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NORMATIVE AGENTS: FORMAL ANALYSIS AND APPLICATIONS

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Abstract

Modern organizations are faced with many challenges. However, the lack of the appropriate software and modeling techniques, for day-to-day operations, do not allow them to reach their potentials. Agent technology is being treated as the next programming paradigm for developing complex systems with their potentials in the area of social modeling. We propose a formal framework for the development of artificial social systems and the formalization of social determination in normative environments. The proposed specification language captures both the normative and the dynamic aspects of agents' behavior and uses the resolution technique as a verification method.

Keywords: Agent technology, autonomy, deontic logic, resolution, temporal logic.

1. Landscape

In the last two decades markets have become urban, expanded all over the globe while product demand steadily increased and concentrated in specialised markets that reflect a wide industrial spectrum (Taylor 2003). Although these alterations are mostly centred on three themes, namely *change*, *diversity* and *connectivity* (Sherratt et al. 2004), the dramatic and sustained growth of computing in line with the introduction of various flavours of networking technologies has fuelled the breadth of these interactions by spanning them over various spatial and organizational boundaries. In tandem with this evolution, new business drivers have been emerged and aggressively started influencing today's business environments. For example, outsourcing changed from being a rarity and just became a common practice; the increased use of the Internet for business-to-business and business-to-consumer operations has become just a matter-of-fact resulting in erratic product demands while the increased competition and diversity of various goods has led to the abatement of products life-cycle (Radjou 2003). In fact, this situation contributes to a high degree of uncertainty, unpredictability and volatility in these environments.

Typically, today's organisations exploit software for designing, implementing, automating and, in general, improving their operations. However, these kinds of applications lack certain essential principles. For instance, they may be able to provide an in-depth analysis of business processes but they are isolated from their environment resulting in their incapacity to act autonomously. Moreover, as business operations tend to be dispersed across geographical boundaries the notion of control and decision making also becomes geographically distributed contributing to a higher degree of complexity.

Experience has stressed the need for improved software development tools, based on possibly new software engineering paradigms (Zambonelli et al. 2002) that will be able to deal with issues such as complexity, unpredictability, uncertainty and volatility (Georgeff et al. 1998). The dual aspect of these paradigms should reflect the process of developing these kinds of complex applications while the characteristics or artefacts of these paradigms should also be exploited to address other important areas such as simulations and modelling.

2. Motivation

Agent technology is being considered as the next programming paradigm for conceiving, designing and implementing complex software systems (Guilfoyle et al. 1994; Sycara 1998). In fact, these cover depth and breadth of systems that range from information-intensive and unpredictable to open and dynamic environments, in which the notions of control, interaction and decision-making are dispersed over various interconnected nodes. The central aspect of this technology is the notion of *environment* in which agents act. Other key qualities with which agents are ascribed reflect the notions of *autonomy*, *pro-activeness*, *responsive-ness* and *social ability* (Jennings et al., 1998; Wooldridge et al. 1994). These notions refer to agents' capability to control their actions and internal states, to have goals as future state of affairs they wish to bring about, to act in a stimulus response fashion according to what they perceive and to interact with others by coordinating their activities in a collaborative or competitive fashion.

The co-existence of agents in the same environment provides several advantages but it may also generate conflicts among the participants. For example, possible actions of one agent may not fit well with actions performed by others or the achievement of an agent's goal may prohibit the achievement of goals that other agents have. These interferences may stem from the decision and control of these interactions is left solely to agents. Therefore, uncontrolled interaction may generate conflicts resulting in degrading of the performance of the overall system.

Unfolding our inspirations, we propose a formal framework for the development of artificial social systems and the formalization of social determination in normative environments. The proposed specification language captures both the normative and the dynamic aspects of agents' behavior and uses the resolution technique (Bolotov et al. 1999) as a verification method. More precisely, our work considers the normative point of view these kinds of systems should exhibit, as a mean for controlling autonomy and interaction between them while it focuses on the development of groups of agents characterized by specific normative aspects. Therefore, agents' behavior is determined by their goals, intentions and at the same time, by obligations that reflect the society, as a whole. Towards this end, our future inspirations are twofold. The first corresponds to the application of this formal framework in business domains, such as e-commerce, while the second can be useful in developing qualitative methods in modeling business environments (Taylor 2003).

3. Representing Normative and Temporal Notions

Research in agent technology has accumulated a number of formal frameworks that aim at the representation, implementation and understanding of complex software systems. One common characteristic of these frameworks is the combination, known also as fusion, of various logics that aim to address agents' properties. For instance, the notion of knowledge and belief are expressed by the modal logic systems KD45 and S5, respectively; the dynamic aspects are formalised by various temporal logics such as CTL while the motivational aspects reflect the modal system KD (Dixon et al. 2002). Despite this fact, there is a lack of work in this field regarding the development of formal frameworks able to address social issues such as normative aspects and provide proof of their correctness. In this section, we present work in order to address these issues while we place the fundamental substrate for future developments.

