CONTEXTUAL KNOWLEDGE AND BELIEF: REPRESENTATION AND REASONING

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ABSTRACT

Contextual knowledge reasoning requires precise but flexible formalisms in such a way that, together with the capacity to reason with well defined information, be capable as well to deal with not well defined information in the context. Three-valued models of Kripke are proposed as the contexts formal setting. Is showed how those representation knowledge frameworks are adequated to allow the dynamic manner in which context information evolve. Operation devoted to expand or to change contexts are defined. In addition, the heuristical adequacy of so defined contexts can be established through the direct correspondence between them and the Analytic Tableaux demonstration method.

Keywords: belief revision, causality, cognitive modeling, knowledge representation.

1 INTRODUCTION

The necessity to have context formal setting is recognized in almost every computational related areas: multi-agent intelligent systems, linguistic and computational linguistic; any kind of modal logics in artificial intelligence, namely, epistemic, temporal, deontic and dynamic logics, among others. The content of this paper is concerned with context formalization in epistemic logics. Some related approaches in the literature so far, are now briefly summarize.

In [Gi 93], Giunchiglia *et al.* have defined non-omniscient context-based reasoning agents. They define the non-omniscience of belief agents depending on several kinds of incompleteness: language, basic facts, axioms or inference rules, etc. The relative agent's believes are defined based upon any of these kinds of incompleteness. The authors contrast these agents with respect saturated or omniscient agents to possesing complete information and inference rules.

By the other hand, McCarthy's proposal [McC 93] deals with formalization of **contexts**, by considering organized informations sets, inside which sentences are declared or derived. Each context can be embedded into another, and conversely; each context is constituted by several contexts. McCarthy suggests some basic operations among contexts and provides motivations for their development.

In a cognitive sense suggests to consider the individual mental states as *outer* context which afford the reasons (*pedegrees*) of each actual (*inner*) individual believes. McCarthy's intuition is that a set of sentences cannot describe an individual mental state. Underling each statement there are several reasons that do not appear directly associated to the statement but determine it in a deeper way. Hence the convenience to consider an outer context that caters the reason for particular statement.

Our approach is very close to that way to understand individual mental states. A formalism providing enough flexibility to formalize knowledge and belief is a non-classical semantic of possible worlds, namely, that defined over Kleene's Strong Three-Valued Logic (KSTL) [Kl 52]. The proposed representation framework, then, are the so called three-valued models of Kripke defined below. Those frameworks allow to capture adequately, the dynamic manner in which we consider any agent's knowledge evolve.

Definition of contexts through three-valued models is heuristically well suited, due to the direct relationship that can be establised between them and the Analytic Tableaux. Contexts operations are *concatenation* and *revision*. Through them, contextual knowledge and belief change are permited.

Thus, the paramount of this paper is twofold:

- To show the intuitive representation for contextual knowledge reasoning using Three-Valued Models of Kripke (KTM).
- To outline the close relationship between the operativity on KTM and Analytic Tableaux, such that this last powerful proof method [Fi 88] is used to proceed in a computational perspective but intuition preserving.

The rest of this paper is organized in the following mode: Section two is dedicated to context formal definition. In section three, contextual knowledge and belief definitions are given. Section four is devoted to epistemic reasoning operations over contexts. Finally, in section five the automatization face is outlined.

2 Contexts

Let *true*, *false* and *undefined* be truth-values denoted with t, f and u. For KSTL, propositional language L is defined from a finite set of atomic sentences P. Let F be the minimal set of $L(P)$-formulas. Semantical definitions for disjunction and negation in KSTL are given in Table 1. Conjunction $\wedge$ and implication $\rightarrow$ connectives are defined in the classical way from ψ and $\neg$.

