Power and Dependence Relations in Groups of Agents

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Abstract

In this paper we present a formal model of Multiagent Systems to analyze the relations of power and dependence underlying group behaviors such as cooperation. Inspired by the work of Castelfranchi we define these relations by means of a description of goals and skills of single agents. We show how our framework can be used to describe social and organizational structures as emergent properties of a collection of individuals.

1 Introduction

An important aim in the field of Multiagent Systems is to study emergent social structures, such as groups and collectives. The relevance of social structures in many fields as Distributed Artificial Intelligence [12, 11, 13], Artificial Life [14], Sociology [8] necessitates a well motivated definition of their conditions of possibility.

In particular, there is property of the individual agents, that has the main role in the emergence of macro-level phenomena, which is their autonomy: the capability to spontaneously act in order to achieve their own goals [14]. In a single agent framework to achieve a given goal an agent has to be self-sufficient with respect to it. On the contrary in a Multiagent framework, especially those in which agents are heterogenous, it is possible that, when an agent is not self-sufficient with respect to some goal, he can resort to another agent, given that the latter cannot be self-sufficient itself in every respect. Hence, agents benefit interacting with the other cohabitants and cooperate. Power and dependence emerge that are the base of the social and organizational structure of a system.

In the last years the BDI model is turned out as one of the most prolific frameworks to describe Multiagent Systems. Nevertheless Castelfranchi in [8] points out that works on social behaviors are not grounded in this model, rather, often they seems to be postulated without being deep-rooted on the structure of the single agents [11]. The problem is that it is unclear how many efforts as coalition logics or game theory can be used for Multiagent Systems based on the BDI model. Castelfranchi [8] proposes a semi formal definition of power and dependence, rooting them in the BDI model. However it is not sufficient to build or analyze real systems.

The research question of this paper is how to formalize some of the results obtained by Castelfranchi [8], in particular the notions of power and dependence. Respect to this work more details, as effect rules and concurrency, are described in the definition of a Multiagent System and a definition of cooperation is also given. On the other hand some issues, as power-over or power-of-influencing, discussed in [8] are out of the scope of the present paper.

As methodology we use an algebraic approach which individuates the entities and relations necessary to represent social structures. The advantage of this approach with respect to, e.g., a modal logic one [15] is that it is less involved to describe group actions and the compatibility of effects, and less prone to hidden assumptions.

Moreover, inspired by Sichman and Conte [10], we propose how to extend the notion of dependence to dependence graphs, in order to highlight the topology and the symmetries of dependencies. This graph formalization provides a tool to analyze organizational problems in institutional structures and enterprises.

The emergence of groups is necessary for designing and implementing robust open Multiagent Systems. Giving the agents the ability to reason about their social relations makes it possible to proceed from a hierarchical view of organizational design to a more dynamic approach, where the agents are able to define their own obligations and rights by negotiating contracts with the other agents.

In Section 2 we formalize a Multiagent System, providing the definition of the single agents. In Section 3, the concepts of the abilities, power and lack of power for groups of agents are formalized. Section 4 is dedicated to dependencies, relating them to the previous definitions of power and lack of power, and Section 5 to the definition of cooperation. Conclusion and related works end the paper.

2 Formalization of Multiagent Systems

2.1 Formalization

A Multiagent System can be viewed as an environment populated by a group of agents. The environment is described by means of a set of relevant attributes; their values in a given instant establish the “state of the world” in that instant (sw). Thus, given the set of relevant attributes for an environment $P = \{p, r, s...\}$, an sw is a complete and univocal assignment for them, complete in the sense that every attribute should be set, and also univocal, in the sense that for any attribute only one value can be set.

For the sake of simplicity, we assume that attributes have boolean values. Since we are adopting an algebraic non-logical framework we refer to them with the corresponding symbol of the attribute in P to indicate that the value of that attribute is true or with the over-signed symbol in $\bar{P} = \{\bar{p}, \bar{r}, \bar{s}...\}$ to indicate that the value is false.

