A LOGICAL MODEL OF COOPERATION

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Abstract: This paper proposes a formal definition of the concept of cooperation in distributed systems. The proposed model is based on the use of Modal Logic. More precisely, cooperating activities are seen as activities that can be in different cooperating schemas and, as a consequence, follow different Modal logic systems: T, B, S4, S5. It is in particular shown how this model, using a four-valued logic, is able to express contradictions, because predicates can be both True and False in different domains (scopes) of cooperation.

I. INTRODUCTION

Designing present distributed systems is implicitly or explicitly based on two specifications: the requested properties and the expected behaviours. These specifications are stated using different formal approaches, as Temporal Logic, CCS, Petri nets, Formal Description Techniques (such as Estelle and LOTOS) [MAN] [MIL] [DIA] [DIA1] [VAN]. Different logics have been developed to specify system properties and many studies are presently based on interpretations of Modal Logic [HUG]. Modal Logic gives in particular a good semantical basis for expressing and proving safety and liveness properties. These approaches proved to be of high interest for the design of complex ISO, CCITT and IEEE protocols and services.

Nevertheless, up to now, much less attention has been paid for understanding the basic concepts that exist before and so in some sense imply the selected design.

Defining such a higher level is the purpose of this paper. It considers the cooperative framework in which the distributed behaviour has to occur. Furthermore, its basis will be a formal model, compatible with the previous ones, based upon Modal Logic. How this model is able to express high level cooperation and how it can be located on top of communications will be discussed in the sequel. It will be shown that Modal Logic is able to express powerful semantical links existing between cooperating activities.

The proposed logic based model has been developed in order to formalize an intuitive meaning of cooperation. As the need of a formal semantical model of cooperation is considered to be a major challenge, the syntactical aspects of the logics are not considered in this paper, and only semantics and relationship to reality are addressed.

We shall first make the distinction between communication and cooperation by assuming that communication follows the general OSI Reference model [ZIM]. Also, a distinction is made between cooperation and decision, because decision is assumed to be located at a layer higher than cooperation and is dependent on given cooperations. Then, those decisional mechanisms including entity internal constraints, such as beliefs and desires [FAG][SHO], are not considered in this paper: in the three-layered view - communication, cooperation, decision - proposed here, the latter is assumed to enforce more or less constraints on the potential cooperations, including conflicts [ROS].

After an brief introduction to Modal Logic, Section 2 presents the formal Logic Model whose purpose is to define cooperative logic values and to provide a framework for expressing general cooperations. Section 3 shows that for some cooperation structures don't care values exist and their semantics are given. Section 4 completes the model by presenting how cooperation domains can lead to possible contradictions between these domains and suggest the definition of pragmatics as semantical choices.

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II. A LOGICAL MODEL FOR COOPERATION

Many proposals use non classical logics to express the relationships and properties amongst communicating activities [MAN]. Most of them are based on the possible world semantics of Modal Logic. Furthermore, Modal Logic can easily be related to the set of all possible distributed computations and so allows one to check global behaviours [EME].

As a consequence, the proposed model is based on Modal Logic: it can be related to behaviours and properties and it seems to provide an intuitive and adequate support for expressing cooperations. Also, it allows the expression of subtle and real logical contradictions that may exist in cooperation; this is the case when many different logics, and so consistent true and false values simultaneously exist in susbets or domains of complex cooperative systems.

Cooperations will consequently be defined as sets of different semantics, embedded in adequate logical systems.

II. 1. Modal Logic

Modal Logic is the logic of possibility and necessity. As only semantics will be considered in this paper, validity plays a central role. For Modal Logic, validity is based upon Kripke structures defined as ordered triples <W, **R**, V>, where:

- W is a set of objects or worlds $W = \{w_i\}$

- **R** is dyadic relation defined over the members of W and

- V is a value assignment.

W contains the considered objects or worlds.

R is of importance as it defines different logic systems. Modal Logic can be divided into different logic systems; these systems are such that the validity of the modal formulas depend on them: some logic formulas are valid in some systems while they are not valid in other systems. The most important modal systems, needed in the sequel, are T, B, S4, S5. If **R** is reflexive, it defines a T-system; if **R** is reflexive and symmetrical, it defines a B-system; if **R** is reflexive and transitive, it defines a S4-system; and if **R** is reflexive, symmetrical and transitive, it defines a S5-system.