Definition 1 *A three-valued interpretation I, is a valuation function from F to {t, f, u} in accordance with logical connectives definition . I is equivalent to* $I^t \cup I^f \cup I^u$, *where* I^t *is the set of true formulas,* I^f *the set of false formulas and* I^u *the set of undefined formulas . Let **I** be the set of three-valued interpretations of formulas in F.*

2.1 Information order

The proposed approach use the information order given in [Be77] to deal with knowledge and belief [Be 91]. The intuition indicates that is natural to consider the following :

- Having true, false and undefined statemens, true or false ones provide more information than undefined statements.

We propose that when undefined information turns up defined, as true or false, beliefs could increase, and conversely. Formally, the **information order** among t, f and u truth-values, denoted by $\preceq$, is defined as follows: $u \preceq t$, $u \preceq f$ and t,f are not comparable. In addition $t \preceq t$ and $f \preceq f$.

Let Υ be a subset of $\mathbf{I}$. The information order $\preceq$ is extended over Υ in the following way: Given $I, I' \in \Upsilon$, $I \preceq I'$ is satisfied if and only if $I^t \subseteq I'^t$, $I'^f \subseteq I^f$ and $I^u \supseteq I'^u$. The order $\preceq$ is a partial order on Υ. In this case is said that I' is an **information refinement** of I with respect to the set of formulas F.

Table 1: KSTL

φ	ψ	$\varphi \vee \psi$	φ	$\neg\varphi$
t	t	t		
t	f	t		
f	u	u		
f	t	t	t	f
f	f	f	u	u
u	u	u	f	t
u	t	t		
u	f	u		
u	u	u		

2.2 The three-valued models of Kripke

Definition 2 *Let* $v: W \longrightarrow \mathbf{I}$ *be a global valuation assigning to every* $w \in W$ *a three-valued interpretation in **I**,* $w_0 \in W$, *and* $R \subseteq W \times W$. *A* **three-valued model of Kripke** *is a 4-tuple* $K = <w_0, W, R, v>$.

By considering the order $\preceq$ as the possibility relation R over three-valued worlds (see figure 1), **the specific models used in our epistemic proposal** are obtained, having consequently, the following form, $K = <w_0, W, \preceq, v>$, where, $w_0 \preceq w$ for every $w \in W$ *if and only if* $v(w_0) = \mathbf{I}_0 \preceq \mathbf{I} = v(w)$.

Those three-valued models of Kripke should constitute the contexts over whom information is epistemically characterized in our approach. Those contexts permit the capturation of the intuitions that knowledge in a world depends of *worlds being explored*, it means, of the context information. Gradual exploration of worlds, through which knowledge is extended, is established using the information order.

Let $K = <w_0, W, R, v>$ *be* a three-valued model of Kripke, $w \in W$, P an atomic formula in language L, and φ, ψ composed formulas in the same language. In accordance with semantical definition of connective in table 1 the following satisfiability definition is given.

Definition 3 *A formula* φ *such that* $v(w)(\varphi) = t$ *for some world* w *in **K**, is said* ***satisfiable in K***, *which is denoted* $K, w \models \varphi$. *Thus,* $K, w \models \varphi$ *if and only if* $v(w)(\varphi) = t$.

A set Δ *is satisfied in **K** whenever every formula in* Δ *is satisfied in **K**. j is* **valid** *in **K** if and only if j is satisfiable in every* $w \in W$, *which is denoted,* $K \models \varphi$.

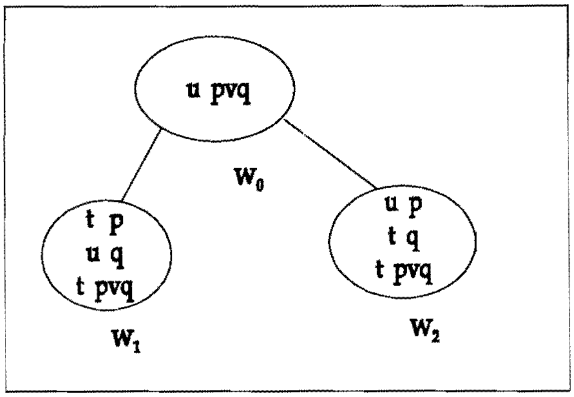

Figure 1: Information order as relation of possibility

3 Contextual knowledge and belief

Above definitions of formulas satisfiability and validity should depend from context K. In a formal setting, a context is fundamentally determined from the valuation v. This relativity is mantained in our epistemic definitions: we propose there is no *absolute* knowledge or belief, but both are relative to current context information. Hence, the epistemic status that formulas describing facts in a *neutral way* have, it directly depends from the underling interpretation in the context.