We introduce a function *values* that, taken an attribute symbol, returns the set of the two possible values (for example, *values*$(p) = \{p, \bar{p}\}$); we extend this function also to sets of attribute symbols so if $B \subseteq P$, then *values*$(B) = \bigcup_{p \in B}$ *values*(p). Another function, $\sim$, associates to a given value the inverse, so $\sim p = \bar{p}$, $\sim \bar{r} = r$ and so on. Now we can formalize $SW(P)$, the set of all possible sw descriptions, by means of the relevant attributes P:

Definition 1 (Feasible states) *Let H be the powerset of $P \cup \bar{P}$, $SW(P)$ is the set of the elements sw of H that are univocal and complete, that is they satisfy the following condition:*
$\forall \beta \in P$, *either* $\beta \in sw$ *or* $\sim\beta \in sw$

For the sake of simplicity, assuming that P is fixed, from now on, we write SW instead of $SW(P)$.

We describe the agents; in particular the actions they can perform and their effects. Let $A = \{a, b, c, ...\}$ the finite set of all actions that can be performed by the different agents, our goal is to formalize rules like *“if in sw the values of the attributes $k_1, \ldots, k_n$ are $v_1, \ldots, v_n$ and an agent performs the actions $a_1, \ldots, a_h$ and the actions $a'_1, \ldots, a'_l$ are not performed, then in sw the values of the attributes $k'_1, \ldots, k'_m$ will be $v'_1, \ldots, v'_m$”.*

The first definition is *Ef*: the set of all possible effects. This set is similar to SW with the difference that its elements respect only the univocality condition:

Definition 2 (Rules effects) *Ef is the set of elements $\mathcal{S}$ of H that satisfy the following condition:* $\forall \beta \in \mathcal{S} \ \ \sim\beta \notin \mathcal{S}$

so, for example $\{s\}$, $\{\bar{s}, \bar{p}\} \in$ *Ef*.

In order to express the relation between an action and its effects we formalize not only the fact that some action should be performed to have some effects, but also that some other action does not have to be performed. For this purpose we use the set $\bar{A}$ in the same manner as $\bar{P}$, so an element $\bar{d}$ of $\bar{A}$ in a effect rule prescribes that the action d have not to be performed.

Considering a function $\sim$ also for the actions, we define, in the same manner as for *Ef*, the set *Act* of compatible sets of action values:

Definition 3 (Rules actions) *Act is the set of the elements $\mathcal{C}$ of $2^{A \cup \bar{A}}$ that satisfy the following condition:*
$\forall \tau \in \mathcal{C} \ \ \sim\tau \notin \mathcal{C}$

Now we are able to define the antecedents of the effect rules as:
Ant $= \{S \cup D : \ S \in$ *Ef* $\wedge \ D \in$ *Act*$\}$

Given an antecedent $pl \in$ *Ant*, we define two functions, *preconditions*$(pl) = pl \cap (P \cup \bar{P})$ and *actions*$(pl) = pl \cap (A \cup \bar{A})$ in order to distinguish actions from preconditions.

Finally we define the set of rules:

Definition 4 (Rules) *R is a set of rules $\psi \rightarrow \phi$, where $\psi \in$ Ant and $\phi \in$ Ef.*

effects$(\psi \rightarrow \phi)$ denotes ϕ and, given $R' \subseteq R$, *effects*$(R') = \bigcup_{r' \in R'}$ *effects*(r'). In the same manner *antecedent*$(\psi \rightarrow \phi)$ denotes ψ.

For example a possible rule is: $\{a, \bar{b}, \bar{p}, s\} \rightarrow \{\bar{s}, q\}$
This rule tells us that in every sw in which $\bar{p}$ and s hold if the action a is performed and the action b is not performed, then is the next state $\bar{s}$ and q hold.

The next step is to define how the world evolves by the effects of some rules. First of all we build a function to describe the evolution of the state of world sw by the change of the attribute q from the value β to the value α as:
$\alpha \frown sw = \{\alpha\} \cup [sw - \{\beta \in sw : \ \beta \in \textit{values}(q)\}]$

Now, to take in account effects that involve more than only one attribute, we will extend the function for a n-ple of values:
$[\alpha_1, ..., \alpha_n] \frown sw = \alpha_1 \frown (\alpha_2 \frown ...(\alpha_n \frown sw)...)$

This extension is not in general commutative if we change the order of $\alpha_1, ..., \alpha_n$, because it can happen that some α_i and α_j are different values of the same attribute. In general, since the agents are autonomous, they act simultaneously and hence they can activate more then one rule. Considering the union of the effects of these activated rules, that is the whole effect of the agents activity on sw, not a particular order should be relevant in the application of the function $\frown$. If this does not happen, then an incompatibility arises. So we tie the compatibility of effects to the commutativity of $\frown$ as follows:

Definition 5 (Compatible attribute values) *If for all the permutations π_i, π_j of $\{1, .., n\}$ and for all $sw \in SW$,*
$[\alpha_{\pi_i(1)}, ..., \alpha_{\pi_i(n)}] \frown sw = [\alpha_{\pi_j(1)}, ..., \alpha_{\pi_j(n)}] \frown sw$
then we say:

- $[\alpha_1, ..., \alpha_n]$ *compatible/commutative*
- $[\alpha_1, ..., \alpha_n] \frown sw \equiv \{\alpha_1, ..., \alpha_n\} \frown sw$

When $[\alpha_1, ..., \alpha_n]$ are compatible, then no conflicts among actions happen and so we can say, since all the permutation leads to the same result, that the set of effects $\{\alpha_1, ..., \alpha_n\}$ entails the evolution of the state sw. The following proposition, that characterizes when effects are compatible, can be proved:

Theorem 1 *$[\alpha_1, ..., \alpha_n]$ are compatible iff $\{\alpha_1, ..., \alpha_n\} \in$ Ef.*

Now we have all the ingredients to define a Multiagent System:

Definition 6 (Multiagent System) *A Multiagent System, MaS, is tuple*
$\langle Ag, goals\colon Ag \rightarrow 2^{Ef(P)}, skills\colon Ag \rightarrow 2^{A}, R\rangle$
where Ag is a set of agents, goals is a function that associates to each agent a set of desires, skills is a function that describes the actions each agent can perform and R is a set of rules.

2.2 Concurrency management

Given a Multiagent System $\langle Ag, goals, skills, R\rangle$, the set of rules R has the function of a shared knowledge base by means of which the agents can plan, in a given state of the world, the right actions to achieve their own goals. When an agent ag wants to perform the antecedent of a given rule r, then we say that ag has *activated* r, but, since more than one rule in sw can be activated by the agents' performances, then even if in any singular rule $\psi \rightarrow \phi$ the outcome ϕ is in *Ef*, this do not guarantee that the union of the ϕ, relative to activated rules, will belong to *Ef*, or, as seen in the previous section, that the effects of the actions performed are compatible.

Sometimes the incompatibility between two outcomes, and hence between two rules, would be interpreted as the impossibility to activate simultaneously those rules, but sometimes we would like to resolve in such a manner that incompatibility (telling for example that one rule has the priority on other one, or that the actions that have activated one rule are stronger of other ones).

As said above every antecedent ψ in a rule $\psi \rightarrow \phi$ is a sufficient way to achieve ϕ, so the rules have to be structured in such a way to avoid incompatibility. Consider two rules $r_1 \equiv \psi_1 \rightarrow \phi_1$ and $r_2 \equiv \psi_2 \rightarrow \phi_2$, with $\phi_1 \cup \phi_2 \notin$ *Ef*, then to assure their feasibility or there is not a state sw in which they are both applicable (i.e., *preconditions*$(\psi_1) \cup$ *preconditions*$(\psi_2) \notin$ *Ef*)), or the respective actions are not compatible (in this way two agents cannot perform them at the same time):

Definition 7 (Feasible rules) *Let $\psi_1 \equiv$ antecedent(r_1) and $\psi_2 \equiv$ antecedent(r_2), two rules r_1 and r_2 are said to be* feasible *iff one of the following items is satisfied:*

1. *effects$(r_1) \cup$ effects$(r_2) \in$ Ef*
2. *preconditions$(\psi_1) \cup$ preconditions$(\psi_2) \notin$ Ef*
3. *actions$(\psi_1) \cup$ actions$(\psi_2) \notin$ Act*

Using the previous definition we formalize when a set of rules R is feasible:

Definition 8 (Feasible set of rules) *A set of rules R is feasible iff each pair of rules is feasible.*

In the following sections we consider only Multiagent System in which the set of rules R is feasible.

2.3 How to build the set of rules

In this section we show how to build up a feasible set of rules R in a given domain. For the sake of simplicity we consider only antecedents withoutpreconditions. Suppose that an agent ag want to achieve the goal s and that, if it was alone, then performing the action $pl_1 = \{a\}$ it would achieve it.