V is a value assignment satisfying the following conditions:

a) for any propositional variable p_j and any world w_i, either $V(p_j, w_i)=0$ or $V(p_j, w_i)=1$

b) for any wff alpha, for any w_i, $V(\neg alpha, w_i)=0$ if $V(alpha, w_i)=1$ or $V(\neg alpha, w_i)=1$ if $V(alpha, w_i)=0$

c) for wffs alpha and beta, for any w_i, $V(alpha \vee beta)=1$ if $V(alpha, w_i)$ or $V(beta, w_i)=1$; $V(alpha \vee beta)=0$ otherwise

d) for any wff alpha and for any w_i, $V(L(alpha), w_i)=1$ if for every w_j such that $w_i R w_j$, $V(alpha, w_j)=1$; otherwise, $V(L(alpha), w_i)=0$.

L and M can be defined as usual : $M(p)=\neg L \neg(p)$.

There are important differences between these systems. Selecting W, the set of worlds, and **R**, the relation amongst them, is of the utmost importance as they imply the definition of validity. W and **R** will be discussed now for proposing a formal model of cooperation.

II. 2. A Model for Cooperative Systems

The semantical meaning that will be given to cooperation in the model proposed here is that cooperation means sharing information: an activity cooperates with another activity if the former makes its information predicates available to the latter.

To formalize this, let A be a set of activities, $A = \{A_i\}$. Let us now consider each activity, A_i, maintains a set of information or of predicate values, and is embedded in a relational structure linking it to other activities. Furthermore, some predicates will be local and some others exported, the exported predicates being the ones that characterize the cooperation relation.

Let $P = \{p_i\}$ be the set of predicates that are exported by a given activity A_i and so that can potentially be known outside A_i when it agrees to cooperate.

Definition 1: A_i is in cooperation (agree to cooperate) with A_j if A_i allows A_j to get the values of its exported predicates; the exported predicates become known by A_j.

Let **R** be a relation on the members of A such that, if one activity, say A_i, is willing to cooperate with another activity, say A_j, then the ordered pair (A_j, A_i) belong to **R**: an arc is drawn from A_j to A_i , which means that A_j can access and get the exported information predicates located in A_i. The graph given in Figure 1-a means that A_j can access the predicates exported by A_i. In the general case, given a set A, the cooperation structure among the members of A gives **R**, a directed graph, the cooperation graph, having as many vertices as there are elements in A. Figure 1-b gives an example of such a graph.

Note that such a model gives a meaning different from the classical view of knowledge [HAL]. The difficulty, when modelling knowledge, is how to select the set of worlds which are accessible to a given agent. When considering distributed behaviours, the set of accessible worlds can be nicely defined by the reachability graph, the graph of all possible states [JUA]. This is quite coherent with the use of modal and temporal logics for verifying safety and liveness properties in distributed systems. Also, here, the set of the accessible worlds is made precise, but no more related to behaviours. It has the following different intuitive basis: each of the worlds is one activity and the set of worlds that are accessible to an activity A_i is the set of activities that are (have agreed to be) in cooperation with A_i. Consequently, the Kripke structure is exactly the cooperation graph. This view leads to a high level modeling, which seems to be intuitively close to real life cooperations. It only considers information states and not intentional states [WER] as the latter are considered to belong to a different conceptual layer.

a) Evaluating predicates

Let us now give the semantics for such graphs. Let us assume that, in the general case, activities are able to get new values that update their predicates. As a consequence, predicate values may change.

Two resulting cooperative behaviours are possible:

-the first one is such that when a predicate value changes, its new value is sent to the nodes it cooperates with;

-the second one assumes that no information is sent until explicitly requested by a cooperative node.

The case that will be considered here is the one where the relevant information do not lead to frequent value changes: the former view will be used later on.

b) Characterizing **R**

Of course, **R** is reflexive, and $A_i\mathbf{R}A_i$, because it is assumed that any activity knows its own predicates. Nevertheless, in the general case, **R** is neither symmetric nor transitive.

