A FOUNDATION FOR COMMITMENTS AS RESOURCE MANAGEMENT IN MULTI-AGENTS SYSTEMS

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ABSTRACT

From their earliest definitions, systems of distributed intelligent agents, so-called multi-agent systems (MAS) by the DAI community, relie on sociological theory and use centrally the concept of commitment. A definition of this concept as well as a tentative computational model of commitments, emerge from research in sociology such as Elihu Gerson's and research in computer science such as Alan Bond's. Both threads lead naturally to the study of resource management. We claim that effective resource management in a distributed system requires powerful control structure yet to be founded. We propose a model of control that stems from the psychology of human emotions, introducing "emotion-like control structures" that should be part of the fundamental definition of more autonomous, reliable and adaptive multi-agent systems. We illustrate how the introduction of "emotion-like control structures" improves a great deal the architecture of a computational model of distributed agendas, using a model of communication rooted in speech act theory.

• INTRODUCTION

Communities of cooperating autonomous agents as well as human societies use resources whose management is at the core of any organized activity. Resources are defined more or less as energy is in physics, whatever is required for producing work : it basically amounts to the cost of work or actions. Needs, such as hunger and thirst, are the motivational processes that insure management and regulation of directly consumable resources, be it available food or water for animals or processing time for a computer. These are <u>first-order resources</u>. Besides, there exist <u>second-order resources,</u> which one gets only indirectly, through having others committed to provide them : newborns have access to food only through having their parents get the feeding resources for them.

Commitments, essentially measured in terms of resource allocation and constraints upon resources appear to be the main reason for the setting up of multi-agent societies. By regulating exchange, they enable using each other as a way to access additional resources otherwise unaccessible or too costly to obtain. From their earliest definitions, systems of distributed intelligent agents, so-called multi-agent systems (MAS) by the DAI community, relie on sociological theory [Gasser 91] and use centrally the concept of commitments [Fikes 82]. Building upon the seminal work of symbolic interactionists such as [Gerson 76], [Bond 90] and [Dongha 94] propose a definition and a computational model of the concept of commitment that leads naturally to the study of resource management. We think that effective resource management in a distributed system requires powerful control structures yet to be founded.

The main purpose of this paper is to sketch the design for such a model of control that stems from the psychology of human emotions [Oatley 92]. The first section defines first-order and second-order resources, and revisit the concept of commitments in this context. The second section proposes a model of control that stems from the psychology of human emotions. It introduces emotions as powerful control structures that act so as to protect agents - and societies of agents - from running out of resources, typically second-order-ones. The third section takes a closer look at the utilisation of speech acts as communication primitives between agents and introduces the new concept of emotional acts, as a way to resolve ambiguities inherent to the expressive and declarative illocutionary categories. We claim that "emotion-like control structures" should become part of the fundamental definition of more autonomous, reliable and adaptive multi-agent systems.

I • FROM RESOURCES TO COMMITMENTS

I.1 • First-order and second-order resources

If agents are ever to get autonomous, it will only be through getting control over their motivations, by having ways of setting their own goals. The idea of providing agents with the capability to generate their own top level goals is not alien to the DAI community : it can be found in Maes' earlier work [Maes 91] while the concept of *motivated agency* is introduced by [Norman & Long 95]. Motivations - needs and emotions - essentially have to do with managing resources : this is what is most crucial and vital for the agents, and what becomes their ultimate goals. In the agent context, resources are defined more or less as energy is in physics : whatever enables - and is required for - producing work. It could be physical energy like heat or electricity or food, but also time, money, affiliation, power, knowledge... Basically, the concept seems tantamount to the cost of work or actions, but it is however essential to refine it and distinguish at least two kinds of resources : first-order and second-order.

• First-order resources are directly consumable ones that an agent already has at disposal (e.g. available food or water for animals, processing time or memory for computer). Needs - such as hunger, thirst, fatigue, shelter, sex... - are the motivational processes [Toates 86] that insure management and regulation of first-order resources.

• Second-order resources are those that you get only indirectly, through having other agents committed to give them to you : newborns have access to food only through having their parents get the resources for them. Money as well should be seen as a second-order resource : any piece of money always amounts to a commitment to exchange some goods for it. And one should keep in mind that it is always revocable, be it only through the variation of currency!

