Agent-Based Social Simulation with Coalitions in Social Reasoning

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Abstract. There is a growing belief that the agents' cognitive structures play a central role on the enhancement of predicative capacities of decision-making strategies. This paper analyses and simulates the construction of cognitive social structures in the process of decision making with multiple actors. In this process it is argued that the agent's rational choices may be assessed by its motivations, according to different patterns of social interactions. We first construct an abstract model of social dependence between agents, and define a set of social structures that are easily identifiable according to potential interactions. We then carry out a set of experiments at micro-social levels of analysis, where the agents' cognitive structures are explicitly represented. These experiments indicate that different social dependence structures imply distinct structural patterns of negotiation proposals, which appear to have diverse patterns of complexity in the search space. It is subsequently shown that this observation emerges as an issue of ambiguity in the regulation of different decision-making criteria, relative to motivation-oriented and utility-oriented choices. In the scope of this ambiguity, we finally make some conjectures relative to further analytical and empirical analysis around the relation between patterns of complexity of social structures and decision-making.

1 Introduction

The problems encountered in the implementation of autonomous agents that decide and adopt goals on behalf of other agents, have determined a growing need to implement different degrees of social reasoning abilities in the individual agent's machinery [26]. The need for an increasing autonomy in Multi-Agent Systems (MAS) shares some of the difficulties encountered in explanatory models of purposive action [18,20] in the social sciences. These models rest on the assumption that actors in a dynamic social world are purposive, and act in ways that produce intended and/or beneficial results. By advancing the postulate that individual action is goal directed the prevalent question runs around the way people, given their values, beliefs and high-level normative organization behaviors, make choices. The same question naturally arises when designing artificial autonomous agents, and the discipline of Multi-Agent Based Simulation (MABS) naturally emerges as an adequate platform for the study of social reasoning and decision-making strategies in natural or artificial societies. Agents in artificial social systems do not always have control over the other agents' decisions, including the goals they should pursue and the actions they should execute. Such conditions are either constrained by the inherent distribution of goals and knowledge in the system (most problem solving systems using a MAS approach, e.g., [13]) or deliberately defined by the system designer to investigate cognitive aspects of the individual agent and/or emergent properties of the system as a whole (most systems in MABS [14]). In either way, rational autonomous agents need social reasoning abilities to choose goals and partners with adequate capabilities, and to generate proposals to convince the others to collaborate favorably to their collective or individual goals.

The problem of rational choice among a set of feasible alternatives is frequently associated with the question of choice between different decision-making strategies. Some authors advocate a context-bounded notion of rationality, such that different contexts call for different decision-making strategies [7]. For instance, utility theory based on the classic economic principle of rationality does not always conform to human choice behavior [18] and significant evidence in the MABS field seems to show that the ordering of alternatives to maximize the difference between benefits and costs does not provide an increase on the number of coalitions in a multi-strategy world [7]. Even if information is obtained easily and the perfect rationality assumption is relaxed, the individual must often consider alternatives sequentially and decide about them as they are presented. Limited information-processing capacity causes agents to rely on a number of heuristic principles that reduce the complexity of even simple problems, meaning the assumption of utility maximization is discarded for the weaker assumption of procedural rationality [27]. Moreover, there is a growing belief that agents' cognitive and motivational structures play a central role in the enhancement of predicative capacity of decision-making strategies. For instance, this seems to be the main motivation behind the design of the Belief-Desire-Intention (BDI) (e.g.[21]) and the Belief-Values-Goals (BVG) [2] architectures.

There are other attempts to introduce cognitive individual ingredients in the process of decision making, in which, unlike BDI architectures, the social structures between agents are explicitly represented, lending it easily to social simulation based-analysis. In the Theory of Social Power and Dependence Networks [4,26] agents have different capabilities that are complementary to achieve a set of goals. The individual agent behavior is determined by its motivations, according to patterns of social interactions that may occur with other agents, like, for example, social exchange or cooperation. The type of social interactions is determined by the agent's situation in his structure of dependence relations. The notion of rationality is thus based on relational notions of dependence, allowing the definition of different taxonomies of dependence situations between agents. In the present work we will call this type of rationality *motivation-oriented* rationality, and will analyze and simulate the construction of social power and dependence structures [4,26,6,24,8] in the scope of high-level collaboration with generation of proposals for making coalitions with multiple actors. The objective is to analyze the properties of associating motivation-oriented and utility-oriented decision-making criteria in artificial institutions by using multi-agent modeling and multi-agent based simulation.

There are several reasons to account for high-level collaboration models in multi-agent based simulation (MABS) and more generally in multi-agent systems (MAS)[1].

Firstly, agent social interactions frequently occur through high-level communication languages, and consequently are conducted on levels of abstraction within or above Newell's Knowledge Level [19,16]. On a practical level, the system designer usually prescribes the agent's goals. However, the unpredictable nature of the other agents' motivations, and high-level normative organizational behaviors, raises higher the dynamics of the other agents' goals to the eye of the agent. Agents may not only need to exchange tasks or specific actions, but may need to measure, exchange and adopt each other's goals in substantive terms. Secondly, the complexity of social reasoning in terms of goal adoption and goal delegation structures has been shown to be a NP complete problem [10]. Such complexity calls for active experimentation on both micro-social and macro-social levels, in order to assess patterns of interdependencies that may enhance the search for adequate partners and the collaboration process among cognitive agents.

In the scope of this article, we therefore adopt a two step methodological analysis, the first one based on multi-agent modeling and the second on controlled experimentation.

In the first step, we analyze cognitive representations of social dependence structures in the context of relations from a single agent to a non-empty set of agents (1:n). Different power and dependence structures are systematized, conceding different effects in one agent's ability to find and influence others to collaborate. The agents' decision mechanisms use both utility-oriented and motivation-oriented criteria to choose adequate partners and proposals to form coalitions.

In the second step, we use agent-based simulation to test our rationality approach. Here, we advocate that the complexity of social power and dependence patterns may be assessed with the simulation of dependence structures in artificial societies. These simulations may range from highly controlled experiments with emphasis on the individual agent representations of social structures (with an explicit relation to the cognitive agent's machinery) to highly stochastic experiments with a descriptive analysis of the artificial system as a whole (where the relation to the cognitive agent's machinery is more difficult to assess). One objective in our experiments is to emphasize the simulation of cognitive representations of dependence structures at the micro-social level, as being complementary to the simulation and assessment of patterns of dependence at the macro-social level, the last one being usually analyzed in statistical terms.

Perhaps with the exception of Conte and Pedone [7], where the authors try to assess some cognitive ingredients of individual rationality on micro-social and macro-social levels of analysis, one may notice that the literature of MABS [14] has prevalently

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[1] An extensive review concerning possible vectors for cross-fertilization among Multi-Agent Systems and Agent-Based Social Simulation may be found in the introductory chapter of the last MABS workshop [14].

simulated social phenomena from a macro-social perspective of analysis. This report shares some foundational aspects with [7], namely, that an experimental manipulation of cognitive internal variables is necessary to increase the predicative capacity of decision making and social scientific theories. However, we will restrict our experiments to the micro-social perspective of analysis, and present some further conjectures for future vectors of research that may require us to use a macro-social level of analysis.

We start in section two by presenting a cognitive model of social reasoning that generates different dependence structures and proposals of coalitions with multiple agents. This model is based on a social reasoning mechanism [26,8] and in this paper especially stresses its emphasis on the paradoxical usage of both utility-oriented and motivated-oriented decision-making criteria for selection of partners and generation of proposals. In section three we proceed with the simulation of these representations and present our preliminary results.