If **R** is symmetric, the cooperation is called bilateral; if **R** is transitive, the cooperation is called (completely) hierarchical; if **R** is both symmetric and transitive, it is said to be perfect or total.

The semantics of the cooperation, which define the behaviour of a given activity, will then depend on relation **R**, i. e. the cooperation framework.

Let us now consider Figure 2. Its nodes, which define W and **R**, can be considered different ways. For instance, let us consider first only nodes A1, A2 and A3 and arcs connecting them. Those nodes are in total cooperation, as the cooperation is restricted to vertices A1, A2 and A3 and to the 6 arcs relating them: **R1**, such a restriction of **R**, is symmetric and transitive. On the other hand, restricting now the graph to the set {A3, A5, A8, A9} and to the arcs relating them, leads to **R2**(A3, A5, A8, A9), which shows that the subgraph including A3, A5, A8, A9 is hierarchical. It then clearly appears that A3, for instance, can be considered as being involved in two different (sub)cooperations, one being total, **R1**(A1, A2, A3), and the other hierarchical, **R̃2**(A3, A5, A8, A9. Also, of course, A3 can be seen as involved in one global cooperation relation, the one defined by all nodes and all arcs existing in Figure 2.

Consequently, A3 can be related to other activities in different settings: selecting {{A1, A2, A3}} defines a total cooperation for A3; selecting {{A3, A5, A8, A9}} defines a hierarchical cooperation and selecting the whole graph defines a general cooperation.

It follows that the logic that has to be followed by an activity depends on the cooperations the activity is involved in:

-when an activity is involved in a total cooperation, it will follow the logic of the S5 modal logic system together with all activities involved in this total cooperation;

-when it is involved in a hierarchical cooperation, it follows the logic of the S4 system together with the activities involved in this hierarchical cooperation;

-when it is involved in a bilateral cooperation, it will follow the logic of the B system together with the activities involved in this hierarchical cooperation;

-in all other cases, it follows the logic of the T system.

c) Domains of cooperation

Let us now consider how predicates can be evaluated by nodes. Let us consider, in Figure 2, that a given predicate p that appears in A3 and A5 has been evaluated to 1 in A3 and to 0 in A5; this means that, although A3 sees A5 (arc from A3 to A5), they do not agree on the value of p. The basic problem is to decide whether such a resulting situation is a logically consistent one. Of course, in any classical system, it will be considered as inconsistent. The answer here is Yes: such a situation can be considered as consistent if it is noticed that values in A5 only depend on values in the cooperation {{A5, A8 and A9}}, while values in A3 furthermore depend on values in activities A1, A2 and A4.

This leads to consider that predicate p could be true for A5 and false for A3, this for instance because of A4.

In order to simplify the model, let us consider that cooperations can be split into different cooperation domains related to coherent sub-problems or to coherent sub-applications. Those domains define in some sense some manageable sets of activities.

Definition 2: Let a global cooperation be split into different cooperation domains which form subgraphs of the complete graph. These domains are such that all predicates in a domain can be given either the value True or the value False (but not both).

It follows that predicates cannot evaluate to contradictory values inside one domain. Intuitively, it means for instance that tasks are carefully allocated to activities inside a domain and that all predicates are evaluated in a coherent way; and this is precisely what sub-cooperation could mean. Therefore, if a given predicate has different logical values, then the corresponding different evaluations must not be located inside the same domain.

Now, in the general case, depending on the structure of the relation it has with its neighbours, an activity may be involved in different cooperation domains and may belong to different logical systems.

For instance, in Figure 2, some alternatives for A3 are:

a) A3 is considered together with all activities and follows the logical system T; or

b) A3 is viewed as belonging to three domains, one following S5 (with A1 and A2), one following S4 (with A5, A8 and A9) and one following T (with A4 and A10).

In b), A3 has three different cooperation relations, derived from the domains.

Of course, it should be clear that total cooperations lead to a great simplification, which easily follows from the S5 logic.

