# Modeling Multiagent Knowledge Systems based on Implicit Culture

**Bogdan Okreša Đurić, Markus Schatten**
University of Zagreb
Faculty of Organization and Informatics
Pavlinska 2, 42000 Varaždin, Croatia
bogdan.okresa.duric@hotmail.com, markus.schatten@foi.hr

**Abstract.** *Since there are many ways in which one could establish a multiagent knowledge-based system, some of the most popular ways should be evaluated and presented in an end-user-friendly form. One such assumption is based on the phenomenon of implicit culture, where agents interact with each other. Such a system has been developed, but has some room for improvements, so as to be easier to understand, easier to implement and comprehend. Thus the main aim of this paper is to define the agents cooperating in a multiagent knowledge-based system, using GPLKTF through the usage of PLKFT, language of propositional logic (PL) paired with knowledge (K), temporal (T) and forgetfulness (F) operators. This way, the authors would like to give implementation guidelines based on the foundations implicit culture based multiagent systems as put forward earlier.*

**Keywords.** implicit culture; multiagent system; knowledge management; PLKTF; GPLKTF

## 1 Introduction

Multi-agent systems (MAS), an important new paradigm in software engineering provide a powerful metaphor for building knowledge management systems. An important issue, as opposed to artificial intelligence, is how agents learn in a collaborative environment. When it comes to learning, in artificial intelligence one is concerned with the individual learning of some agent mostly based on the perception of its environment, while in MAS the environment includes interaction and collaboration with other agents and thus learning from it's peers.

A conceptualization of such learning is the idea of implicit culture [3, 2, 1], which can informally be defined as an "relation existing between a set and a group of agents such that the elements of the set behave according to the culture of the group" [2]. Thus, agents acquire implicit knowledge from agents they collaborate with in a group through interaction with them - one might say they adapt to the culture of the group.

To model such a relationship in MAS, we will introduce GPLKTF, a graphical language for modeling complex MAS. We believe that with applying the knowledge, group knowledge, distrubuted knowledge and common knowledge operators together with the usual temporal operators of PLKTF (the non-graphical counterpart of GPLKTF) and agent forgetfulness we can formalize a implicit learning, the complex processes happening in implicit culture based MAS.

The rest of the article is organized as follows: in section 2. we give a profound review of the implicit culture concept and provide a formal definition. In section 3. we introduce GPLKTF with special accent on the operators needed to formalize implicit learning. In section 4. we demonstrate how implicit culture can be modeled by using GPLKTF. In the ending section 5. we draw our conclusions and provide guidelines for future research.

## 2 Implicit Culture

Implicit culture phenomenon is generally described as a situation of the observed world, when an agent, ignorant of the rules of acting of another group of agents, learns about their ways and adopts these rules the group works by, getting to know the groups culture, assimilating in a way, behaving in the way the group does. More formally, we can say that implicit culture can be defined as a "relation between a set and a group of agents such that the elements of the set behave according to the culture of the group." [2] The system responsible for establishing implicit culture phenomenon is System for Implicit Culture Support (SICS).

Defined in a formal way, according to [2], implicit culture is defined as follows.

Should we consider agents and objects as primitive concepts to which we refer with strings of type agent_name and object_name, respectivly, we can define the set of agents $P$ as a set of agent_name strings, and the set of objects $O$ as a set of object_name strings, along with the environment $Env$ as a subset of the union of $P$ and $O$, i.e. $Env \subseteq (P \cup O)$. Furthermore, let action_name be a type of strings, $E$ be a subset of the environment ($E \subseteq Env$) and $s$ an action_name.

An action is defined as:

**Definition 1** *An action $\alpha$ is the pair $\langle s, E\rangle$ where $E$ is the argument of $\alpha$ ($E = arg(\alpha)$).*

Let $Act$ be a set of actions, and $A \subseteq Act$ and $B \subseteq Env$. A scene is then defined as:

**Definition 2** *A scene $\sigma$ is the pair $\langle B, A\rangle$ where, for any $\alpha \in A$, $arg(\alpha) \subseteq B$; $\alpha$ is said to be possible in $\sigma$. Set of all scenes is called a scene space $S_{(Env,Act)}$.*

Let T be a numerable discrete totally ordered set, with the minimum $t_0$, called discrete time. Let $a \in P$ be an agent, and, remember, $\alpha$ is an action and $\sigma$ a scene. A situation is then defined as:

**Definition 3** *A situation at the discrete time $t$ is the triple $\langle \alpha, \sigma, t\rangle$. In general, we say that agent $a$ faces the scene $\sigma$ at time $t$.*

An execution of an action is defined as follows:

**Definition 4** *An execution at time t is a triple $\langle a, \alpha, t\rangle$. We say that agent $a$ performs action $\alpha$ at time $t$.*

Furthermore, a situated executed action is defined as follows:

**Definition 5** *An action $\alpha$ is a situated executed action if there exists a situation $\langle a, \sigma, t\rangle$, where agent $a$ performs action $\alpha$ at the time $t$ and the action $\alpha$ is possible in situation $\sigma$. We say that $a$ performs $\alpha$ in the scene $\sigma$ at the time $t$.*

After each action, an alteration happens in the current environment, presenting the agent with a new scene. The way this change happens depends heavily on the characteristics of the environment and the laws its dynamics is described by. An action performed by an agent in time $t$ will have the defined effect on the environment and the agent will be faced with the new scene at the time $t + 1$.

An expected action is defined as:

**Definition 6** *The expected action of the agent $a$ is the expected value of the variable $h_{(a,t)}$, that is $E(h_{(a,t)})$.*

**Definition 7** *An expected situated action of the agent $a$ is the expected value of the variable $h_{(a,t)}$ conditioned by the situation $\langle a, \sigma, t\rangle$, that is $E(h_{(a,t)}|\langle a, \sigma, t\rangle)$.*

In the situation when we have more than one agent, we define a party as:

**Definition 8** *A set of agents $G \subseteq P$ is said to be a party.*

Having many agents, we have to make sure they understand each other and communicate. Therefore, let $Lang$ be a language we use to describe the environment and everything needed, and let $G \subseteq P$ be a party of agents. Then we can introduce some constraints into the world of our agents, and define cultural constraint theory as:

**Definition 9** *The Cultural Constraint Theory for G is a theory expressed in the language $Lang$ that predicates on the expected situated actions of the members of G.*

Now that we have order amongst the party of agents, we can define a group as follows:

**Definition 10** *A party $G$ is a group if there exists a cultural constraint $\Sigma$ for $G$.*

A group of agents acts according to their cultural constraint theory, so we have cultural actions defined as:

**Definition 11** *Given a group $G$, an action $\alpha$ is a cultural action with regard to $G$ if there exists an agent $b \in G$ and a situation $\langle b, \sigma, t\rangle$ such that $b\{E(h_{(b,t)}|\langle b, \sigma, t\rangle) = \alpha\}$, $\Sigma \nvdash \bot$ where $\Sigma$ is a cultural constraint theory for $G$.*

Finally, with all the definitions set, we come to the final part; we shall define implicit culture as:

**Definition 12** *Implicit culture is a relation between two parties G and $G'$ such that G and $G'$ are in relation iff G is a group and the expected situated actions of $G'$ are cultural actions with regard to G.*

In the end, we reached the implicit culture phenomenon, which we define as:

**Definition 13** *Implicit culture phenomenon is a pair of parties $G'$ and G related by the implicit culture.*

# 3 PLKTF

The language PLKTF (Propositional Logic + Knowledge + Temporal operators + Forgetfulness) is defined as [4, 5, 6]:

**Definition 14** *PLKTF is a set of formulae. A formula in PLKTF above a set of basic propositions $P$ and a set of agents $A$ is defined recursively:*

- *- Every basic proposition from $P$ is a formula*
- *If $F$ and $G$ are formulae then so are $\neg F$, $(F \wedge G)$, $(F \vee G)$, $(F \Rightarrow G)$, and $(F \Leftrightarrow G)$.*
- *If $F$ is a formula then so is $K_i(F)$, $\forall i \in A$ whereby $K_i$ is the modal knowledge operator.*
- *If $F$ and $G$ are formulae then so are $N(F)$ (next), $A(F)$ (always), $Ev(F)$ (eventually), $F\ U\ G$ (until), $F\ W\ G$ (unless or waiting for) whereby $N$, $A$, $Ev$, $U$ and $W$ are temporal operators for the future.*

- *If $F$ and $G$ are formulae then so are $N^p(F)$ (previous), $A^p(F)$ (has always been), $Ev^p(F)$ (once), $F\ U^p\ G$ (since), $F\ W^p\ G$ (back to) whereby $N^p$, $A^p$, $Ev^p$, $U^p$ and $W^p$ are temporal operators for the past.*
- *If $G$ is a formula then so is $F_i(G)$, $\forall i \in A$ whereby $F_i$ is the modal forgetfulness operator.*