The results suggest that distinct dependence situations [26] span different patterns of proposal structures for coalition formation, which seem to have different patterns of complexity in the search space. We further show that such patterns introduce ambiguity in the orderliness of different criteria, related to individual utility-oriented and motivation-oriented decision making. While the agent deliberation dynamics in MAS and MABS calls for combined measures of motivation-oriented and utility-oriented rationality, we suggest that additional analytical work at micro-social levels of analysis and empirical work at macro-social levels of analysis is required, in order to understand and change dynamically the agent's rational abilities according to relations between dependence patterns and the corresponding complexity in the search space.

2 Goal Hierarchies and Adoption

Agents might depend on others (or prefer the others) to achieve some of their goals, which ultimately leads them to negotiate and exchange partially delegated goals. An agent's endogenous goal (e.g. a goal assigned by the system designer) will often need to explore social objects in the exterior world. Strictly speaking, by endogenous we mean a goal that is stored at the Knowledge Level in Newell's sense. Accordingly, new goals (and beliefs) may be acquired in the Knowledge Level owing precisely to the social world. Goals may in fact be adopted instrumentally in order to obtain some advantage in return [4]. If this is the case, the adopted goal may be seen as a "means-to-ends" link to a higher order goal in a tree hierarchy of goals.

We may consider the multiplicity of potential pairs [adopted goal/partner] to be an or-hierarchy sub-tree associated with an agent's endogenous higher-order goal. The question for a rational agent is therefore: which external goals to adopt and to which partners send the corresponding proposals for collaboration? This work does not concentrate on the decision problem related to choice of active endogenous goals, but on the choice of external goals pertaining to such or-hierarchy sub-trees.

In previous work we have proposed a decision model built upon the social reasoning mechanism [26,8], which is based on the Theory of Dependence and Social Power

[4]. Shortly, if an agent depends on a third-party agent in order to achieve his goal, the third-party's goals may become candidates for adoption, meaning the adoption is strictly instrumental. The choice of a goal among a set of goal candidates for adoption is based on both quantitative and qualitative measures of dependence relations between the agents.

2.1 Dependence Relations

We consider that the agent ag_0 Č Ag is a generic agent in a finite set of agents, designated *subject* agent, who uses his social reasoning mechanism in order to better propose/accept coalition proposals to/from other agents. Agents model the other agents' goals, plans and controlled actions through a data structure that we call *external description*. The external description comprises a finite set of *entries*, each one holding a set of goals, plans and controlled actions for each known agent in the agency. With such a structure a subject agent is able to calculate a set of dependence relations between any specific agent, which here we will call object agent, and his peers[2].

An object agent ag_0 is dependent on a third-party agent ag_t, in regard to a specific goal g, according a specific set of plans P, iff the object agent needs to execute an action controlled by the third-party agent and not controlled by the object agent - $d\_on(ag_0,ag_t,g,P)$. One may have several types of dependence relations among two agents: *unilateral*, *bilateral*, *mutual* and *reciprocal* dependencies. A ***M****utual Dependence* (MD) between the object and the third-party agents represents a bilateral dependence concerning the same goal. A ***R****eciprocal* ***D****ependence* (RD) defines a bilateral dependence in regard to two different goals. Another concept in the model is the notion of *dependence situation* (dep-sit), which tries to capture an agent's susceptibility to adopt another agent's goal. Dependence situations relate two agents and a goal, and may be locally or mutually believed, depending on their *source*, i.e. the set of plans that is used to infer them. This is actually a somewhat intuitive notion. For example, let us imagine we are pondering to create a new business company and we are looking for interested partners: it is rather insightful to examine to what extent may we use exclusively our plans to collaborate, meaning the dependence situation is locally believed, or question ourselves if they share an identical opinion, meaning the dependence is mutually believed[3].

In this paper, we will use $P_{ag_0}(ag_0)$ when referring to the object's agent set of plans, and $P_{ag_0}(ag_t)$ when referring to the plans the object agent believes the third-party has. In the latest case we will often abbreviate $P_{ag_0}(ag_t)$ simply to *the third-party agent set*

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2 For simplicity and clarity we assume here that the subject and object are the same, i.e., the subject agent reasons about his own properties. We also assume that agents have complete and correct beliefs about each other. These assumptions are not restricted in the social reasoning model, as it may be seen in [25]. Furthermore, we assume that agents are sincere, meaning they do not communicate to others information in which they do not believe.

3 More precisely, meaning that we believe that the dependence is mutually believed. We use this notion of mutual belief in the rest of the paper.

of plans. In addition, we will omit the explicit reference to the object agent in the formulae and will often use $P(ag_t)$ instead of $P_{ag_o}(ag_t)$.

Two elementary relations of dependence called *Inverse Dependence Relations* (IDR) are particularly useful in our work. Each IDR represents a certain amount of power owned by an object agent over a specific third-party agent and goal. Such power may be inferred according to the object agent's set of plans or according to the third-party agent set of plans. We call a third-party agent dependence on the object agent, inferred according to some goal and the plans the object agent thinks the third-party has, a ***R****emote* ***B****elieved* ***I****nverse* ***D****ependence*:

$RBID(ag_o,ag_t,g)\text{ø}_{def}\ d\_on(ag_t,ag_o,g,P(ag_t))$.

Conversely, a ***L****ocal* ***B****elieved* ***I****nverse* ***D****ependence* defines a third-party agent dependence on the object agent according to the object agent's set of plans:

$LBID(ag_o,ag_t,g)\text{ø}_{def}\ d\_on(ag_t,ag_o,g,P(ag_o))$.

For instance, consider the following airline companies scenario, with an object agent *Af* and his external description shown in figure 1.

Identity: <Af af.somewhere.com 3856> Goals: Paris/Sydney(120)
Actions: Paris/Moscow(52); Paris/London(8); Paris/Lisbon(26)
Plans: Paris/Sydney:= Paris/Lisbon, Lisbon/Macau, Macau/HongK, HongK/Sydney.

Identity: <Tp tp.north.com 7352> Goals: Lisbon/Moscow(300)
Actions: Lisbon/Paris(26); Lisbon/Macau(156); Macau/HongK(2)
Plans: Lisbon/Moscow:= Lisbon/Paris, Paris/Moscow.

Identity: <Au au.anywhere.com 7366> Goals: Sydney/SaoPaulo (45)
Actions: Sydney/BuenosAires(147); HongK/Sydney(100)
Plans: Sydney/SaoPaulo:= Sydney/BuenosAires, BuenosAires/SaoPaulo.

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Tp tp.north.com 7352>
|------ Lisbon/Moscow (300) (RBID)
      |------ Lisbon/Moscow:= Lisbon/Paris, Paris/Moscow. (Feasible NLSource)
            |------ Paris/Moscow (52)
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Figure 1. An example of dependence relations.

Here, goals can be satisfied by flight carriers with desired departure and destination points. Plans represent routes with multiple stops to fulfill multiple market shares.

According to *Af*'s beliefs it is possible to infer that he depends unilaterally on agents *Tp* and *Au*, when considering the goal Paris/Sydney and his own set of plans: *Tp* controls actions Lisbon/Macau and Macau/HongK, and *Au* controls HongK/Sydney. Conversely, agent *Af* may infer a remote believed IDR relative to agent *Tp* and goal Lisbon/Moscow, since *Tp* depends on *Af* for action Paris/Moscow according to *Tp*'s plans. One may also notice that agent *Au* does not originate any IDR according to *Af* beliefs. In fact, *Af* does not have anything to offer to *Au*, either according to *Af*'s plans or *Au*'s plans. The dependence structure in the bottom of the figure identifies agent *Af*'s possible offered goals, plans and actions relative to agent *Tp*. Here, we say that the goal Lisbon/Moscow is an *offered-goal*. The corresponding plan is designated *offered-plan* and the action Paris/Moscow is called an *offered-action*.