Suppose there are also the actions $pl_2 = \{b, c\}$ and $pl_3 = \{d\}$ that, if performed alone, would entail $\bar{s}$ and, moreover, pl_2 invalidates pl_1, whereas pl_1 and pl_3 invalidate with each other.

This means that when ag performs pl_1 if another agent ag' performs pl_2, then the final result will be a sw in which $\bar{s}$ hold, vice versa if ag' performs pl_3, then the value of s will be the same of that in sw. We can formalize this feature in the following way: $pl_1 \wedge \neg pl_2 \wedge \neg pl_3 \rightarrow s$; $pl_2 \rightarrow \neg s$; $pl_3 \wedge \neg pl_1 \rightarrow \neg s$. Since antecedents are conjunctions of actions we have:

$$a \wedge \neg(b \wedge c) \wedge \neg d \rightarrow s$$
$$b \wedge c \rightarrow \neg s$$
$$d \wedge \neg a \rightarrow \neg s$$

The last two formulas are directly translated in terms of rules, respectively:

$$\{b, c\} \rightarrow \{\bar{s}\} \qquad \{d, \bar{a}\} \rightarrow \{\bar{s}\}$$

Since the antecedents in a rule are sufficient condition to achieve its effects, then the first formula is converted in a disjunctive form:

$(a \wedge \neg b \wedge \neg d) \vee (a \wedge \neg c \wedge \neg d) \rightarrow s$

That is translated in the following two rules:

$$\{a, \bar{b}, \bar{d}\} \rightarrow \{s\} \qquad \{a, \bar{c}, \bar{d}\} \rightarrow \{s\}$$

3 Formalization of Power

In this section we define the relation of power as in Castelfranchi [8]. By power we mean the capability of a group of agents, possibly composed by only one agent, to achieve some goals; it should be emphasized that power does not consist only of the group's abilities (skills, physical and mental attitudes) to achieve some effects, because there should be a group of agents which desires those effects.

Before defining the relation of power we first formalize when, in a state sw, a group of agents Q would be able to achieve the set of effects G by means of the actions $K \in Act$. First of all Q should be able to perform all the positive actions belonging to K, moreover there should be some rules such that: they involve in sw all the effects in G, the conditions to apply this rules are satisfied by sw, finally the actions that these rules prescribe (to perform or to not perform) are all listed in K.

Definition 9 (Agents abilities) *A group of agents $Q \subseteq Ag$ is able to achieve the effects $G \in 2^{Ef}$ by the actions $K \in Act$ in the state $sw \in SW$, $Able(Q, G, K, sw)$, iff:*

1. $K \cap A \subseteq \bigcup_{ag \in Q} skills(ag)$
2. $\exists \hat{R} \subseteq R\ [\bigcup_{g \in G} g \subseteq effects(\hat{R}) \frown sw\ \wedge$ $\bigcup_{\hat{r} \in \hat{R}} actions(antecedent(\hat{r})) = K\ \wedge$ $\forall \hat{r} \in \hat{R}\ preconditions(antecedent(\hat{r})) \subseteq sw]$

It is easy to see that the following theorem holds:

Theorem 2 *The relation Able is monotonic with respect to the union of groups of agents:*
$Able(Q, G, K, sw) \Longrightarrow \forall \hat{Q} \subseteq Ag\, Able(\hat{Q} \cup Q, G, K, sw)$

This is correct from an ontological point of view since, when an agent is added to a group, then the set of effects the new group should be able to achieve have to grow. Nevertheless if an agent looks for a set of agents that is able to achieve a subset G of its goals, then it would consider only those sets Q that satisfy a property of minimality, i.e., Q is the minimal set of those that contain it which is able to achieve G. This involves the definition of *Min_Able*:

Definition 10 (Abilities with minimality) *Suppose that $Able(Q, G, K, sw)$ holds, then $Min\_Able(Q, G, K, sw)$ holds iff: $\forall \hat{Q} (\neq \emptyset) \subseteq Q\ \neg Able(Q \setminus \hat{Q}, G, K, sw)$*

What does the *Able* definition lack to be a definition of power? First of all power concerns the possibility to use some skills in order to achieve some own goals or as exchange goods for other agents' goals [8, 9]. To have skills that all the community considers useless do not add any power to a set of agents. Furthermore there should be no way, for the other agents, to obstruct Q to achieve G.