Our feeling about knowledge and belief formalization coincides with the commented by Kripke and Hintikka, concerning the suited use of *certain* semantic of possible worlds in order to formally deal with. However, in contrast with those authors, we paramount as fundamental the use of a semantic of possible worlds, with a relation of accessibility, having a *constructive-like* character. Possible worlds in our approach are semantical refinements of current world, and refinements of possible worlds turn out possible worlds of possible worlds, and so on. This gradual process of refinement allows the modeling of the contextual dynamic of the knowledge growth .

Definition 4 A **world** *z is* **maximal** *in* **K** *if and only if there is no z' in K such that* $z \prec z'$*, where* $\prec$ *means* $z \preceq z'$ and $z \neq z'$.

In our epistemical approach, current maximal worlds evolve in such a way that their information eventually could become knowledge in the context. The condition we consider intuitive to be fullfiled for information becoming knowledge, is to be true in every most informed accessible worlds. By the other hand, current information in some, but not all maximal worlds, is considered belief or *local knowledge* in the context (see figure 2).

Definition 5 φ *is* **knowledge** *in* **K** *if and only if* φ *is satisfiable in every maximal world z in* **K**. *This is denoted*

$$K, w_0 \models K\varphi \quad \text{if and only if} \quad K, z \models \varphi.$$

Definition 6 $K' = < w'_0, W', \preceq, v' >$, *is a* **subcontext** *of* **K** *if and only if:*

1) $W' \subseteq W$

2) there is $w \in W$ *being* w'_0 *a refinement of* w, *and*

3) v' *is the restricion of* v *to* W'.

A subcontext **K'** *of* **K** *is a proper subcontext if and only if* $K' \neq K$.

Definition 7 φ *is* **belief** *in* **K** *if and only if is knowledge in a subcontext* $K'=<w'_0, W', \leq, v'>$ *of* **K**. *This is denoted* $K,w_0 \models B\varphi$ *if and only if* $K', w' \models K\varphi$.

Therefore, belief is *local* knowledge in the context. Notice that this definition remains open the possiblility that $\neg\varphi$ can be belief in other proper subcontext of K. It means that a statement and its negation can be believed in the same model context, whenever each one appear in distinct context's subcontexts. It provides to proceed in our framework with non-consistent information in a non-trivial way. There are common situations in which the involved rational agents need to deal with contradictory information but without lost control of inferred information. It arise natural to consider this kind of information to be satisfied in a restricted scope in the context. In this way, that information is not rejected in the total scope, but nor globally considered. In this sense, our formalism provides an alternative treatment of non-consistent information to paraconsistent logic [Co 74].

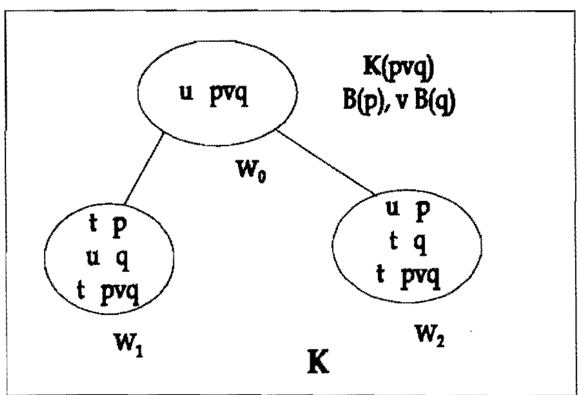

Figure 2: Contextual knowledge and belief

4 Contextual epistemic reasoning

4.1 Knowledge growth

In order to performe reasoning over contexts, the *concatenation* operation over them is introduced. The intuitive idea of concatenation is the following:

- To add information to a maximally informed world in the context, if possible, in such a way that it allows to increase believes.