In the context of high-level negotiation, any IDR may be seen as a potential proposal to the third-party agent. The object agent has power over the third-party agent desired goal, which is ultimately associated with a set of actions partially controlled by the proponent and some set of plans. We use IDRs to define the set of all possible *offered goals* to the third-party agent.

Formally, the set of offered goals comprises all goals making the third-party agent ag_t dependent on the object agent ag_o, either according to the object agent's set of plans or the third-party agent set of plans, i.e., local or remote believed IDRs:

$$O\text{-}G(ag_t)\text{ø}_{def}\ \{g \text{ Č } G(ag_t) \mid LBID(ag_o,ag_t,g) \text{ Ę } RBID(ag_o,ag_t,g)\}.$$

The corresponding set of possible *offered plans* comprises plans in the object agent's set of plans $P(ag_o)$ or in the third-party agent set of plans $P(ag_t)$ for which the third-party agent depends on the object agent[4]:

$$O\text{-}P(ag_t)\text{ø}_{def}\ \{p\text{Č}(P(ag_o)\text{Ć } P(ag_t)) \mid A(a\text{Č } adep(ag_o,ag_t),g\text{Č } O\text{-}G(ag_t))(uses(p,a) \text{ ė } goal(p)=g)\}.$$

Finally, the associated set of possible *offered actions* comprises members of the object agent's set of controlled actions $A(ag_o)$ for which the third-party agent depends according to the set of offered plans and offered goals. Note that an offered action must necessarily be performed by the object agent, although it may be performed according to a plan believed by the object agent and/or believed by the third-party agent:

$$O\text{-}A(ag_t)\text{ø}_{def}\ \{a \text{ Č } A(ag_o) \mid A\ (p \text{ Č } O\text{-}P(ag_t))\ (uses(p,a) \text{ ė } a \text{ č } A(ag_t))\}$$

Offered goals are captured by the notion of conjunctive dependencies, namely multi-goal *and*-dependencies, where the third-party depends on the object agent for multiple goals. Conversely, a set of offered plans relative to a same offered goal is captured by the notion of multi-plan *or*-dependencies. In Conte and Castelfranchi [6] and David *et al*. [8] it is shown in a substantive sense that conjunctive IDRs augment the power over the third-party, while disjunctive IDRs increases the flexibility for negotiation by augmenting the set of available alternatives.

2.2 Performance, Choice and Rationality

The problem of choice among a set of feasible proposals is inherently connected with expected performance. Generally, if the principle of non-benevolence is assumed, we may find two major trends for measuring the agents' individual performance [5,7,9].

The first one adopts a utility oriented scale, calculated according to the cost of the agents' actions against the worth of the corresponding goals, whatever goals these may be. Such theories specify that when as agent is acting rationally, the agent is engaging in some kind of optimization. The agent's decision functions are fundamentally concerned with the *choice of actions* that maximize utility, often according to the classic principle of economic rationality (e.g.[29]). Choice of goals is not so critical to the individual agent since the agent designer often prescribes (hardwires) the goals in the agent's machinery. Paradoxically, utility-oriented agents may have to drop high value

[4] $adep(ag_o,ag_t)$ is the set of actions controlled by the object agent but not controlled by the third-party.

goals in favor of lower value goals if the difference between benefits and costs in the latter case is higher than the former. Also, agents are usually required to have a high level of knowledge and computational ability with which to determine and evaluate a set of available alternatives.

A motivation oriented perspective of individual rationality will most probably value a *substantive* [7,9], hedonistic view, of rationality; that is, individual *performance* measured in terms of the agents' attained goals (e.g. number of goals). Here, similar to Newell's principle of rationality, the real *motive* for being rational is focused on the agents' own goals. In this case, the agent's decision functions are essentially concerned with the choice of adequate partners in order to achieve a set of individual goals. Here, the choice of proper interactions among a set of alternatives is generally qualitative in nature, according to orderings of qualitatively different patterns of dependence between agents.

A number of problems have been identified with classical utility decision theory, like orderability of preferences or computational complexity (e.g.[22]). Nevertheless, these theories seem to be adequate to model a number of social phenomena, such as the problem of emergence of cultural groups [15] or social trade networks [11]. Similarly in MAS with real distributed and open environments (e.g. the Internet), the agents abilities are specified to a great extent in terms of auctions and services (e.g. white and yellow pages, search engines), making utility oriented decision theories adequate to applications such as electronic commerce.

While different utility-oriented models share the fact that agents are purposive, in the sense that they act in ways that tend to produce beneficial results, the heterogeneity of agents and their different goals makes a motivation-oriented notion of performance also desirable. Together with other authors [18,4,7], we advocate that goal directed behavior often results not a from a conscious weighing of the expected future benefits of alternative lines of action, but from a less deliberate response to beliefs internalized through the socializing influences of social structure. For instance, in artificial societies, a crucial operational issue in coalition formation is the problem around the choice of offered goals, selected from a given set of candidate alternative proposals. Another related problem is the issue of delegation and goal adoption, which seems to play a crucial role in human-computer interaction [3]. In a dynamic and heterogeneous world there may be different decision-making strategies to accept coalition proposals, with some agents possibly being more hedonistic and others utilitarian.

These issues ask for complementary types of rationality for the generation of proposals, which in our view must use both utility-driven and motivation-driven strategies. The agents' evaluation of receiving proposals against their goals means that an explicit and social structural link may be established between selection of partners and choice of proposals. In this work we simulate such an approach and utilize the notion of *dependence situations* and *dependence strength*.

The former notion is a motivated-oriented definition of qualitatively different patterns of dependence, calculated according to different configurations of dependence relations between agents.

The later concept has an intended utility and motivation oriented hybrid character, a function expressing the object agent's preferences, with equal probabilities, between actions that may be offered to a same third-party agent. For each possible partner in a coalition, the object agent's *offered action strength* is calculated according to its cost and the substantive contribution to all possible offered goals and plans. This means that for each possible partner there will be a finite set of possible atomic states, each one corresponding to a different action controlled by the object agent. Naturally such a function, which we call *offered action strength*, will often be a domain dependent function. To our ends, we will use the following simplified formula:

$\text{a-strength}_{ag_t}(a) =_{def} (\sum_i N_{plans}(g_i, a).w(ag_t, g_i))/c(ag_o, a))$, where g_i is any offered goal for which the offered action a can contribute, $w(ag_t, g_i)$ is the goal importance according to the third-party agent[5], $N_{plans}(g_i, a)$ is the number of offered plans for goal g_i that use the offered action, and $c(ag_o, a)$ is a positive integer representing the cost of the offered action according to the object agent. Notice that the numerator expresses a hedonistic view of preferences, favoring actions that maximize the contribution to the importance of offered goals.

The notion of dependence strength considers the number of possible offered actions and ponders and integrates their strength:

$$\text{dep-strength}(ag_t) =_{def} \sum_{a \in O\text{-}A(ag_t)} \text{a-strength}_{ag_t}(a)$$

The latter definition identifies the most dependent agents on the proponent according to the relevance of his set of available proposals. The former formula suggests the most valued offered actions, playing an important role during the selection of negotiation proposals.

2.3 Choice of Partners and Proposals

Suppose that some object agent ag_o is pursuing some goal g_e and commits to some plan p_e called respectively the *engaged goal* and *engaged plan*. Let us assume he is dependent on others to achieve that goal and execute that plan. Also, for every action a^d on which the agent depends on others in the plan p_e, there is a non-empty set of possible partners represented in the external description that are able to perform it (i.e. the plan is feasible [23]). Furthermore, possibly different patterns of dependence relations will hold for each possible partner.