So, in order to define a power relation, we define a relation that regards the capability of a group of agents Q_1 to obstruct another group Q_2 in the achievement of a set of effects G. First of all Q_2 should be able to achieve G by means of some actions K, then Q_1 can obstruct Q_2 if one of its agents is skilled to perform an action and K prescribes that it should not be performed. This is not the only way Q_2 can obstruct Q_1. Suppose that the current state sw is equal to $\{s, \bar{r}\}$ and that two rules can be used: $a \rightarrow r$ and $b \rightarrow \bar{s}$. If the goal of Q_2 was $\{s, r\}$ and one of its agents was able to perform a, then Q_2 would be able to achieve its goal. Nevertheless suppose that one of the agents of Q_1 was able to perform b, so it could nullify the efforts of Q_2 making s false. The previous considerations lead to:

Definition 11 (Achievement obstruction) *A group of agents Q_1 can obstruct another group Q_2 in the achievement of the set of effects G by means of K, $Can\_obstruct(Q_1, Q_2, G, K, sw)$, iff $Able(Q_2, G, K, sw)$ and one of the following conditions holds:*

1. $\exists c \in K \cap \bar{A}\ \exists ag \in Q_1\ c \in values(skills(ag))$
2. $\exists e \in Ef\ \exists \hat{W} \in Act\ [Able(Q_1, e, \hat{W}, sw)\ \wedge$ $e \cup \bigcup_{g \in G} g \notin Ef\ \wedge\ (K \cap A) \cup (\hat{W} \cap \bar{A}) \in Act]$

Now we define the relation of power as the capability of a group Q to perform some actions that achieve, without the possibility to be obstructed, some effects G in which a group, possible the same Q, is interested. We define a minimality condition also for power and we will use it in the next section to define the dependence relation.

Definition 12 (Agents' power) *Let $Q \subseteq Ag$, $G \in 2^{Ef}$, $K \in Act$, then the group of agents Q has the power to achieve the set of goals G by means of the actions K in the state of the world sw, $Power\_of(Q, G, K, sw)$, iff all following items are satisfied:*

1. $\exists Q' \subseteq Ag\ \forall g \in G\ \forall ag \in Q'\ \ g \in goals(ag)$
2. $Able(Q, G, K, sw)$
3. $\neg \exists \bar{Q} \subseteq (Ag \setminus Q)\ \ Can\_obstruct(\bar{Q}, Q, G, K, sw)$

If the previous conditions are satisfied with Min_Able instead of Able, then $Min\_Power\_of(Q, G, K, sw)$.

Even if a group has some power in the achievement of, individually, two goals g_1 and g_2, it is not implied that it has a power for the set $\{g_1, g_2\}$ since there could be that the agents that are interested to g_1 are not interested to g_2 and vice versa. Even if we do not consider preferences on goals, it is reasonable to assume that they are monotonic with respect to subset relation between sets of goals, and hence the more a set of goals a group can provide to another one increases, the stronger is the power over it.

We also define *Lack_power_of*(Q, G, sw) when a group of agents Q desires some set of goals G but it has not the power to achieve it.

Definition 13 (Agents' lack of power) *A group of agents $Q \subseteq Ag$ lacks the power to achieve a set of goals, $G \in 2^{Ef}$, Lack_power_of(Q, G, sw), iff these two items are satisfied:*

1. $\forall g \in G \, \forall ag \in Q \;\; g \in goals(ag)$
2. $\neg \exists K \in Act \;\; Power\_of(Q, G, K, sw)$

Since the first condition entails the first condition of the definition of power, then it is not possible that the second condition of *Lack_power_of* holds because G is useless, in other words the following theorem holds:

Theorem 3 *If Lack_power_of(Q, G, sw) holds, then* $\forall K \in Act \; [\neg Able(Q, G, K, sw) \; \vee$
$\exists \bar{Q} \subseteq (Ag \setminus Q) \;\; Can\_obstruct(\bar{Q}, Q, G, K, sw)]$

Example

An important issue is the security of the computer net. The security can be jeopardized if a user checks suspicious mails or the system manager does not update the antivirus. To assure the security of the system is a goal of both the manager ag_M and the user ag_U, moreover the user has the goal to use the mail. Updating the antivirus is denoted by the action a, checking suspicious by b and checking normal mails by c.