I.2 • Commitments as second-order resources

Commitments are essentially measured in terms of allocation of resources and constraints upon resources [Gerson, 76] [Bond 90] [Dongha 94]. They appear as the main reason for the setting up of multi-agent societies : by regulating exchange, they enable using each other as a way to access additional resources that would remain otherwise unaccessible, or would be too costly to obtain :

• An agent A commits certain of its resources to another agent B (commits stands for “does not give right away, but promises to give eventually”). As a consequence, B is allocated new resources, while A is constrained as to the usage of its own resources. For instance, A might be constrained not to consumate all of them and to take into account some amount that has to remain available to fulfill the commitment. On the other hand, such commitment could also involve for A setting the goal of acquiring for B some resources that A does not already possess.

One important corollary is that, by virtue of making resources available, commitments themselves are to be counted as resources. Within complex species that pursue multiple goals, and who absolutely require as such the cooperation of other agents, commitments might well become the most important of all resources! Hence, it is very likely that, in social species like ours, evolutionary forces would have favored and selected out precisely those organisms that would have become equipped with powerful mechanisms to insure control over commitments!

II • EMOTIONS AS A METAPHOR FOR CONTROL STRUCTURES

II.1 • The Appraisal Structure Of Emotions : Valence, Certainty, Agency

• **Valence : Positive And Negative Emotions** In higher (social or at least nurturing) animals, emotions - such as anger, fear, joy, sadness, guilt... - are the motivational processes that insure management and regulation of second-order resources, namely commitments. Very much like needs, emotions are powerful control structures that act so as to protect agents - and societies of agents - from running out of resources. Hence they require being allocated a higher level of processing priority than most other mechanisms. These control processes are triggered by significant variations in the flow of resources available or required for an agent (or a community of agents). There indeed has to be regular variations in the daily consumption of resources, without these overpowerful processes intervening within the ongoing computation. Significant variations here means that the amount of increase or decrease of resources should exceed a certain predefined (although eventually ajustable) threshold.

There obviously has to be two main classes of emotions, positive and negative, that deal respectively with significative gain or loss in resources (leading respectively to joy or sadness).

> • Positive emotions act so as to reinvest the gain (that triggered them in the first place) in order to "buy" access to further resources : they operate as accumulators or amplifiers [Isen 93].
>
> • Negative emotions, on the other hand, are used so as to patch the breach, slow down the running waste, and eventually to call for help so as to replace the incurred loss : they operate as regulators.

Of course, these processes are themselves costly and it might not seem too adaptive to spend so much resources when one is already losing some. Yet, even if one has to pay for the plumber, it might well be worth to do so before completely running out of water! Sometimes, this protection function of negative emotions against the loss would rather be met by setting the agent in economy mode, i.e. by isolating it from the others and reducing its activity level, as it often happens with people suffering from grief or severe distress.

• **Certainty, Uncertainty and Temporal Dynamics** On the other hand, emotions being (as motivations) intrinsically related to the goal structure of an agent, they forcefully have to be related also to planning and expectations. That is to say, emotions are necessarily subject to a temporal dynamics, and could then be triggered by actual as well as by anticipated gain or loss (leading to hope or fear). While actual gains would be reinvested to obtain further resources, anticipated gains would rather insure goal persistence, by acting so as to justify sustaining the actual investment, or even spending more resources in the pursuit of the current goal. While actual loss would trigger calling for extra resources from other agents, anticipated loss would rather induce significative change in the current planning strategy. In order to do so, the required resources will generally have to be substracted from other current (goal-pursuing) processes that would then get temporarily (and even sometimes definitively) suspended.

• **Agency** Moreover, in multiagent societies, gains and losses are most frequently caused by the action of agents (self or others). In other words, due to the very structure of commitments as second-order resources, agency is, in those societies, the general cause that a resource management system should"naturally" (i.e. "evolutionarily") get a grip upon!

Before classifying emotions according to their appraisal structure, let's first recall what is agency in the psychology of emotions :

> • Agency, is understood as causal attribution [Weiner 85] : if something happens to agent A, it tries to attribute the responsibility to some other agent B. This is a way, for A, to get a grip on who can be held responsible for the considered upcoming event in order to react efficiently.
>
> • Anger is the process that gets control over situations when a significant loss of resources is attributable to the action of another agent [Hutchinson 72] [Averill 83] .

• On the other hand, if the loss is caused by self, it is the guilt emotion that steps in. [McGraw 87] .

• When someone else is seen as responsible for some noticeable gain, gratitude is triggered.

• Finally, pride takes charge when it is self that appears clearly responsible for the gain.