If the object agent depends on a possible partner for the engaged goal and plan, he may wish to calculate if the latter also depends on him for some of his goals and plans. However, their set of plans may differ, and the object agent may infer, for instance, a mutual dependence relating him and a possible partner, whereas the latter does not infer the same bilateral dependence according to his plans. In order to capture this

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[5] We assume that the importance of the third-party agent goal is known to the object agent - the computation of the exact importance is in fact not possible in most situations. We however assume that the object agent stores this information in his external description when considering his qualitative knowledge about these goals (e.g. to a certain extent different companies may know each others' order of preferences of strategic goals). Since we do not deal with learning and perception issues in this paper, we do not loose generality in the model and experiences, since their focus is essentially on the properties of social dependence networks and its cognitive representations.

possible awareness of the partners, a notion called *dependence situation* was defined [26]. In the rest of this paper we adopt the taxonomy and partial ordered set of dependence situations used in [24]: MBMD > (MBRD,LBMD) > LBRD > UD (meaning for instance that MBMD is *higher* than UD).

The last two letters in the acronyms differentiate Mutual Dependencies (MD) from Reciprocal Dependencies (RD). As for the first two letters, if the dep-sit is Mutually Believed (MB) it indicates that is inferred according to both the object and the third-party set of plans. If the dep-sit is Locally Believed (LB) indicates that the dep-sit is inferred according to the object agent's set of plans. UD stands for Unilateral Dependence, meaning the object agent depends on the third-party but the latter does not depend on the former according to the object agent's set of plans, i.e., there are no LBIDs. There is a minor difference here from [24] in that we do not use the situation named IND (Independence), since we assume the object agent depends on others for the engaged goal.

Consider the function dep-$sit_{ag_o}(ag_t,g_e)$ that calculates the dependence situation according to the object agent, a third-party agent ag_t Č Ag and the object agent' engaged goal g_e Č G(ag_o). We next describe a collection of partial ordered sets and decision functions with respect to the choice of possible partners and the corresponding proposals.

Choice of Partners - if two agents pertain to a same set of possible partners for the object agent, then ag' $á_{parrtner}$ ag iff: (**1**) ag'=ag; or (**2**) if ag' dep-sit regarding ag_o and g_e is lower then ag; or (**3**) agents have equal deps-sits and ag' dependence strength is lower than ag; or (**4**) agents have equal dep-sits, equal dependence strengths and the cost of the action a^d according to ag' is higher than ag.

In conclusion, for each action the preferred partner is chosen from the corresponding set of possible partners according to a sequence of priorities, primarily motivation-driven (first and second criteria), but also utility-driven (second and third criteria).

Choice of Offered Goals - Except for unilateral dependencies, the set of *chosen offered goals* for each preferred partner, results primarily from the set of offered goals originating the highest dep-sit.

C-OG(ag_t,g_e)ø

{g_e}	if dep-sit_{ag_o} (ag_t,g_e)=MBMD or LBMD
{g'Č O-G(ag_t) | LBID(ag_o,ag_t,g') ė RBID(ag_o,ag_t,g')}	if dep-sit_{ag_o} (ag_t,g_e)=MBRD
{g'Č O-G(ag_t) | LBID(ag_o,ag_t,g')}	if dep-sit_{ag_o} (ag_t,g_e)=LBRD
{g'Č O-G(ag_t) | RBID(ag_o,ag_t,g')	if dep-sit_{ag_o} (ag_t,g_e)=UD

Notice in the case of unilateral dependencies (UD), that all chosen offered goals result necessarily from the set of plans the object agent thinks the preferred partner has, i.e., Remote Believed IDRs. In the case of mutual dependencies the engaged goal and the chosen offered goal are necessarily the same.

Choice of Offered Plans - Similar to the computation of offered goals, the set of *chosen offered plans* is highly dependent on the inferred dep-sit. The best feasible offered plans are the ones believed by both agents. Local believed plans are also preferred to non-local believed plans.

Consider a set of offered plans calculated according to the chosen offered goals. The *chosen offered plans* – $C\text{-}OP(ag_t,g_e)$ – are calculated according to the following partial order: $p1 \; á_{plan} \; p2$: iff (**1**) p1=p2 or p1 is not feasible and p2 is feasible; or (**2**) both are feasible and p1 is not mutually believed and p2 is mutually believed; or (**3**) both plans are feasible and p1 is not locally believed and p2 is locally believed.

Choice of Offered Actions - Consider a set of offered actions calculated according to the chosen offered plans. The set of *chosen offered actions* – $C\text{-}OA(ag_t,g_e)$ – are the ones calculated according to the chosen offered plans and sharing the highest dependence strength.

In summary, the preferred offered action is chosen from the object agent's set of controlled actions associated with (1) offered goals originating the highest dep-sit; (2) feasible and convenient source set of plans; (3) the maximum observed action strength. Formally, the final proposal for each preferred partner ag_t, relative to the object agent's engaged goal g_e is therefore:

$decide_{prop}(ag_t,g_e) =_{def} (a, P(a), G(a))$, with,

$a = random(C\text{-}OA(ag_t,g_e))$,

$P(a) = \{p \; Č \; C\text{-}OP(ag_t,g_e) \mid uses(p,a)\}$

$G(a) = \{g \; Č \; C\text{-}OG(ag_t,g_e) \mid A \; (p \; Č \; P(a)) \; (goal(p)=g)\}$.

Strong offered actions are likely to cause positive social interference with several offered plans and goals, increasing the quality of a proposal and the preferred partner's susceptibility to accept the coalition.

3 Experimentation

Social simulation was the way to evaluate our ideas and find predominant patterns of dependence that may be better accommodated in the model. We have implemented short experiments for e-contracts with software packages for reuse [8] and more extensive experiments for strategic reasoning with airline transportation carriers. The latter example, which we will present here, is a typical domain where companies may establish coalitions in order to increase the number of carriers and destinations, for instance, when building packages of lower price flights between multiple cities that one individual company can not provide.

The experiments proceed in small steps and are highly controlled, with an almost absence of random variables. The classical social simulation approach, inspecting over emergent phenomena on a macro-social level (usually described in statistical terms) is not our aim here. This would in fact be a difficult task as all objects (goals, plans and actions) have a clear semantics, and are not randomly generated. Furthermore, and to a certain extent, the model itself shapes the relations that agents are allowed to establish. Following [24], we therefore adopt a lower level analysis and try to proceed slowly for an incremental understanding of social structures created by deliberative agents.

3.1 A First Simple Example

Companies must have a number of common goals and cross dependent carriers so as to make an effective strategic agreement. Goals are available or desired carriers. Each company ascribes a certain importance to their goals. Plans represent routes with multiple stops to fulfill multiple market shares. There may be several plans for a same carrier and each company has its own set of preferred plans. Initially, suppose that there are two agents known to agent *Af*: the agents *Tp* and *Au*. In figure 2 we show the external description of agent *Af*.

I'm agent Af, running at af.somewhere.com, with pid 3856.

Identity: <Af af.somewhere.com 3856>
Goals: Paris/Sydney(120); Paris/Dublin(116); Rome/Boston(40); Rome/Marseille(33)
Actions: Paris/Moscow(52); Paris/London(8); Paris/Lisbon(26); Paris/Argel(22); Paris/Marseille(6); Argel/Dackar(22); Paris/NewY(102); Paris/Toulouse(5); Toulouse/Marseille(6)
Plans: Paris/Dublin:= Paris/London, London/Dublin.
Paris/Sydney:= Paris/London, London/HongK, HongK/Sydney.
Paris/Sydney:= Paris/Lisbon, Lisbon/Macau, Macau/HongK, HongK/Sydney.
Rome/Boston:= Rome/Paris, Paris/NewY, NewY/Boston.
Rome/Marseille:= Rome/Paris, Paris/Toulouse, Toulouse/Marseille.