III. PREDICATES AND THREE VALUED LOGIC

Let us first consider cooperation schemas with only one domain.

III-1- Cooperation Predicates

Let us for instance consider an acyclic S4 graph, where **R** is transitive. Any node in the hierarchy has the potentiality of seeing all exported values in all nodes below it, and so the root activity knows all values in the tree. The predicates which are evaluated by the antecedents of A_j cannot be known by A_j, as there is no arc from A_j to its antecedents. Such a case appears in Figure 3-a where the root node can see the values of all predicates, while the leaf nodes only know the values of the predicates they evaluate.

Of course, the relation can be not trivial in terms of predicates. In Figure 3-b, a predicate as K in A3, which depends on both X and Y, is not known by A4 for its evaluation may use other predicates, as Z in the figure, local to A3; but K is known by A2. Also, J is only known by A2 and A1, and G only by A1. This means that A4 knows the value of X and Y; A3 knows Z, X, Y and K; A2 knows I, J, K and Z; and A1 knows I, J, G and F.

Here, we assume that all nodes in the graph own a copy of all predicates they see; in particular, the root node in an acyclic S4 graph has a copy of all predicates, by definition of S4. Although it can be relaxed, this assumption simplifies the definition of validity for the modal operators, even if it leads to handle some unneeded predicates.

Let us now consider the simple T system given in Figure 3-b, where for instance A1 cannot directly know the values located in A3. So, if A2 do not explicitly export to A1 the values evaluated by A3, then those values are not known by A1. This is the assumption we make here: any predicate evaluated by a given activity A_j is only accessible to the activities linked by the cooperation relation to A_j. So, the knowledge of predicates depends on the location of the activities inside the cooperation graph. As an example, A1 in Figure 3-b cannot access the values of predicates X, Y, K and Z.

Definition 4: In each node of a model, predicates are exported or local:

-if a predicate is evaluated locally inside a node, it can be exported to the activities that are in cooperation with this node,

-if a predicate is exported by a node, then it becomes local to the importing node (and is not known by the antecedents of the importing node).

This does not prevent one node of transmitting a given imported value, for it is sufficient to affect the received value to a new predicate which becomes evaluated by this node (using the identity function).

Of course, allocating the evaluations of predicates to activities is a major design step.

When graphs with cycles are considered, then the mapping of the predicates to the activities must be coherent with the constraints resulting from the cycle of predicates.

III-2- Three valued Semantics

As a consequence, any logic predicate is assumed to take its value inside a three valued logic system:

1 or True, 0 or False,

ø or Don't care or Irrelevant.

True and False are the classical logical primitives and ø is defined as the value of predicate p in all nodes in which predicate p is not defined, i. e. not known. Then, the previously given value assignment V has to be extended to account for this new value.

The three value assignment VD will be defined as the value assignment satisfying the following conditions:

a) for any propositional variable p_j and any world w_i,

either $VD(p_j, w_i)=0$ or $VD(p_j, w_i)=1$ or $VD(p_j, w_i)=\emptyset$.

b) for any wff alpha, for any w_i, VD(¬alpha, wi)=0 if VD(alpha, w_i)=1 or VD(¬alpha, w_i)=1 if VD(alpha, w_i)=0 or VD(¬alpha, w_i)=ø if VD(alpha, w_i)=ø

c) for wffs alpha and beta, for any w_i, VD(alpha ∨ beta)=ø if VD(alpha, wi) and VD(beta, w_i)=ø. Else, if one is not equal to ø, VD(alpha ∨ beta)=1 if VD(alpha, w_i) or VD(beta, w_i)=1; VD(alpha ∨ beta) equals 0 otherwise.

d) for any wff alpha and for any w_i, VD(L(alpha), w_i)=ø if for every w_j such that w_i**R**w_j, VD(alpha, w_j)=ø. If VD(L(alpha),w_i) is not ø, then: VD(L(alpha), w_i)=1 if (VD(alpha, w_i)=1 or VD(alpha, w_i)=ø) and if (for every w_j such that w_i**R**w_j, either VD(alpha, w_j)=1 or VD(alpha, w_j)=ø); otherwise, VD(L(alpha), w_i)=0.