The knowledge of a group of agents is defined as:

**Definition 15** *Let $M$ be a Kripke structure and $p(t)$ the state of a multi-agent system at time t. Let furthermore $G = \{1, 2, ..., n\}$ be a group of $n$ agents. With $E_G(H)$ we denote that everyone in group $G$ knows $H$. Thus $(M, p(t)) \vDash E_G(H)$ iff $(M, p(t)) \vDash K_i(H)$, $\forall i \in G$.*

The common knowledge of a group of agents is defined as:

**Definition 16** *Let $M$ be a Kripke structure and $p(t)$ the state of a multi-agent system at time t. Let $G = \{1, 2, ..., n\}$ be a group of $n$ agents. With $C_G(H)$ we denote that H is the common knowledge of group G. Thus $(M, p(t)) \vDash C_G(H)$ iff $(M, p(t)) \vDash E^k_G(H)$ where $k = 1, 2, 3, ...$; $E^0 = H, E^1 = E(E^0), ..., E^{k+1} = E(E^k)$.*

Distributed knowledge of a group of agents is defined as:

**Definition 17** *Let $G = \{1, 2, ..., n\}$ be a group of n agents. Let further $K^{p(t)}_i$, $i = 1, ..., n$ denote the knowledge of agent $i$ in state $p(t)$. With $D_G(H)$ we denote the distributed knowledge of group G, whereby $(M, p(t)) \vDash D_G(H)$ holds iff $(K^{p(t)}_1 \cup ... \cup K^{p(t)}_1) \vdash H$.*

GPLKTF (Graphical PLKTF) is a graphical language for modeling complex multiagent systems. It was introduced by [7] and later extended in [8] and [9]. It defines 22 basic graphic elements including: formula, state, possibility relation, run, formula holding at state, formula not holding at state, disjunction, conjunction, implication, equivalence, agent knows formula in state, agent doesn't know formula in state, as well as temporal operators next, eventually, always, until, unless, previously, once, always been, since, and back to. These elements were later extended with an additional element (forgets) for the forgetfulness operator.

# 4 Modeling Implicit Culture with GPLKTF

Let $G$ be a group of agents ($G \subseteq P$) such that the way they act is defined by $\Sigma$, their cultural constraint theory. This group of agents has their usual behaviour, though $\Sigma$ expands as the agents communicate with each other; they evolve, we could state. Let $a$ be an agent, $a \in P$ and let $G'$ be a group without agent $a$ ($G' = G - a$). This agent $a$ is trying to imitate and act along the rules of $G$ (namely, $\Sigma$), but has some predefined actions supposed to be carried out in specific environments.

## 4.1 Agent has no contradicting old knowledge

Let $F$ be a formula, representing some knowledge. Furthermore, let $F$ be common knowledge of $G'$ ($C_{G'}(F)$). What we want to find out is the way agent $a$ will learn $F$ from the group $G'$. Let $K_a(F) = \bot$, denoting that agent $a$ does not know $F$ in the observed structure.

We start observing the described situation at time $t_0$. That is the moment agent $a$ knows nothing, and the group $G'$ acts according to $\Sigma$. In PLKTF we express:

$$(M, p(t_0)) \models \neg K_a(F)$$

Assuming $C_{G'}(F) \forall t \in T$, whereby $T = 0, 1, 2, ...$ is linear time, we shall not represent knowledge of $G'$ in PLKTF expressions.

Agent $a$ is going to learn $F$ eventually, at a moment in the future. Expressed in PLKTF:

$$(M, p(t_0)) \models Ev(K_a(F))$$

.

Let $t \in T$, such that $t = t_0 + n$, be the moment at which agent $a$ learns $F$. At time $t - 1$ the following situation applies:

$$(M, p(t-1)) \models N(K_a(F))$$

Finally, time $t$ is when agent $a$ learns $F$:

$$(M, p(t)) \models K_a(F)$$

Then we have the moment immediately after $t$:

$$(M, p(t+1)) \models N^p(K_a(F))$$

At last, in general, at any moment $t' \in T : (t+1) < t'$, we define that $K_a(F)$ from a point in time past:

$$(M, p(t')) \models Ev^p(K_a(F))$$

The last formula is depicted on figure 1. Above we described the situation where agent $a$ has no contradicting old knowledge and is going to learn $F$, a piece of knowledge group of agents $G'$ knows. Agent learns $F$ at time $t$, the moment from which $K_a(F) = \top$. Wether the agent posesses the ability to forget is not a concern of ours right now, since we have been considering the situation where agent has no contradicting old knowledge. For the sake of this section, let us suppose the agent cannot forget what they learned.