I have received the following messages of introduction:

Identity: <Tp tp.north.com 7352> Goals: Lisbon/Moscow(300)
Actions: Lisbon/Paris(26); Lisbon/Macau(156); Macau/HongK(2)
Plans: Lisbon/Moscow:= Lisbon/Paris, Paris/Moscow.

Identity: <Au au.anywhere.com 7366> Goals: Sydney/SaoPaulo (45)
Actions: Sydney/BuenosAires(147); Sydney/Pretoria(156); HongK/Sydney(100)
Plans: Sydney/SaoPaulo:= Sydney/BuenosAires, BuenosAires/SaoPaulo.

Figure 2. External description of agent *Af*.

In figure 3, agent *Af* builds his dependence network. We will present hereafter two different kinds of networks. The first type, called *dependence network*, is constructed when the agent reasons about his goals and expresses in a same structure all the object agent's needed actions, considering all of his goals and plans. The second one, called *proposal network*, is constructed when reasoning about partners and presents all possible partners and possible proposals for each needed action in some engaged plan.

In the dependence network, it can be observed that the agent has two goals (Paris/Sydney and Rome/Marseille). However, agent *Af* has only one achievable goal – Paris/Sydney. He has two plans for that goal, but only one of them is feasible. Even though the plan passing by Macau and Hong Kong might not be the most advantageous plan, there are no other feasible plans for his goal and he will try to form a coalition. He is dependent on agent *Tp* for two needed actions – Lisbon/Macau and Macau/HongK – and on agent *Au* for needed action HongK/Sydney.

The information that agent *Af* captures from the proposal network is related to the goals, plans and actions that he can offer to his possible partners. For each needed action and possible partner in the engaged plan we may find information concerning the highest dep-sit (d-sit), the dependence strength on the object agent (d-strength), and the cost ascribed by the possible partner to the needed action (d-a-cost).

```
========== Reasoning about goals ...
My dependence network is:
 <Af>
-- Paris/Sydney (120) (achievable)
  |---- Paris/Sydney:= Paris/London, London/HongK, HongK/Sydney. (NFeasible)
  |    |---------- London/HongK (NA)
  |    |           |********** UNKNOWN
  |    |           | HongK/Sydney (EC:100.0)
  |    |           |********** <Au 7366> (100.0)
 ( . . . )
  |    | Paris/Sydney:= Paris/Lisbon, Lisbon/Macau, Macau/HongK, HongK/Sydney. (EC:284)
  |    |---------- Lisbon/Macau (EC:156.0)
  |                |**********  <Tp 7352> (156.0)
  |                | Macau/HongK (EC:2.0)
  |                |**********  <Tp 7352> (2.0)
  |                | HongK/Sydney (EC:100.0)
  |                |********** <Au 7366> (100.0)
 ( . . . )
  | Rome/Marseille (33) (not achievable)
  |---- Rome/Marseille:= Rome/Paris, Paris/Toulouse, Toulouse/Marseille. (NFeasible)
       |---------- Rome/Paris (NA)
                   |---------- UNKNOWN
                              |----------
The engaged goal is: Paris/Sydney (120)
The engaged plan is:
  Paris/Sydney:= Paris/Lisbon, Lisbon/Macau, Macau/HongK, HongK/Sydney. (EC:284)
========== Reasoning about partners ...
My needed actions are: <Lisbon/Macau>, <Macau/HongK>, <HongK/Sydney>
My possible partners, offered goals, plans and actions for each needed action are:
 Lisbon/Macau and Macau/HongK
|-- <Tp tp.north.com 7352> / d-sit: UD / d-strength: 5.4 / d-a-cost: 156.0 and 2.0
   |------- Lisbon/Moscow (300) (RBID)
          |------- Lisbon/Moscow:= Lisbon/Paris, Paris/Moscow. (Feasible NLSource)
                 |------ Paris/Moscow (52)
                        |------
 HongK/Sydney
|-- <Au au.anywhere.com 7366> / d-sit: UD / d-strength: 0.0 / d-a-cost: 100.0
   |-------- no offered goals
```

Figure 3. Dependence and proposal network of agent *Af*.

In this scenario, all inferred dep-sits are Unilateral Dependencies (d-sit=UD). However, agent *Af* has in fact something to propose to agent *Tp*. The power of *Af* over *Tp* is not insignificant, according to the plans *Af* thinks *Tp* has: agent *Af* may be able to use in an instrumental way the Remote Believed IDR with his proposal involving the offered goal Lisbon/Moscow and the offered action Paris/Moscow. On the contrary, agent *Au* dependence strength on *Af* is zero. Agent *Af* will not propose anything to agent *Au* as shown in figure 4.

In figure 4, agent *Af* receives *Tp*'s acceptance of proposal. On the other hand, agent *Au* will reject *Af*'s proposal, which is justified by the non-benevolence principle. In reality nothing was proposed to *Au*. The plan is no longer feasible since there are no more possible partners available and all the agent's goals become non-achievable.

The coalition was not formed. This example demonstrates on a practical level is that it seems intuitive to specialize Sichman's dependence situations on both qualitative and quantitative levels. A same dependence situation may be associated with different influencing power conditions. Zero dependence strength implied scarcity of substantive arguments to offer to agent *Au*. Yet, unilateral dependencies inferred according to the proponent's plans, with non-zero dependence strength, may be reciprocated - it is also a priority to search for relations of power on the others agents' beliefs. This was the case of agent *Tp*. Accordingly, it seems clear that social exchange [4] may be triggered by unilateral dependencies coupled with remote believed IDRs (e.g. *Af* with *Tp*), at least if not adopting pure cognitive-psychological examples like in [24].

```
========== Deciding about partners ... (Partner choices criteria: d-sit > d-strength > action_cost )
The selected partner(s) and proposal(s) are :
| Needed actions: Lisbon/Macau, Macau/HongK                | Needed action: HongK/Sydney
| Partner: <Tp tp.north.com>                               | Partner: <Au au.anywhere.com>
| Offered goal/action:<Lisbon/Moscow>/<Paris/Moscow>      | Offered goal/action: NONE/NONE
========== Sending and receiving messages ...
Sending proposals of coalition to <Tp tp.north.com 7352> ... <Au au.anywhere.com 7366>
The messages received are: (Acceptance <Tp 7352>), Refusal <Au 7366>)
My new list of possible partners, offered goals, plans and actions is:
 HongK/Sydney
|------ no possible partners (empty list)
Informing agent <Tp tp.north.com 7352> that the proposal of coalition was canceled ...
========== Reasoning about goals ...
The engaged goal is no longer achievable.
```

Figure 4. Selection of partners and proposals.

3.2 Second Example

Let us suppose that after the previous events, four agents arrive at the agency: *Ba*, *Tw*, *Ai1* and *Ai2*. Additionally, to save space, suppose that agents *Tp* and *Au* had left the agency. In figure 5 we show *Ai1*, *Ai2*, *Ba* and *Tw* external description entries.

In this scenario, the autonomy of agent *Af* increases significantly, with all his goals becoming achievable - figure 6. Still, his most important goal will be the same - Paris/Sydney - even though he will choose another plan due to feasibility conditions. There are two needed actions in this plan, London/HongK and HonK/Sydney. In the dependence network represented in the figure, all four agents are able to execute *Af*'s needed action HongK/Sydney.