Note that this is a Modal extension of the boolean don't care value.

IV. FOUR-VALUE PREDICATES AND CONTRADICTIONS

Let us now consider the general case where the cooperation graph is of any shape. Such an example is given in Figure 2. Considering it as a whole, all activities belong to a T system. In fact, it seems intuitively sound to say that real complex systems are not designed that way. Complex systems follow some high level structuring rules that define relationships between activities: subsets of all activities are linked together depending on defined and identified subwork. It is assumed here that these subrelationships exactly define what we called cooperation domains.

IV. 1. Semantical domains

Then, a cooperation domain defines a set of strongly linked activities that have agreed to cooperate and that have agreed on the distribution of relevant predicates. In multi-domains cooperation, each of the predicates is evaluated only by one of the activities of the domain it belongs to; this implies a coherent view of all predicates inside a domain.

Let us now consider the set of all domains. Let A_j be an activity. A_j may belong to different domains, for instance two, depending on its cooperations. Let us now assume that one predicate p_k is known by A_j and that this predicate appears in the two domains A_j belongs to: then, by definition, this predicate p_k is consistent with respect to the first domain and is also consistent with respect to the second one, as long as they are considered independently. Nevertheless, and this is the key point, nothing prevents p_k to be incoherent when both domains are considered together, and in particular by A_j, because A_j accesses the two domains: a predicate, p_k , can appear to be evaluated as both false in one domain and true in the other, leading to a real but coherent contradiction, which does not prevent reasoning [MUR] if semantics are given.

IV. 2. Semantics

Consequently, in general cooperation schemas, predicates are assumed to take their values inside a four valued logic:

1 or True, 0 or False,
ø or Irrelevant or Don't care,
¿ or Contradiction.

The value assignment has now to be extended to account for this fourth logical value. The problem is how to handle cases where contradictions occur. As before, in order to simplify the notations, it is assumed that each node keeps a copy of the predicates it can see. The difference is that now predicates are related to more than one domain.

VC is a value assignment satisfying the following conditions:

a) for any propositional variable p and any world w_i, either VC(p, w_i)=0 or VC(p, w_i)=1 or VC(p, w_i)=ø or VC(p, w_i)=¿

b) let us first consider two domains and any world w_i that belongs to two domains without contradiction: for any propositional variable p_j,

VC(p_j, w_i)=ø if VD(p_j, w_i)=ø in the two domains w_i belongs to;

VC(p_j, w_i)=¿ if VD(p_j, w_i)=0 in one domain and VD(p_j, w_i)=1 in the other;

else ((VC(p_j, w_i) different from ø and ¿) : VC(p_j, w_i)=0 if either VD(p_j, w_i)=0 or VD(p_j, w_i)=ø in the two domains w_i belongs to; VC(p_j, w_i)=1 if either VD(p_j, w_i)=1 or VD(p_j, w_i)=ø in the two domains w_i belongs to.

This definition can easily be recursively extended to N general domains by defining that if VC(p_j, w_i)=¿ when considering domains k and k+1, then VC(p_j, w_i)=¿ for all j > k+1. Note that this means that contradiction is recorded and not solved when observed.

c) for any wff alpha, for any w_i, VC(¬alpha, wi)=0 if VC(alpha, w_i)=1; or VC(¬alpha, w_i)=1 if VC(alpha, w_i)=0; or VC(¬alpha, w_i)=¿ if VC(alpha, w_i)=¿ ; or VC(¬alpha, w_i)=ø if VC(alpha, w_i)=ø

d) for wffs alpha and beta, for any w_i,

VC(alpha ∨ beta)=¿ if VC(alpha, w_i) or VC(beta, w_i)=¿;

else (both different from ¿): VC(alpha ∨ beta)=1 if VC(alpha, w_i) or VC(beta, w_i)=1;

else (both different from ¿, 1): VC(alpha ∨ beta)=0 if VC(alpha, w_i)=0 or VC(beta, wi)=0;

else (both different from ¿, 1, 0): VC(alpha ∨ beta)=ø (if VC(alpha, wi) and VC(beta, w_i)=ø);