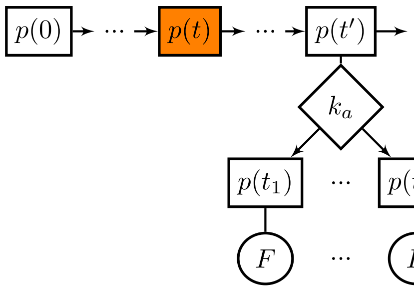


Figure 1: Agent $a$ will eventually know $F$ in GPLKTF

### 4.2 Agent has some contradicting old knowledge

Let $F$ be a formula, representing some knowledge. Furthermore, let $C'_G(F)$, i.e. $F$ is common knowledge of group $G'$. What we want to find out is the way agent a will learn $F$ from the group $G'$. Let $K_a(F) = \perp$, denoting agent $a$ does not know $F$ in the observed structure. Let $H$ be a formula in contradiction with $F$, but $K_a(H) = \top$, meaning that $a$ knows $H$ at given time, but this knowledge is in direct opposition to $F$ and accordingly $\Sigma$ for $G$.

We start observing the described situation at time $t_0$. That is the moment agent $a$ knows his old knowledge, and the group $G$ acts according to $\Sigma$. In PLKTF we express:

$$(M, p(t_0)) \models \neg K_a(F) \wedge K_a(H) \wedge A^p(K_a(H))$$

Assuming $C_{G'}(F)$ and $C_{G'}(\neg H)$, and that these formulae remain true $\forall t \in T : t \geq t_0$, we shall not represent knowledge of $G'$ in PLKTF expressions.

Since agent $a$ is going to learn this new piece of knowledge ($F$), which will be in opposition with $H$, the agent has to forget this contradicting old knowledge before he learns the new one. We assume that agent $a$ is going to know $F$ at time $t \in T : t = t_0 + n$, where $n$ equals the agent's learning speed. In PLKTF we express:

$$(M, p(t_0)) \models Ev(K_a(F))$$

According to the former assumption, agent $a$ is going to forget $H$ by the time he learns $F$:

$$(M, p(t_0)) \models Ev(F_a(H))$$

In a more simple manner, we can state:

$$(M, p(t_0)) \models Ev(K_a(F)) \wedge (K_a(H) U K_a(F))$$

Let $t$ be the time when agent $a$ learns $F$ ($t = t_0 + n$). Agent $a$ has to forget $H$ before he can learn $F$ because these are two opposing pieces of knowledge. Therefore, at time $t - 1$ we have:

$$(M, p(t-1)) \models F_a(H) \wedge N(K_a(F))$$

At time $t$ we have situation where $H$ was forgotten at time $t - 1$, and $F$ is being learned:

$$(M, p(t)) \models K_a(F) \wedge N^p(F_a(H)) \wedge \neg K_a(H)$$

Immediately after agent $a$ learns $F$, the situation is as follows:

$$(M, p(t+1)) \models K_a(F) \wedge \neg K_a(H)$$

In general, at any moment $t' \in T : (t+1) < t'$, we can state that agent $a$ knew $H$ until the moment when it learned $F$:

$$(M, p(t')) \models K_a(H)\ U^p\ K_a(F)$$

Figure 2. shows this expression in GPLKTF. Through these expressions, we have provided a representation of an agent learning new knowledge which is known to a group of agents and forgeting old contradicting knowledge, through a span of time.

## 5 Conclusion and further work

Motivation for this paper came from the fact that there is no rendition of implicit culture in PLKTF, while such a model of implicit culture could be useful for modeling MAS based on implicit culture, for the benefits it presents, considering logical, knowledge, temporal and forgetfulness operators.