I'm agent Af, at af.somewhere.com, with pid 3856, I have received the following messages of introduction:

Identity: <Ai1 ai1.anywhere.com 3855>
Goals: Rome/Boston(55); Rome/Marseille(34); Rome/London(20)
Actions: HongK/Sydney(113); Rome/Lisbon(23); Rome/Paris(12)
Plans: Rome/Boston:= Rome/Lisbon, Lisbon/NewY, NewY/Boston.
Rome/Boston:= Rome/Paris, Paris/NewY, NewY/Boston.
Rome/Boston:= Rome/Paris, Paris/London, London/NewY, NewY/Boston.
Rome/Marseille:= Rome/Paris, Paris/Marseille. Rome/London:= Rome/Paris, Paris/London.

Identity: <Ai2 ai2.somewhere.com 3860> Goals: Rome/Boston(55)
Actions: HongK/Sydney(113); Rome/Lisbon(23); Rome/Paris(12)
Plans: Rome/Boston:= Rome/Lisbon, Lisbon/NewY, NewY/Boston.
Rome/Boston:= Rome/Paris, Paris/NewY, NewY/Boston.

Identity: <Ba ba.somewhere.org 3861> Goals: London/Maputo(100); London/Argel(90)
Actions: London/Paris(8); London/HongK(158); HongK/Sydney(113); London/Dublin(4)
Plans: London/Argel:= London/Paris, Paris/Argel.

Identity: <Tw tw.air.org 3865>
Goals: NewY/Argel(67); NewY/Camberra(60); NewY/Marseille(64); NewY/Dackar (66)
Actions: HongK/Sydney(103); NewY/London(115); NewY/Paris(120); NewY/Boston(10)
Plans: NewY/Argel:= NewY/London, London/Paris, Paris/Argel.
NewY/Dackar:= NewY/Paris, Paris/Argel, Argel/Dackar.
NewY/Argel:= NewY/Paris, Paris/Argel. NewY/Marseille:= NewY/Paris, Paris/Marseille.

Figure 5. *Ai1*, *Ai2*, *Ba* and *Tw* entries in the external description of agent *Af*.

With respect to the action HongK/Sydney shown in figure 7, both agents *Ai1* and *Ai2* share a higher dep-sit - Mutual Believed Reciprocal Dependence (MBRD) - than the one originated by *Tw* and *Ba* - Unilateral Dependence (UD). However, *Ai1*'s dependence strength on *Af* (=17.2) is higher compared to *Ai2* (=0.5), giving to *Af* a significant potential flexibility to negotiate with *Ai1*. For example, *Af* is aware that the action Paris/London may be useful for two of *Ai1*'s current goals (Rome/Boston and Rome/London). Also, notice that agents *Ai1*, *Ai2* and *Ba* share the same and the highest cost (d-a-cost=113.0) for the referred needed action HongK/Sydney. Yet, in figure 8, the strategic choice to execute the needed action will not fall on agent *Tw*, which assigns the lowest cost to the needed action but originates the lowest dep-sit (UD).

As shown in figure 8, agent *Ai1* was thus selected to execute the needed action HongK/Sydney. The possible chosen offered goals are the ones originating the highest dep-sit - Rome/Boston and Rome/Marseille (MBRD). The final choice of proposals to *Ai1* – Rome/Boston as the offered goal and Paris/NewY as the offered action – holds some subtle points: (1) the action Paris/London, although less expensive, belongs to a non-feasible local believed plan (NFeasible, LSource) – there would be no apparent reason for *Af* to send this proposition; (2) even though actions Paris/Toulose and Toulouse/Marseille appertain to feasible plans, they are solely associated with *Af*'s local believed plans (LSource) – there would be no apparent reason for *Ai1* to accept such propositions; and (3) action Paris/Marseille is associated with a non-local believed plan (NLSource) – although it may be possible that the partner would be willing to accept it, there is one other plan believed by both sources that seems to be a better choice for *Af*.

```
========== Reasoning about goals ...
My dependence network is:
 <Af>
-- Paris/Sydney (120) (achievable)
  |------ Paris/Sydney:= Paris/London, London/HongK, HongK/Sydney. (EC:276.5)
  |      |---------- London/HongK (EC:158.0)
  |      |           |**********  <Ba 3861> (158.0)
  |      |           | HongK/Sydney (EC:110.5)
  |      |           |**********  <Ai1 3855> (113.0), <Ai2 3860> (113.0), <Ba 3861> (113.0), <Tw 3865> (103.0)
 ( . . . )
  | Paris/Dublin (116) (achievable)
  |------ Paris/Dublin:= Paris/London, London/Dublin. (EC:12.0)
  |      |---------- London/Dublin (EC:4.0)
  |                |----------   <Ba 3861> (4.0)
  |                          |----------
  | Rome/Boston (40) (achievable)
  |------ Rome/Boston:= Rome/Paris, Paris/NewY, NewY/Boston. (EC:124.0)
  |      |---------- Rome/Paris (EC:12.0)
  |                |**********   <Ai1 3855> (12.0), <Ai2 3860> (12.0)
  |                | NewY/Boston (EC:10.0)
  |                |**********   <Tw 3865> (10.0)
 ( . . . )
The engaged goal is: Paris/Sydney (120)
The engaged plan is: Paris/London, London/HongK, HongK/Sydney. (feasible) (276.5)
```

Figure 6. Dependence network of agent *Af*.

```
========== Reasoning about partners ...
My needed actions are: <London/HongK>, <HongK/Sydney>
My possible partners, offered goals, plans and actions for each action are:
London/HongK
|-- <Ba ba.somewhere.com 3861> / d-sit: UD / d-strength: 4.1 / d-a-cost: 158.0
   |-- London/Argel (90) (RBID)
      |--- London/Argel:= London/Paris, Paris/Argel. (Feasible NLSource)
         |--------- Paris/Argel (22)
HongK/Sydney
|- <Ai1 ai1.anywhere.com 3855> / d-sit: MBRD / d-strength: 17.2 / d-a-cost: 113.0
  |---  Rome/Boston (55) (MBRD)
  |  |--  Rome/Boston:= Rome/Paris, Paris/NewY, NewY/Boston. (Feasible BSources)
  |  |  |--------- Paris/NewY (102)
  |  |  |          |------
  |  |  | Rome/Boston:= Rome/Paris, Paris/London, London/NewY, NewY/Boston. (NFeasible
  |  |  |--------- Paris/London (8)                                          NLSource)
  |  |             |------
  |  | Rome/Marseille (34) (MBRD)
  |  |--  Rome/Marseille:= Rome/Paris,Paris/Toulouse,Toulouse/Marseille.(Feasible LSource)
  |  |  |--------- Paris/Toulouse (5), Toulouse/Marseille (6)
  |  |  |          |-------
  |  |  | Rome/Marseille:= Rome/Paris, Paris/Marseille. (Feasible NLSource)
  |  |  |--------- Paris/Marseille (6)
  |  |             |-------
```

```
|   | Rome/London (20) (RBID)
|   |--  Rome/London:= Rome/Paris, Paris/London. (Feasible NLSource)
|       |--------- Paris/London (8)
|                 |------
| <Ai2 ai2.somewhere.com 3860> / d-sit: MBRD / d-strength: 0.5 / d-a-cost: 113.0
|---- Rome/Boston (55) (MBRD)
|    |-- Rome/Boston:= Rome/Paris, Paris/NewY, NewY/Boston. (Feasible BSources)
|        |--------- Paris/NewY (102)
|                 |------
| <Ba ba.somewhere.com 3861> / d-sit: UD / d-strength: 4.1 / d-a-cost: 113.0
|---- London/Argel (90) (RBID )
|    |-- London/Argel:= London/Paris, Paris/Argel. (Feasible NLSource)
|        |--------- Paris/Argel (22)
|                 |-----
| <Tw .air.org 3865> / d-sit: UD / d-strength: 95.4 / d-a-cost: 103.0
|---- NewY/Argel (67) (RBID)
     |--  NewY/Argel:= NewY/London, London/Paris, Paris/Argel. (Feasible NLSource)
     |  | NewY/Argel:= NewY/Paris, Paris/Argel. (Feasible NLSource)
     |  |--------- Paris/Argel (22)
     |            |-----
     | NewY/Marseille (64) (RBID)
     |-- NewY/Marseille:= NewY/Paris, Paris/Marseille. (Feasible NLSource)
     |  |--------- Paris/Marseille (6)
     |            |-------
     | NewY/Dackar (66) (RBID)
     |-- NewY/Dackar:= NewY/Paris, Paris/Argel, Argel/Dackar. (Feasible NLSource)
        |--------- Paris/Argel (22), Argel/Dackar (22)
```