In the initial state the system is not infected and the user did not use the mail service: $sw = \{s, \bar{u}\}$. If the user checks mails, then he uses the mail services, but if the mails he checks are suspicious then the system is not safe. Moreover, even if the user takes precautions in checking mail, the system manager have to update the antivirus to assure security. The formalization of the Multiagent System is given by the tables:

agents	skills	goals
ag_M	a	$\{s\}$
ag_U	b,c	$\{s\}, \{u\}$

rules
$\{c\} \rightarrow \{u\}$
$\{b\} \rightarrow \{\bar{s}, u\}$
$\{\bar{a}, c\} \rightarrow \{\bar{s}\}$

Considering the previous definitions we ask if *Lack_power_of*$(ag_U, \{\{u\}, \{s\}\}, sw)$. First of all ag_U desires both $\{u\}$ and $\{s\}$, so the first item of the definition is satisfied. For the second item ag_U has not the power to achieve both of them since the only way to make u true is performing b or c, but in both cases, considering the rules two and three, he is not able alone to maintain s true. On the other side also ag_M lacks the power of achieve his goal s because he can not prevent ag_U in checking suspicious mails. Luckily, if ag_U performs only c, ag_M, by performing a, makes the last rule no more applicable, hence, remaining s true, the system is safe. This involves that the group $\{ag_M, ag_U\}$ has the power to achieve the goal $\{\{s\}, \{u\}\}$ by means of the actions $\{a, c, \bar{b}\}$.

4 Formalization of Dependence

Now the concept of dependence is formalized. A dependence exists when a group Q_1 lacks the power to achieve some goals, whereas some other group Q_2 can achieve it. Obviously the agents in the group Q_2 should be all necessary for the fulfillment of the goals, because we do not want to formalize the dependence on useless agents. As said in the previous section the definition of *Able* grants the presence of useless members ($Able(Q, G, K, sw) \implies \forall \hat{Q} \subseteq Ag \;\; Able(\hat{Q} \cup Q, G, K, sw)$), so also the definition of *Power_of* satisfies the same property: adding new members to a group cannot increase the obstruction capability of the others, it can only decreases. To avoid this problem we consider the definition *Min_Power_of* shown in the previous section that satisfying the minimality condition not allowing the presence of useless members.

We define the dependence of a group of agents Q_1 on another group Q_2 to achieve the goals G as: all members of Q_1 desire G, but they lack the power of achieve it, whereas Q_2 is a minimal group which has the power to achieve G:

Definition 14 (Agents dependence) *The set of agents Q_1 depends on the set of agents Q_2 to achieve, in the state sw, the goals G by the actions $K \in Act$, Depend(Q_1, Q_2, G, K, sw), iff the following items hold:*

1. *Lack_power_of*(Q_1, G, sw)
2. *Min_Power_of*(Q_2, G, K, sw)

In the previous definition there could be $Q_1 \subseteq Q_2$ in the case that also the elements of Q_1 take part in the achievement of G, otherwise some or all the members of Q_1 are not capable to give any contribution. Moreover several groups of agents can collect the same actions and thus the ability to achieve the same goals, so an agent can depend on several different groups for the same goal.

Power_of, *Lack_power_of* and *Depend* are the basic relations on which is possible to describe social relations among group of agents. In particular it is possible to define the mutual dependence of two groups to achieve common goals:

Definition 15 (Agents mutual dependence) *Two sets of agents Q_1, Q_2, such that $Q_1 \cap Q_2 = \emptyset$, mutually depend on each other to achieve the goals G by means of the actions $K \in Act$, Mutual_depend(Q_1, Q_2, G, K, sw), iff:*
$Depend(Q_1, Q_1 \cup Q_2, G, K, sw) \; \wedge$
$Depend(Q_2, Q_1 \cup Q_2, G, K, sw)$

To illustrate the given definition we reconsider the example of the previous section.