Joy, sadness, hope or fear are triggered either when no attributable agency could be found as a cause for the loss or gain, or when there appears to be no possible control over the corresponding event. From the «point of view» of control structures over commitments, non-controllable agency is tantamount to no agency at all, and there is no point spending resources against overpowerful agents : better call for help then or fly away (and alert relatives to flee as well)! For instance, in cases of anticipated loss attributable to others, anger would be triggered only if there is something to be done against the agents to prevent their wrongdoing, while fear would be triggered if nothing could be envisioned to prevent it.

II.2 • A Taxonomy Of Emotions

Figure 1 summarizes the preceding categorization of emotions. It is pretty much congruent with the intersecting aspects of the current «appraisal theories» in the psychology of emotion [Ortony, Clore & Collins 88] [Roseman 91] [Scherer 88] [Smith & Ellsworth 85] .

		POSITIVE		**NEGATIVE**	
		actual	**anticipated**	**actual**	**anticipated**
AGENCY	**none**	JOY	HOPE	SADNESS	FEAR
	others	GRATITUDE		ANGER	
	self	PRIDE		GUILT	

Fig. 1 The appraisal structure for the basic categories of emotions.

The first four emotions (joy, sadness, hope and fear) act so as to set up or generate new commitments (through giving and sharing resources, strengthening affiliation, building up trust and confidence, calling for help and support...) between agents. The last four emotions (pride, guilt, gratitude and anger) act so as to handle or prevent the breaking of current commitments between agents (through praising or threatening...) or to strengthen and sustain them.

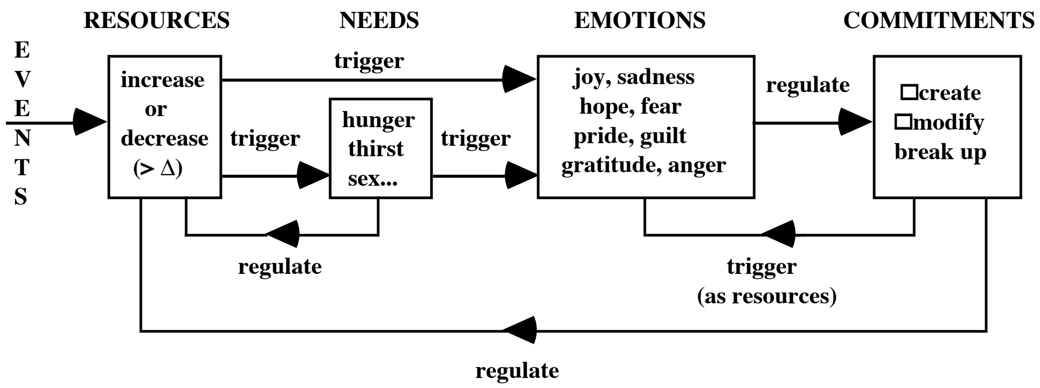

Fig. 2. The flow of control in the management of resources.

Figure 2 illustrates the model we have sketched above for the flow of control relative to the management of resources. It could be seen from this diagram that needs could themselves activate emotions in their attempt to regulate a significant variation of resources, for instance when a hungry baby gets distressed or even angered at not being fed. It also seems to be the case that first-order resources could activate emotions directly, when the variation is large enough to cross the critical threshold so as to «launch» emotional expression «evolutionarily» designed to commit others to set in and react (so they would help or flee or repent...) : states of exhaustion often lead to distress, and sudden intense pain is a well documented releaser of anger [Berkowitz 93] .

III • EMOTIONS IN THE CONTEXT OF AGENT COMMUNICATION

III.1 • Agent Communication Deals With Commitments

In the context of MAS, communication has to be about interagent binding, resource sharing, cooperation or conflict, and then has to rest upon establishing and managing commitments. In other words, communication has to be very closely related to the emotional control mechanisms. Obviously, all communications will not be emotional : variations in commitments (as resources) do not always exceed the critical threshold (as stated above) beyond which emotions are triggered. But all emotions - as commitment operators - sure have to be communicative (i.e. they have to make use of communication methods)!

III.2 • Speech Acts Are Communication Primitives

Both linguistic and DAI communities agree that, in human languages, the basic units of communication are speech acts, i.e. various ways of specifying intentions - and, as a consequence, commitments [Winograd & Flores 86]. Classically [Searle 79] and later [Vanderveken 90], reformulating [Austin 62] both provide a taxonomy for these communication primitives.