In this paper we showed how implicit culture can be modeled by using PLKTF using two examples. The first, a more simple one, depicts the use of PLKTF when an agent has no contradicting old knowledge. This agent is going to learn a piece of knowledge which the observed group of agents knows already. Such a process is going to happen at moment $t \in T : t = t_0 + n$, where $n$ is a variable depending on how fast a learner the agent is. The second example represents a slightly more complex situation, where the agent has some old knowledge which contradicts the knowledge

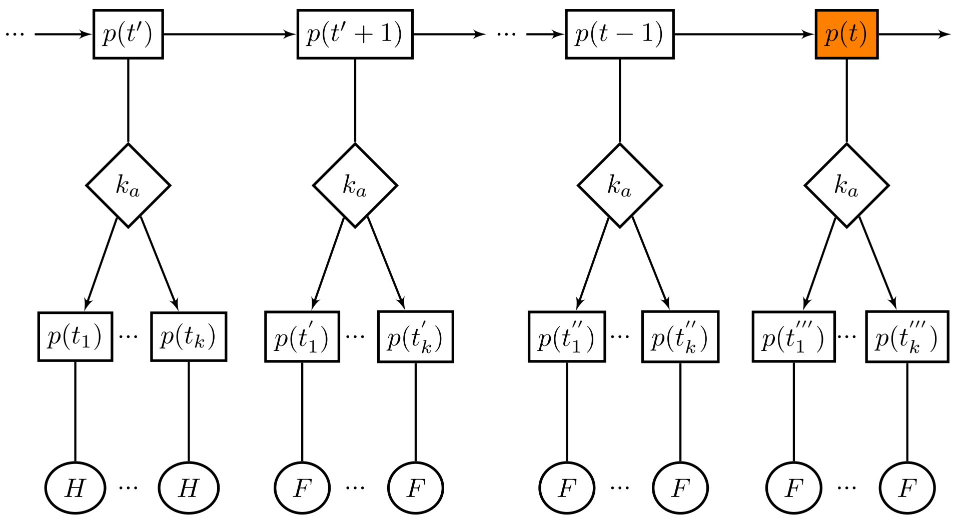


Figure 2: Agent $a$ knew $H$ until the moment he learned $F$

of the group. Since an agent cannot operate with contradicting knowledge, it has to forget this old knowledge before it can learn the new one. If learning of the new happens at time $t \in T : t = t_0 + n$, the agent forgets the old knowledge at time $t - 1$.

Using this conceptualization we are now able to analyze more complex implicit culture situations including implicit learning of groups of agents, teaching agents, all-knowing agents and others. A very interesting situation is the case of intercultural implicit learning - what will happen if two groups of agents interact? How will they transfer their knowledge mutually? Who will learn, and who will forget? These and similar questions are subject to our future research.

# References


[1] BIRUKOU, A., BLANZIERI, E., AND GIORGINI, P. Implicit culture as a tool for social navigation. Tech. rep., Informatica e Telecomunicazioni, University of Trento, 2006.

[2] BLANZIERI, E., GIORGINI, P., GIUNCHIGLIA, F., AND ZANONI, C. Implicit Culture-Based personal agents for knowledge management. 2003, p. CH439.

[3] BLANZIERI, E., GIORGINI, P., MASSA, P., AND RECLA, S. Implicit culture for multi-agent interaction support. C. Batini, F. Giunchiglia, P. Giorgini, and M. Mecella, Eds., vol. 2172 of *Lecture Notes in Computer Science (LNCS)*, Springer-Verlag, pp. 27–39.

[4] MALEKOVIĆ, M. Reasoning about knowledge: Some agent properties. *Journal of Information and Organizational Sciences 22*, 1 (1998), 1–11.

[5] MALEKOVIĆ, M. Agent properties in multi-agent systems. *Informatica, An International Journal of Computing and Informatics 23* (1999), 283–288.

[6] MALEKOVIĆ, M. Multi-agent systems: Incorporating knowledge and time. *Journal of Information and Organizational Sciences 22*, 2 (1999), 97–105.

[7] MALEKOVIĆ, M. GPLKT: A graphic method for multi-agent systems. *Informatologia 33*, 3-4 (2000), 135–265.

[8] MALEKOVIĆ, M., AND ČUBRILO, M. Some properties of agents in multi-agent systems: Incorporating forgetfulness. In *IEEE International Conference on Intelligent Engineering Systems, Helsinki, Finska, 16-18. 09. 2001.* (Helsinki, 2001), B. Patkai and I. Rudas, Eds., Institute of Production Engineering, Tempere University of Techn, pp. 181–184.

[9] MALEKOVIĆ, M., AND ČUBRILO, M. Some properties of forgetfulness in multi-agent systems. In *IEEE International Conference on Intelligent Engineering Systems* (Opatija, Croatia, 2002), A. Lovrenčić and I. Rudas, Eds.