Example

By means of the definitions of dependencies we give a more informative description of the user-system manager scenario. First we ask if ag_U depends on the group $\{ag_U, ag_M\}$ in the achievement of u, i.e., $\exists K \in Act\ Depend(ag_U, \{ag_U, ag_M\}, \{u\}, K, sw)$. We know by the rules one and two that ag_U performing b or c is able to achieve his goal u and ag_M can not obstruct him. So ag_U alone has this power, and hence, since the first condition of the definition of *Depend* is false, it does not depend on the the group $\{ag_U, ag_M\}$. Considering also the goal s we found that both ag_U individually lacks the power to achieve the set of goals s and u. Nevertheless together with ag_M, he has the power to achieve them performing respectively the actions c and a and not performing the action b, so $Depend(ag_U, \{ag_U, ag_M\}, \{s, u\}, \{a, c, \bar{b}\}, \{s, \bar{u}\})$. In the same manner it can be verified that $Depend(ag_M, \{ag_U, ag_M\}, \{s\}, \{a, \bar{b}\}, \{s, \bar{u}\})$.

Even if both the user and the system manager desire the security of the system, they do not mutually depend for it. ag_U, abstaining from checking mail at all, could alone assure security, so for him the presence of the system manager is constrained only to the possibility to add to the security also the usability of the net.On the other hand this issue is not relevant for the system manager, in fact, as it emerges from the last dependence relation, the only thing about the user the system manager cares is simply that he does not check suspicious mails.

The dependence relation describes the structure underlying possible cooperations and exchanges. The topological properties of this structure, as shown in [9, 10], are crucial for an analysis of the cohesion of these phenomena. Following [10] a good way to visualize this structure is to represent the dependencies among agents as a graph. In particular we use tagged graphs:

Definition 16 (Tagged graphs) *Given a finite set of tags* $TAG = \{\tau_1, \ldots, \tau_n\}$, *a tagged graph is a pair* $G \equiv (V, E)_{TAG}$, *where* V *is finite set called the set of nodes and* $E \subseteq \{(v_1, v_2)_\tau :\ v_1, v_2 \in V \ \wedge\ \tau \in TAG\}$ *is called the set of tagged arcs.*

In our framework the nodes in V represent groups of agents, the arcs in E the existence of a dependence between to groups and the tags in *TAG* the goals and actions relative to a dependence:

Definition 17 (Dependence graphs) *Given a Multiagent System* $MaS \equiv \langle Ag, goals : Ag \rightarrow 2^{Ef(P)}, skills : Ag \rightarrow 2^A, R\rangle$, *a tagged graph* $(V, E)_{TAG}$ *is the dependence graph relative to MaS in a given state* sw *iff two injective functions* $\mathbf{f} : V \rightarrow 2^{Ag}$ *and* $\mathbf{g} : TAG \rightarrow 2^{Ef} \times Act$ *exists such that:*

$$Depend(Q_1, Q_2, G, K, sw) \Leftrightarrow \exists (v_1, v_2)_\tau \in E\ [\mathbf{f}(v_1) = Q_1 \ \wedge\ \mathbf{f}(v_2) = Q_2 \ \wedge\ \mathbf{g}(\tau) = (G, K)]$$

Dependence graphs allow to obtain more concise pictures of the system, lacking details that do not play a role in the analysis of the achievement possibilities. Dependence arcs collect all together the actions needed to achieve a set of goals and the agents that can provide them. E.g.,if in any dependence relation when an agent ag_1 provides an action a always another one ag_2 provides an action b, then the corresponding dependence arcs do not distinguish between the two agents, grasping the symmetry with the system in which ag_1 provides b and ag_2 provides a.

5 Formalization of Cooperation

In this section we formalize the notion of cooperation among agents. The reason for a cooperation is the existence of a mutual dependence, but if mutual dependence is a relation still untied to the intentions of the agents, cooperation concerns what they actually want to achieve and the actions they are going to perform. Consider an agent ag, let $intend(ag) \subseteq Act$ represents the actions it intends to perform. We assume that if an ag intends to perform some actions, then he is also skilled to. The elements in $intend(ag)$ that belong to A are the actions ag intends to perform, the elements that belongs to $\bar{A}$ are the actions the agent wants to be not performed, finally the actions not mentioned will not be performed but only for an economical principle (in other words, ag guesses that actions will not entail particular benefits or damages).