Figure 7. Proposal network of agent *Af*.

```
========== Deciding about partners ... (Partner choices criteria: d-sit > d-strength > action_cost)
The selected partner(s) and proposal(s) are:
¦ Needed action: HongK/Sydney, Partner: <Ai1 ai1.anywhere.com>
¦ Offered goal/action: <Rome/Boston>/<Paris/NewY>
¦ Needed action: London/HongK, Partner: <Ba af.somewhere.com>
¦ Offered goal/action: <London/Argel>/<Paris/Argel>
```

Figure 8. Selection of partners and generation of proposals.

In effect, the action Paris/NewY is associated with a plan believed by both sources (BSources) and there is a mutual interest to form a coalition associated with that plan and goal. This is actually true and in figure 9 the proposal networks of agent *Ai1* shows that there is in fact a Mutual Believed Mutual Dependence (MBMD) relative to the proponent *Af* and to the goal Rome/Boston that is the most valuable for *Ai1*.

Agent *Ai1* accepts the proposal since he needs in fact the proposed offered goal and offered action, as shown in figure 9. This mutual dependence arises since *Af* has the goal Rome/Boston as well. Nevertheless, it differs from *Af*'s dep-sit relative to *Ai1* since they do not share the same set of plans.

```
========== Reasoning about messages ...
I have received a proposal of coalition: (PROPOSAL <Af af.somewhere.com 3856>
```

```
========== Reasoning about plans ...
My dependence network with reference to the proposed goal <Rome/Boston> is:
 <Ai1>
-- Rome/Boston (55) (achievable)
  |---Rome/Boston:= Rome/Lisbon, Lisbon/NewY, NewY/Boston. (NFeasible)
     |---------- Lisbon/NewY (NA)
     ( . . . )          ( . . . )
     | Rome/Boston:= Rome/Paris, Paris/NewY, NewY/Boston. (EC:124.0)
     |---------- Paris/NewY (EC:102.0)
     |          |********** <Af 3856> (102.0)
     |          |          |----------
     |          | NewY/Boston (EC:10.0)
     |          |**********  <Tw 3865> (10.0)
     |                     |----------
     | Rome/Boston:= Rome/Paris, Paris/London, London/NewY, NewY/Boston. (NFeasible)
     |---------- Paris/London (EC:8.0)
                |********** <Af 3856> (8.0)
                |          |----------
                | London/NewY (NA)
               ( . . . )
The engaged plan is: Rome/Paris, Paris/NewY, NewY/Boston. (feasible) (124.0)
My possible partners, offered goals, plans and actions are (action Paris/NewY):
Paris/NewY
|--
  | <Af af.somewhere.com 3856> / d-sit: MBMD / d-strength: 88.0 / d-a-cost: 102.0
  |---- Rome/Boston (40) (MBMD)
      |----- Rome/Boston:= Rome/Lisbon, Lisbon/NewY, NewY/Boston. (NFeasible LSource)
      |    |-------- Rome/Lisbon (23)
      |    |         |-----
      |    | Rome/Boston:= Rome/Paris, Paris/NewY, NewY/Boston. (Feasible BSources)
      |    |-------- Rome/Paris (12)
     ( . . . )
I will accept the proposal, because I do not have a better partner.
```

Figure 9. Dependence and proposal network of agent *Ai1*.

Agent *Ba* accepts *Af*'s proposal as well and the coalition is formed (not shown here). Similar to the first experiment, the proponent *Af* uses his bargaining power over *Ba* according to the plans he thinks *Ba* has (using *Ba*'s goal London/Argel and needed action Paris/Argel).

3.3 Some Preliminary Comments - Substance, Utility and Complexity

The model seems to present a coherent behavior, however there are some comments to be pointed out. For instance, a critical issue concerns the use of the decision-making criteria for choice of partners, in which the motivation oriented criteria (dependence situations) deliberately preceded the combined utility/motivation-oriented criteria (dependence strength). A closer look to the second example would show that a change of priorities in the partner selection criteria would elect agent *Tw* instead of *Ai* for the needed action HongK/Sydney. Agent *Tw* originates a lower dependence situation (UD) than agent *Ai1* (MBRD). That is, the experiments give no clue whether high dependence situations with small dependence strengths should be preferred to low dependence situations with high dependence strengths.

A solution to this problem may be possible if a relation between dependence situations and some kind of expected dependence strength can be predicted. For example, let us admit the possibility of a higher trust between partners pursuing a same goal, against the case of pursuing different goals [4,24]. Accordingly, we have considered Mutual Dependencies (one single offered goal) more valuable than Reciprocal Dependencies (one or more offered goals). Nevertheless it is possible to observe, after running multiple experiments, that MDs seem to contribute less than RDs to the overall network dimension and thus overall dependence strength.

A similar point can be noticed with respect to the locality of plans: Mutual Believed Reciprocal Dependencies usually exhibit lower network dimensions than Local Believed Reciprocal Dependencies, since the number of plans in the network seems to be reduced with the mutual believed case, due to the intersection set of remote and local believed IDRs (see section 2.3).

These issues raise some questions in terms of patterns of complexity in the search space. For instance, mutual dependencies often offer a constrained expected space of search for alternatives due to lower network dimensions. It is well known that agents have bounded rationality [27]. We thus may ask: when should trust on a reduced set of alternatives (e.g. mutual dependencies) be preferred to complex, but flexible, networks of possible proposals and bargaining power, eventually with better expected utility benefits (e.g. reciprocal dependencies)? Also, unlike our model of hybrid rationality that confronts both decision approaches in the same level of abstraction, should utility oriented analysis be analyzed on a distinct level of abstraction from the motivation perspective, like for example in [1]? Interestingly, the software engineering oriented work of Jennings and Campos [17] raises higher a set of utility oriented principles to the Social Level of abstraction, above Newell's Knowledge Level.

Complexity can certainly get worse as may be observed at the end of the second experiment. Here, the partner's Mutual Believed Mutual Dependency (*Ai1*) relative to the proponent (*Af*) plays an important role for the coalition settlement, suggesting that it could be interesting for the proponent to analyze the dependence situations relating himself to the other agents. The case would get farther worse if transitive relations were analyzed, leading to analysis of group cohesion.

Regarding these latter points, our experiences are not yet satisfactory. Our conjecture is that further effort is needed to account for a clear relation between complexity and frequently observed dependence patterns. Such effort must be made, on one hand, with further analytical considerations on the complexity of dependence structures (micro-social level) and, on another hand, with empirical analysis of patterns of dependence structures (macro-social level). If such a relation is established, then a dynamic readjustment between utility-oriented and motivation-oriented rationality may be better achieved, by adapting dynamically the agents' rational abilities according to the complexity associated with each dependence situation and available resources. We would also add that this observation clearly establishes methodological evidences around the complementary character of (i) analytical and empirical considerations on the complexity of cognitive social structures at micro-social levels and (ii) empirical analysis of patterns of social dependence structures at macro-social levels.