III.3 • A Taxonomy Of Illocutionary Speech Acts

Speech acts classify several kinds of communication in terms of underlying intentions and commitment and thus, introduce a taxonomy of communication primitives :

- Assertive speech acts inform, i.e.commit to some information being reliable.
- Directive speech acts request, i.e. ask someone to commit to accomplish some action.
- Promissive speech acts promise, i.e. commit oneself to accomplish some action for someone else.
- Declarative speech acts declare, i.e. commit, and request from others to commit as well, to some significative change in status.
- Expressive speech acts express some feelings or emotions.

• **<u>Expressive Speech Acts</u>** However there are a few well documented problems with this taxonomy. On the one hand, [Austin 62] and [Searle 79] themselves argue that the <u>expressive</u> category has indeed a special character («a very funny one»), and most further formalisms of speech acts bluntly ignored it. We claim that expressive speech acts cluster intentions that should not belong to the same processing level as those from other categories, in particular because they correspond to different processing priorities. We would rather consider the expressive category as <u>emotional acts</u> (vs speech acts). Our contention is that, although this category also has to do with managing and conveying intentions, it simply does not stand on the same level as the others, and rather corresponds, on the verbal level, to a «vestigial» form of a more primitive underneath layer for the handling of commitments in social animals! It amounts to the verbal aspect of a much wider channel of emotional expression (emotional acts) that already flows through various facial, postural, or sound (v.g. crying, yelling, growling, laughing...) behaviors.

> • <u>From speech acts to emotional acts</u> : we contend that agent communication should shift back from speech acts to emotional acts whenever the threshold in the variation of second-order resources is exceeded or crossed over.

Hence, communication between agents should non only reflect the verbal aspect of typical human communication but most importantly emotional non-verbal aspects as well. The choice of a platform for a testbed should take this into account : each script used by an agent for communicating with others would have to embody the specific way - in terms of speech or emotional acts - through which it operates upon commitments.

• **<u>Declarative Speech Acts</u>** On the other hand, the case for declaratives is also peculiar : it looks like a very special device of using some authority (i.e. agents with a high status - like judges in our societies) as a third party or witness to guarantee that a whole community of agents would at once subscribe to (i.e. get bound to) a new commitment (which for instance happens when a new status is ascribed to some agent - «I name you President» - or when some object of collective usage is given a new name - «From now on, this street will be called Kennedy Avenue»). This peculiar kind of commitment, shared by a whole community at once, is what [Wooldridge & Jennings 94] would call a <u>convention</u>.

• **<u>Assertive, Directive And Promissive Speech Acts</u>** In line with some other implementations [v.g. Shoham 93], we think it is mandadory to use INFORM as assertive and REQUEST as directive. But in addition to current usage, we think it is also necessary to incorporate an explicit converse for each act, v.g. DENY and UNREQUEST. On the other hand, some authors [Winograd & Flores 86] have made notice that certain categories of speech acts are reciprocal in nature, namely promissives (such as ACCEPT, and hence PROMISE) most typically act as replies to directives (such as REQUEST). Similarly, since different categories should be defined so as to capture different kinds of commitments, we think it is profitable to distinguish the assertive that commits the emitter to the information transmitted being reliable, from the (reciprocal) reply that commits the receiver to believe in what is being said (v.g. «Granted» or «I would agree on that» as opposed to : «You're fooling me!» or «I just can't believe it»)... We will use AGREE and DISAGREE to capture the reciprocal assertives that may be used as replies to INFORM or DENY respectively. And REFUSE will be used as the converse of ACCEPT. Figure 3 summarizes our categorization of the preceding speech acts related to assertives, directives and promissives.

	FROM EMITTER		**FROM RECEIVER**	
	positive	**negative**	**positive**	**negative**
COMMIT TO INFORMATION	INFORM	DENY	AGREE	DISAGREE
COMMIT TO ACTION	REQUEST	UNREQUEST	ACCEPT	REFUSE

Fig. 3 A categorization of assertives, directives and promissives.

As of <u>declaratives</u>, DECLARE will be used to set up new conventions, with the essential condition that the emitter's status should be high enough so as to enforce the new regulation. Receivers belonging to the same community would as such be constrained to respect it. Finally, the special case of <u>expressives</u> will be settled as emotional acts implemented as special messages handled by emotional actors.

IV • THE DISTRIBUTED AGENDAS TESTBED

The choice of a proper testbed for the kind of control structure we had in mind was not obvious. First, the problem had to be complex enough so as to require distributing computation over a small community of agents, yet it had to remain manageable enough so we could draw useful conclusions from its implementation. It also seemed interesting that it would be resonant or consonant with the kind of problems inhabiting the DAI culture. Finally, we felt that the nature of the problem should - when raised in human or animal societies - frequently, if not inherently, call for «emotional means of resolution». Distributed meeting scheduling emerged as a rare case satisfying enough with respect to all such criteria.

