  be sets of sentences in  $\mathcal{L}$ .  $\Gamma$  preferentially entails  $\Psi$ , written  $\Gamma \models \Psi$ , if and only if, for all preferred models of  $\Gamma$ , written  $\forall \mathcal{M} \in Pmod(\Gamma)$ ,  $\mathcal{M} \models \Psi$ .  $Pmod(\Gamma)$  is the set of preferred model frames of  $\Gamma$ .

#### 4.1 Example

The set  $\Gamma$  is the initial information. The subformulas appearing in the successive  $I_i$ ,  $i = 1, 2, 3, 4$  are the interpreted true formulas of refinement.

$$\Gamma = \{(P \rightarrow Q)^T, (Q \rightarrow R \vee S)^U, (R \rightarrow T)^U\}$$

$$I = \{Q\}$$

$$I_1 = \{Q, R \vee S\}$$

$$I'_1 = \{Q, R, R \vee S, T\}$$

$$I_2 = \{P, Q, R \vee S\}$$

$$I'_2 = \{Q, R, R \vee S, T, S\}$$

In $I$	$B$	$K_p$	$K_{apr}$	$K_{aps} \Rightarrow K$
1 <sup>st</sup> iteration	$R, T$	$R, T$	$Q$	$R \vee S$
2 <sup>nd</sup> iteration	$P, S$			

Let  $\mathcal{M} = \{I, I_1, I_2\}$ ,  $\mathcal{M}' = \{I, I'_1, I'_2\}$ . The set  $\Psi = \{R \vee S\}$  is preferentially entailed by  $\Gamma$ . By other hand,  $\mathcal{M}$  is a preferred model frame with respect to  $\mathcal{M}'$ .

The  $\mathcal{EL}$ -formulas in the table are refered to  $I$ . In  $I_1$ , is satisfied  $K_{aps}(\{P\})$  meanwhile in  $I'_1$   $K_{aps}(\{S\})$ .

### Proof method

The proof method given in [2] can be used in the obtention of the epistemic model frames of our enterprise. This proof method is an extension of Gentzen analytic tableaux. We can add our knowledge and belief conditions in the open branches containing the sentences of actual interest. So, the formalism we are using, based upon partial interpretations and model frames emphasizes the semantical entailment, but its proof method is realized by extending the powerful analytic tableaux method [9], [3].

## 5 Conclusions and future work

This paper emphasizes the relativity of knowledge and belief based upon the actual information. We propose epistemic and doxastic definition based upon the SKL\*\* partial logic. The formal definitions are recursive and constructives. The derivations capabilities are characterized by epistemic entailment. Our approach is closer to the characterization of actual information by contexts and that knowledge and belief depends of this ones.

### Aknowledgments

The developpe of this work has been benefitted from several interesting discussions with Lluís Godó and Carlos Sierra (CEAB), Ton Sales, Miguel Carrillo and Ricardo Rodríguez (LSI, UPC).

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