e) for any wff alpha and for any w_i,

VC(L(alpha), w_i)=¿ if there is a w_j such that $w_i\mathbf{R}w_j$ and VC(alpha, w_j)=¿;

else VC(L(alpha), w_i)=ø (if for every w_j such that $w_i\mathbf{R}w_j$, VC(alpha, w_j)=ø);

else VC(L(alpha), w_i)=1 if for every w_j such that $w_i\mathbf{R}w_j$, either VC(alpha, w_j)=1 or VC(alpha, w_j)=ø;

else VC(L(alpha), w_i)=0 (if for every w_j such that $w_i\mathbf{R}w_j$, either VC(alpha, w_j)=0 or VC(alpha, w_j)=ø).

The previous definitions allow one to define pragmatics in the sequence "syntax, semantics, pragmatics", where pragmatics are above semantics. As a consequence, pragmatic decisions will be defined as decisions, above semantics, that make the selection of one of the logical values True or False, i. e. of one semantics. [DIA2] develop this view, different from [WER] and in the spirit of [VAR].

VI - CONCLUSION

In applications based on computer supported communication and cooperation, cooperation has been seen as a conceptual level different from, on top of communication. This paper gives a starting basis for high level modeling of complex distributed systems. From intuitive definitions, it proposes a logical model for expressing some aspects of the semantics of cooperation, including: a modal logic of cooperation, four-valued predicates, domains of coherence, and logical inter-domain contradictions. Furthermore, it alllows [DIA2] to discuss unicity of predicates, relationships with protocols and also cooperation pragmatics, where a pragmatic decision is a decision that allows the selection of one of the semantics that exist in the formal cooperation framework.

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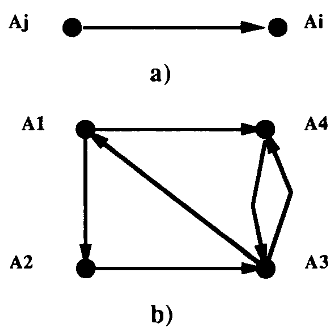
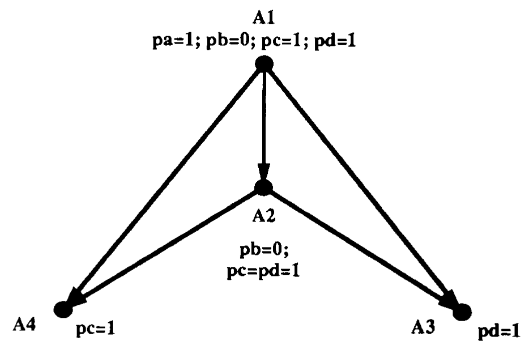


Figure 1



a)

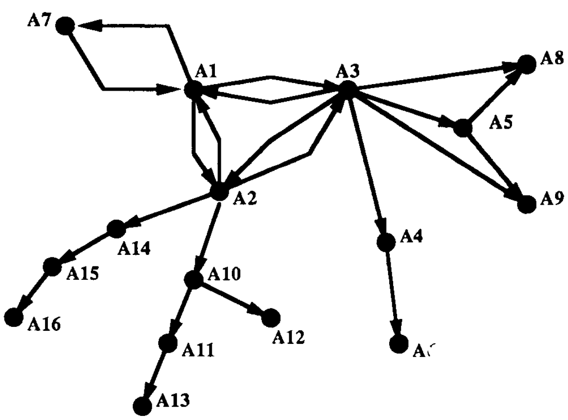
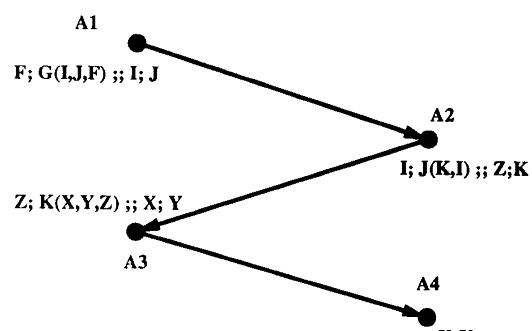


Figure 2



b)

Figure 3