In the context of meeting scheduling (agendas),

- relevant first-order resources are :
  - periods of time (to be allocated for the various meetings);
  - processing priority;
  - knowledge (about self or others' available periods of time, or constraints, or preferences or commitments...).

- relevant second-order resources are :
  - commitments over time periods reserved for the meetings;
  - reliability of the knowledge exchanged.

- special kinds of commitments have to do with :
  - alliances (or affiliation between agents that would then feel committed to cooperate with each other);
  - status (i.e. allocated roles and power, that could sometimes enable obtaining - or even imposing - consensus among subordinates).

- two types of knowledge have to be considered :
  - declarative, through which is characterized the internal state of the agent;
  - procedural, through which is defined its behavior.

From what we said in the beginning of this article regarding motivations, it should be clear that goals (for instance, setting some specific meeting) are basically about getting resources (and from then on, preserving them) or about setting commitments (and from then on, keeping them). But this does not preclude that they could also bear upon exchanging resources (i.e. give away some resources in order to «buy» other ones that are required for the current activity), especially when this leads to creating new commitments. Plans are means to achieve goals, i.e. sequences of primitives or procedures (methods) owned by the agent, that could be assembled and executed so as to get to the expected results. As such, plans could be counted as part of the knowledge resource. From the above, it is easy to see that an agent's emotions are to be very closely related to its goal structure. For instance, blocking access to a required resource, would generally amount to goal blocking, which sure is one «universal» way (i.e. wide across cultures - and even across species!) of triggering anger [Averill 83] [Hutchinson 72] [Oatley 92] .

In the context of meeting scheduling, there forcefully has to be many agents involved at the same time, each pursuing many different goals, having to keep and fulfill various commitments, sometimes requiring help and additionnal resources from a small set of intervening emotions. In terms of implementation, this means that not only agents should be represented as dynamic entities and operate in parallel, but this should be the case as well for goals, commitments and emotions! That is, all four concepts have to be represented as actors operating concurrently by sending and receiving messages asynchronously [Agha 86]. An agent does set a goal when asked for a new meeting, or as a subgoal of a current goal (while following a plan). Achieving goals could mainly be done through communicating with other agents and making commitments with them. Of course, some checks and bookkeeping also have to be performed within the agent's internal state, be it only to make sure that the target period is free, or that the request does not interfere with other commitments. Sometimes, meetings could be settled quite easily, when there is no conflict as to the allotted period of time. But with many people from many different groups, there are problems to be solved (and plans to be unfolded) often enough, especially as time goes and as more periods get allocated (hence becoming unavailable for further meetings). Then an agent might think of reconsidering a commitment concerning some «minor» meeting, or try make use of alliances and status as resources in convincing others to revoke theirs. This is typically on such occasions that emotions do step in! In the spirit of this testbed, one should envision that some requests have high enough priority (as when the meeting is about getting a doctor for an urgency» or if the requester owns a much higher status than self) so that reactions such as fear or distress do appear «natural» and practically unavoidable. In order to be able to interrupt ongoing activity, emotions actors should be allocated a higher processing priority than goals actors or commitments actors. Emotions are to be triggered when current goals or commitments go awry.

IV.1 • Implementation Issues

The implementation uses the Actalk actor platform built on top of ST-80 [Briot 94]. It takes profit of the Smalltalk exception handling system in which an exception is defined as a situation when computation could not be completed [Dony 90]. When such a situation can be clearly described, it could also be foreseen and prevented by having a signal watch for its occurrence. Again, as was stated before, proper signals to raise for the triggering of emotions have to do with significant variations in the stock of resources, more precisely those involved within the critical goal or commitment (the one which caused problem). Once a signal is caught, control is transfered to a well-tailored handler that could execute some appropriate piece of code before resuming or halting computation.

V •□CONCLUSION

Effective resource management in a distributed system requires powerful control structure yet to be founded. We proposed a model of control, rooted in the psychology of human emotions, that introduces "emotion-like control structures" in the context of multi-agent systems. We pointed out how such control structures fit naturally into an inter-agent communication scheme based on speech act theory. Their introduction improves the potential autonomy of agents by taking explicitly into account the management of the resources that are the core of their activity and that should hence be part of the fundamental definition of more autonomous, reliable and adaptive multi-agent systems.

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