Let $K_1 = \langle w^1_0, W_1, \preceq, v_1 \rangle$, $K_2 = \langle w^2_0, W_2, \preceq, v_2 \rangle$ be contexts.

Definition 8 *The context* $K = \langle w^1_0, W, \preceq, v \rangle$ *is the* **concatenation** *of* K_2 *whith* K_1, *denoted* $K = K_1 \ominus K_2$, *if and only if :*

1) w^2_0, *is a maximal interpretation of* K_1,

2) $W = W_1 \cup W_2$,

3) $v(w)(\varphi) = v_1(w)(\varphi)$ *for* $w \in W_1$ *and* $v(w)(\varphi) = v_2(w)(\varphi)$ *for* $w \in W_2$.

By definition, $w^1_0 \preceq w'$ for every $w' \in W_1 \cup W_2$. Notice that concatenation is defined over maximal worlds only. Thus, whenever possible, further information is added to maximally informed worlds in the context[1].

The possiblility to concatenate K_2 to K_1 depends from worlds in K_2 can be information refinements from maximal worlds in K_1 (see figure 3). Concatenation is applied to increase knowledge or belief from *undefined* statements in a maximal world, by changing u formulas truth-value to *t* or *f*. From an epistemic viewpoint it means to increase beliefs *taking opinion* about some so far undefined statements. Concatenation provides then a constructive way to extend beliefs from current opinionless information. In the same way, expansion of knowledge is obtained.

Between contexts, concatenation becomes an extension of the relation of possibility worlds. That contexts relation is called of *compatibility*, being underline with the following intuitive idea :

- Given a current context describing a situation, any context being consistently more informed than it, is compatible with it. (Think in the particular case when contexts are given by single worlds.)

Definition 9 *Let* K_1, K_2 *be contexts.* K_2 **is compatible with** K_1 *if and only if there is a succession of contexts* $N_1,\ldots N_n$ *such that* $N_1 = K_1$, $N_n = K_2$, *and* N_{i+1} *is concatenated to* N_i, *for* $i = 1,\ldots,n-1$.

[1] It could be of interest to define concatenation for every world in the context, but this is beyond the scope of this work.

Then, compatible with K_1 are information refinements that can be obtained from a maximal world in K_1 (see figure 3). By definition, any concatenated context to K_1 is compatible with it. Until now, only the concatenation operation has been introduced, which is useful to expand information in the context. Now we should concern with an operation useful to change contexts in a wider sense. It is necessary to make a brief summary about main paradigms of change in epistemic logics.