In order to involve agents intentions we extend the definition of Multiagent Systems given in section 2:

Definition 18 (Extended Multiagent System) *An extended Multiagent System is a tuple*

$$e\text{-}MaS \equiv \langle Ag, goals\colon Ag \rightarrow 2^{Ef(P)}, skills\colon Ag \rightarrow 2^A, R, intend\colon Ag \rightarrow Act\rangle$$

where intend is a function that satisfy the condition: $\forall ag \in Ag\ \ intend(ag) \subseteq values(skills(ag))$

We now need a formalization of the actions a group of agents intends to perform, starting form the individual intentions. We preliminarily define:

Definition 19 (Positive union) *Let* $p_1, p_2 \subseteq A \cup \bar{A}$, *then the positive union* $p_1 \oplus p_2$ *between* p_1, p_2 *is:*

$$p_1 \oplus p_2 \equiv p_1 \cup p_2 - \{\alpha \in \bar{A} : \sim\alpha \in p_1 \cup p_2\}$$

It can be proved that $\oplus$ is a *commutative monoid*, so for every permutation π of $\{1, .., n\}$:

$$\bigoplus_{i=1}^{n} p_i \equiv p_1 \oplus ... \oplus p_n = p_{\pi(1)} \oplus ... \oplus p_{\pi(n)}$$

Given two agents ag_1 and ag_2, if I_1 is the intention of the former and I_2 of the latter, then the intentions of both of them will be $I_1 \oplus I_2$ since all the positive actions listed in I_1 and I_2 will be performed by one agent, even if the others refrain from performing it.Even if the notion of intentions related to groups of agents can rise philosophical debates, what we simply consider here is the set of actions that actually a group of agents will perform by means of the actions that, separately, the agents will to perform. Stated this, we can formalize the notion of a intentions for groups of agents.

Definition 20 (Group intentions) *Given* $Q \subseteq Ag$*, and for any* $ag \in Q$ *a particular intention intend*$(ag) \in Intentions(ag)$*. Then the intention of the group* Q *is:*
intend$(Q) \equiv \bigoplus_{ag \in Q}$ *intend*(ag)

Now a cooperation between two groups exists when they mutual depend in the achievement of a set of goals and the actions they intend to perform enable the satisfaction of this dependence.

Definition 21 (Cooperation) *We say that the two groups* $Q_1, Q_2 \subseteq Ag$ *are cooperating to achieve the set of goals* G *in the state* sw *given their intentions intend*(Q_1)*, intend*(Q_2)*;* $Cooperating(Q_1, Q_2, G, intend(Q_1), intend(Q_2), sw)$ *iff:*

1. $\exists K \in Act:$ *Mutual_depend*$(Q_1, Q_2, G, K, sw) \wedge K \subseteq$ *intend*$(Q_1) \oplus$ *intend*(Q_2)

6 Conclusion and related works

Our approach gives a description of power and dependence, relating them to the definition of a Multiagent System. In this way it is shown how these concepts, involving groups of agents, emerge from a description of single agents. The basic important issues emphasized in [7] and [8] are addressed in our framework, as the relation of power with the goals and the skills of the single agents or the description of mutual dependence. All these relations are defined in a formal context, quite expressive to take in account not only the capability of the agents to help, but also to obstruct each other. We also formalize the relation between mutual dependence and cooperation distinguishing the possibilities agents have to help each other from what they actually intend to do.

Some approaches aimed in exploring social relations like power and dependence are based on Decision-theoretic techniques [6]. Even if they well address many features of the rational reasoning of inter-dependent agents, they consider group behaviors and their impact on the goals achievement as defined *a priori*, in this perspective our work provides a constructive way to calculate the utility resulting from group behaviors.

Sichman and Conte [10] use graph theory to emphasize the topology of dependencies, but many simplifications reduce the expressiveness of their framework, for example they do not formalize the concurrency management problem so they do not take in account the possibility to obstruct the achievement of a goal. Moreover our framework describes powers and dependencies for groups of agents allowing to scale on structure of the system.

Nevertheless many important issues can be still faced, for example how norms can be introduced to regulate a group [5], how norms can be monitored and enforced [3] and how coordination in a group can be achieved [4]. The second one is to describe more complex situations in which a worth-while net of dependencies tie agents in forming a coalition.

Presently we are working on the relation between the concepts studied in this paper and the notion of coalitions. Moreover, we are studying independent definitions of power, dependence and coalition structures, which diverges our work from the work of Castelfranci. This new approach is explained in [2] and an example of an independent power structure, coalition structure and the relation between them is given in [1].

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