4 Conclusions

While the technology and normative references for agent interoperability in MAS (e.g. [12]) and MABS (e.g. SWARM [28]) is rapidly being deployed in a wide range of platforms, the predicative tools to deal with complex patterns of social dependencies that emerge within and between agent artificial societies are still inadequate. This work followed a two step methodological approach involving modeling and social simulation based-analysis. Our model for coalition formation was built on the assumption that dependence based choices of partners and proposals are obligatorily integrated issues. The experiments were accomplished at the micro-social level and were able to identify different degrees of influencing power for a same dependence situation, suggesting that social exchange may also be triggered by Unilateral Dependencies.

Further experimental results indicated that different dependence situations span different patterns of proposal structures, which appear to have different degrees of complexity in the search space. This observation emerged as an issue of ambiguity in the previous underlined decision model, concerning the orderliness of different criteria with respect to motivation-oriented and utility-oriented choices. While MAS dynamics calls for combined measures of motivation and utility oriented rationality, we claim that additional analytical analysis at micro-social levels and empirical analysis at macro-social levels is required. Such analysis may open the way to disambiguate and dynamically affect the agents' rational abilities according to relations between patterns of dependence and expected complexity in the search space.

References

1. Alonso E. (1998), *How Agents Negotiate Societies*, Proceedings of the 3rd International Conference on Multi-Agent Systems, ICMAS'98, IEEE press, pages 18-29.
2. Antunes L., Faria J. and Coelho H. (2000), *Improving Choice Mechanisms within the BVG Architecture*, The International Workshop on Agent Theories, Architectures, and Languages (ATAL00), Intelligents Agents VII, Springer Verlag.
3. Castelfranchi C. and Falcone R. (1999), *Towards a Theory of Delegation for Agent-Based Systems*, Robotics and Autonomous Systems, vol. 24, N.3 and 4.
4. Castelfranchi C., Miceli M. and Cesta A. (1992), *Dependence relations among autonomous agents*, Proceedings of MAAMAW92, Elsevier Science, pages 215-227.
5. Coleman J. and Fararo T. (1992), *Rational Choice Theory - Advocacy and Critique*, Sage Publications, Key Issues in Sociological Theory.
6. Conte R. and Castelfranchi C. (1996), *Simulating multi-agent interdependencies. A two-way approach to the micro-macro link*, Microsimulation and the Social Science, Mueller U. and Troitzsch K. editors, Lecture Notes in Economics, Springer Verlag, pages 394-415.

7. Conte R. and Pedone R. (1998), *Finding the best partner: The PART-NET system*, Multi-Agent Systems and Agent-Based Simulation, Proceedings of MABS98, Gilbert N., Sichman J.S. and Conte R. editors, LNAI1534, Springer Verlag, pages 156-168.
8. David N., Sichman J.S. and Coelho H. (1999), *Extending social reasoning to cope with multiple partner coalitions*, Multi-Agent Systems Engineering, Proceedings of MAAMAW99, Garijo F. and Bosman M. editors, LNAI1647, Springer Verlag, pages 175-187.
9. David N., Sichman J.S. and Coelho H. (1999), *On being responsible: how to be individualistic and smile benevolence to the others*, Proceedings of the 3rd European Conference on Cognitive Science, ECCS99, 27-30 October, Sienna, Italy, pages 57-62.
10. d'Inverno M., Luck M. and Wooldridge M. (1997), *Cooperation structures*, Proceedings of the International Joint Conference on Artificial Intelligence, IJCAI97, pages 600-605.
11. Epstein J.M. and Axtell R. (1996), *Growing Artificial Societies: Social Science from the Bottom Up,* MIT press.
12. FIPA (1997,1998), *Specification part 2: Agent Communication Language,* http://www.fipa.org.
13. Fischer K. and Muller J.P. (1996), *A decision-theoretic model for cooperative transportation scheduling*, Agents Breaking Away, Proceedings of MAAMAW96, Eindhoven, LNAI1038, Springer Verlag.
14. Gilbert N., Sichman J.S. and Conte R. (1998), Multi-Agent Systems and Agent-Based Simulation, Proceedings of MABS98, LNAI1534, Springer Verlag.
15. Hales D. (1998), *Stereotyping, Groups and Cultural Evolution: A case of Second Order Emergence?*, Multi-Agent Systems and Agent-Based Simulation, Proceedings of MABS98, Gilbert N., Sichman J.S. and Conte R. editors, LNAI1534, Springer Verlag, pages 140-154.
16. Jennings N. (1999), *Agent Oriented Software Engineering*, Multi-Agent Systems Engineering, Proceedings of MAAMAW99, Garijo F. and Bosman M. editors, LNAI1647, Springer Verlag, pages 1-7.
17. Jennings N. and Campos J. (1997), *Towards a social level characterisation of socially responsible agents*, IEE Proceedings of Software Engineering, 144 (1), pages 11-25.
18. Marini M.M. (1992), *The role of models of purposive action in sociology*, Rational Choice Theory - Advocacy and Critique, Coleman J. and Fararo T. editors, Sage Publications, Key Issues in Sociological Theory, pages 21-44.
19. Newell A. (1982), *The Knowledge Level*, Artificial Intelligence, (18), pages 87-127.
20. Prudkov P. and Rodina O. (1999), *Synthesis of Purposeful Processes*, Target Article at PSYCHOLOQUY - American Psychological Association (APA), ftp://ftp.princeton.edu/pub/harnad/Psycoloquy/1999.volume.10/, psycoloquy.99.10.070.purposeful-processes.1.prudkov.
21. Rao A.S. and Georgeff M.P. (1991), *Modeling Rational agents within the BDI Architecture*, Proceedings of the 2nd International Conference on Principles of Knowledge Representation and Reasoning, Morgan Kaufmann.
22. Russel S. and Norvig P. (1995), Artificial Intelligence, a Modern Approach, Prentice Hall, Chapter 16, pages 473-484.
23. Sichman J.S. (1996), *On Achievable Goals and Feasible Plans in Open Multi-Agent Systems*, Proceedings of the 2nd International Conference on Multi-Agent Systems, ICMAS96, Kyoto, Japan.
24. Sichman J.S. (1998), *DEPINT: Dependence-based coalition formation in an open multi-agent scenario*, Journal of Artificial Societies and Social Simulation, 1 (2), http://www.soc.survey.ac.uk/JASSS/1/2/3.html.

25. Sichman J.S. and Demazeau Y. (1995), Exploiting social reasoning to deal with agency level inconsistency, Proceedings of the 1st International Conference of Multi-Agent Systems, ICMAS95, AAAI Press, pages 352-359.
26. Sichman J.S., Conte R., Demazeau Y. and Castelfranchi C. (1994), *A social reasoning mechanism based on dependence networks*, Proceedings of the European Conference on Artificial Intelligence, ECAI94, pages 188-192.
27. Simon, H. (1957), *A behavioural model of rational choice*, Quarterly Journal of Economics, (69), pages 99-118.
28. Terna P. (1998), *Simulation Tools for Social Scientists: Building Agent Based Models with SWARM*, Journal of Artificial Societies and Social Simulation, 1(2), http://www.soc.survey.ac.uk/JASSS/1/2/4.html.
29. Zlotkin G. and Rosenchein J. (1994), *Coalition, cryptograpphy and stability: Mechanisms for coalition formation in task oriented domains*, Proceedings of the American National Conference on Artificial Intelligence, AAAI94, Seattle, WA, USA, pages 432-437.

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