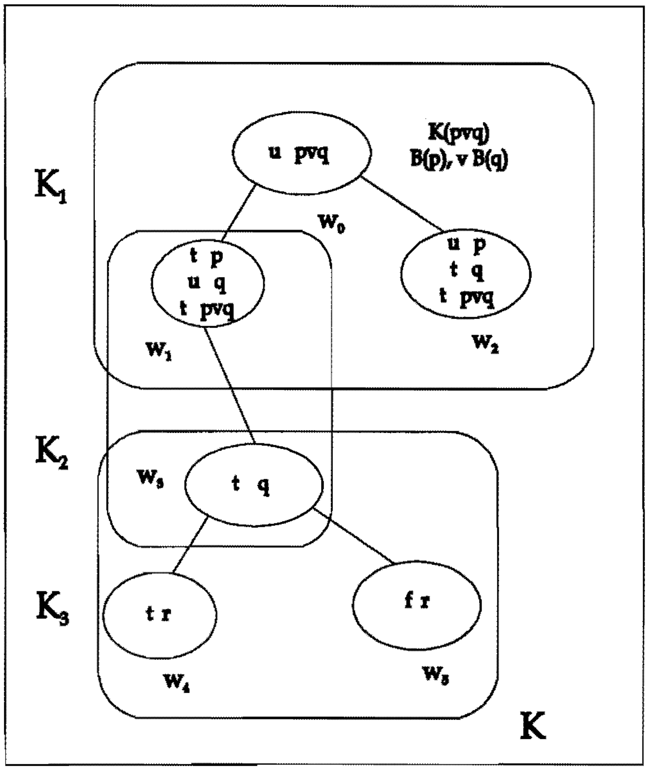

Figure 3: Concatenation of context

4.2 Change of knowledge and belief

Recent major approaches dealing formally with knowledge and belief, are the Alchourron, Gärdenfors and Makinson (AGM) [AlGM 86] and the *Update Theory* of Katzuno Mendelzon [KaMe91]. Both proposals, *known as change of belief*, have becomed classical in epistemic logics and database updating areas. The issue is the adequate treatment of epistemic change, namely, when over statements constituting agent belief, new information is added. AGM propose *expansion*, *contraction* and *revision* operations together with an axioms list to be satisfied for any *revision* operator . KM propose an axioms list in order to updatê the set of beliefs. Semantically, to revise a database Δ with the sentence φ is to take models satisfying φ *closest* to those satisfying Δ. By the other hand, to update Δ whit φ is to choose for each model M of Δ the set of models of φ *closest* to M. The closeness relation, is usually given for a partial order among the models.

4.3 Context change

Given a context K, its epistemic change, namely, change of epistemic formulas status, depends from new added information. It would seem that context changes might be done by adding modal epistemic formulas. However, in our approach becomes unintuitive to change an epistemic context by using a formula *not being epistemically characterized* so far.

Therefore, K is revised only with non-modal formulas; intuitively, only be revised with *neutral information.* But, of course, the result of revising the context K with φ, denoted by K^*_φ, it fully depends from the φ epistemic status in K, if any. Furthermore, it depends from the $\neg\varphi$ epistemic status, due to $\neg\varphi$ is the sentence directly conflicting with φ. In this manner, the (new) epistemic status that φ will have in the revised context will become determined as soon as the revision is performed. It will depend from φ satisfiability over maximal worlds in the revised context.

By revising a context with a formula, or in general with a set of formulas, worlds having unconsistent information with new information, they should be eliminated first. Thereafter, worlds having consistent related information should be *attached.* Whenever added information do not contend with any world information, no world must be eliminated, but only worlds containing new related information -in logical sense- must be attached.

Rejected worlds as well as attached worlds contitute by its own a subcontext, in the revised context. Thus the convenience to establish operation throughout subcontexts. In order to proceed with a context revision, is necessary to precise the maximal sub-contexts of K in which $\neg\varphi$ is (local) knowledge. It determines the effective context revision scope.

Definition 10 *Let K' be a subcontext of K. K'* **is maximal for** φ *in K, if and only if $K', w'_0 \models K\varphi$. Thus, whenever $K, w_0 \models K\varphi$, the maximal subcontext K' for φ is K.*

Definition 11 *Let K be a context and φ a formula of language L. The context $M = K^*_\varphi$ resulting from* ***context K revision with formula*** *φ, is such that $M, z \models \varphi$ for every z maximal world in M.*

Proposition 1 $K^*_\varphi = K$ *if and only $K, z \models \varphi$ for every maximal world z in K. This in the trivial revision case.*

The other opposite is present whenever $\neg\varphi$ is knowledge in context K. In this extreme case, is necessary to revise all the context. By the other hand, having $B\neg\varphi$, it turns necessary to revise each proper K subcontexts in which $\neg\varphi$ is local knowledge. In summary, given the specific circumstances of revision it is realized. In the following we will assume that there is, at least, a subcontext K' in K in which $K', z, \models \neg\varphi$ for every z maximal world in K'. By assuming it, K revision with φ is not trivial.

Theorem 1 *Let $K_1,\dots,K_m$ be sub-contexts of K maximals for , $\neg\varphi$ and $K_{m+1},\dots,K_n$, sub-contexts of K no having worlds satisfing $\neg\varphi$, then*

$$K^*_\varphi = \bigcup_{1\le i\le n} (K_i)^*_\varphi .$$

5 Automatization

Completeness of Gentzen deduction systems for three-valued logics has been characterized by Arnon Avron [Av 91]. This author distinguishes between systems in which the u truth-value denote *unknown* information and those using it to refere to *inconsistent* information. The most known of the first approach corresponds to Kleene's and Lukasiewicz's logics, while for unconsistent view is the Paraconsistent Logics of Newton d'Acosta [Co 74].

Mechanization has been developed recently, e.g. [Wa 94]. Among the most successful are the based in the Analytic Tableaux demonstration method. It is due to the flexibility and heuristically adequacy of that method, that it is capable to deal with complex information. Actually, there are automatic provers not only for three-valued logics but for multivalued logics e.g. [HaBG 96]. We referer the reader to [Sc 94], where a summary of major tableau-based theorem provers is given. Current versions of most of them are broader and powerful than reported there.

In our knowlege and belief contextual approach, the epistemic conditions can be added through tableaux-like rules, over the open branches of a tableaux containing current knowledge. It is easy to show the natural manner in which a context can be represented by an Analytic Tableaux, through the following considerations:

- Current context is contained in the set of paths of the associated tableau.
- The information order over worlds in the context determines the order in which tableaux rules are applied on the initial tableau.
- Whenever a formula becomes *true* in the context, the logical closure that such assigment conveys, by application of tableaux rules, is allowed.
- Classical α, β, π, ν-rules of tableaux [Fi 88] when applied over *true* formulas, evolve in tableau paths such that its three-valued models counterparts are the concatenations of current three-valued model.
- Conversely, extension by concatenation of contexts should correspond with tableau extensions over open branches.

Incorporation of above considerations can be done appending to classical tableaux rules, the following one denoted UD:

- Whenever an ***undefined*** formula becomes *true* or *false*, then a tableau is open and all its logical consequences are deduced.

For further details about the topic, the reader is refered to [Al 97].

Concluding remarks

In this paper the formalization of context is proposed by using Kripke's three-valued models. Contextual knowledge reasoning is performed through context operation of concatenation and revision. Based on them, extension and change of knowledge in a context is attended. Direct correspondence between so defined contexts and Analytic Tableaux is outlined. That reason lets to affirme the heuristical adequacy of the context formalisation proposed. Operation between contexts can be easily implemented as tableaux-like rules. This last point is the topic of our current research.

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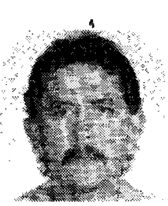

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PÁG. 52 Línea 33 [7]...	Línea 33 [7] A. Rosenfeld. Digital Topology. *Amer.Math. Montly, 86 :621-630, 1979.* [7] G. Matheron. *Random Sets and Integral Geometry.* John Wile and Sons, New York, 1995. [7] B.Vazquez, J.H. Sossa and J.L. Díaz de León Autoguided Vehicle Control using Expended Time B-splines. In *IEEE International Conference on Systems, Man and Cybernetics,* pages 2786 -2791, San Antonio Texas, October, 1994. [7] P. Perner, P. Wang and A. Rosefeld (Eds). Advances in Structural and Syntactical Pattern Recognition, Springer 1996.
PÁG. 53 Línea 14 Loa articulos deben ajustarse a las siguientes especificaciones :	Línea 14 Los artículos deben ajustarse a las siguientes especificaciones :