In the proposed work, we are interested to develop and reason about environments that include a number of autonomous agents that need to interact in order to reach their individual and global objectives. We focus on a particular quality these systems exhibit, which is the notion of sociality. Our work considers the dynamic aspects of these systems i.e. changes that may happen in these environments. At the same time it also takes into account normative notions as a means to control agent's autonomy and ensure system's efficiency. Similar to (Dixon et. al. 2002) these notions are combined in a logical framework that consists of the fusion of CTL (Emerson 1990) logic and its normative counterpart known as *deontic logic* (Føllesdal et al. 1971).

For the deontic logic counterpart, we impose certain restrictions in the accessibility relation regarding the modalities, adopting those that reflect axioms of the normal modal system KD4. These are $(\varphi \Rightarrow \psi) \Rightarrow (O\varphi \Rightarrow O\psi)$ [*O*K.], $O\varphi \Rightarrow P\varphi$ [*O*D.] *and* $O\varphi \Rightarrow OO\varphi$ [O4.] where *O* stands for the "obligation" and "φ" and "ψ" are some propositions. Axiom *O*K does not impose any restrictions in the deontic modalities. Instead, it is inherent in all possible worlds (Fasli 2001). Axiom *O*4. means that what is obligatory in a world continues to be obligatory in the world' deontic alternatives. This makes deontic alternatives transitive and leads to worlds that are in some way better from the standpoint of obligation (Chellas 1980). Axiom *O*D. guarantees the consistency of the system of obligations. In fact, it expresses the concept that whatever is obligatory, it is also permissible. Moreover, we impose some further restrictions on the accessibility relation that correspond to axiom $O4_c$. $OO\varphi \Rightarrow O\varphi$. Intuitively, this axiom expresses that if something is obligatory at its deontic alternatives then it is obligatory to the worlds (current) alternatives (Chellas 1980).

3.1 Formal Aspects

The fundamental substrate of our language, known as *CTDL*, consists of a set of propositional letters such as *{p, q, r, ..}* that represents *atomic propositions;* the set of propositional connectives $\neg$ (negation), $\wedge$ (conjunction), $\vee$ (disjunction), $\Rightarrow$ (implication) and $\Leftrightarrow$ (equivalence) and the propositional constants *true* (verum) and *false* (falsum), as already defined in the propositional calculus (PC). We interpret letters of the alphabet as variables whose values are propositional statements (Hughes et al. 1996). Since, the proposed language stems from the fusion of the computational tree logic (CTL) (Emerson 1990) and a deontic logical system, we enrich the alphabet with any corresponding temporal and deontic modalities.

The modal connectives that represent the temporal dimension are given by the introduction of two essential elements. The first refers to path operators ***A*** and ***E*** that express *universal* and *existential quantification* in a tree. In short, these represent possible execution paths that emerge over time. The second element reflects a set of future time related operators. These are $\Box$ *(always)*, $\Diamond$ *(eventually)*, $\circ$ *(next moment of time)*, *U (until) and W (unless)*. For example, $\Box\boldsymbol{\varphi}$ means that $\boldsymbol{\varphi}$ will happen at all times in the future while $\circ\boldsymbol{\varphi}$ denotes that $\boldsymbol{\varphi}$ should happen at the next time in the future. The combination of these elements with the path quantifiers allows us to express more complex facts, such as $\boldsymbol{\varphi}$ will occur always in the future, at all possible paths. This is expressed by the formulae $\boldsymbol{A}\Box\boldsymbol{\varphi}$. Another example is $\boldsymbol{E}\Diamond\,(\boldsymbol{\psi}\,U\,\boldsymbol{\varphi})$ which expresses the fact that the propositional statement $\boldsymbol{\psi}$ will occur eventually at some future until $\boldsymbol{\varphi}$ holds.

The deontic aspect of the proposed language is given by three additional operators that correspond to ***O*** (obligation), ***P*** (permission) and ***F*** (prohibition). However, as normative aspects obligations are usually imposed by an external regulatory body such as an organisation or a society (Dignum et al. 2000), we extend these modalities to denote normative aspects exacted by external entities. Thus, we introduce a set, ***N*,** that includes the corresponding societies or organisations. Here we need to stress that obligations from the same source should be consistent. Since the deontic modalities introduced should involve the notion of agency, each of these modalities should refer to an individual agent, a member of a society of agents. Therefore, we also introduce a set of agents known as *Ag = {i, j, k, …}*. Now the deontic modalities take the following structure: $^{N}\boldsymbol{O}_i\ \boldsymbol{\varphi}$,, $^{N}\boldsymbol{P}_i\ \boldsymbol{\varphi}$ **and** $^{N}\boldsymbol{F}_i\ \boldsymbol{\varphi}$, respectively.

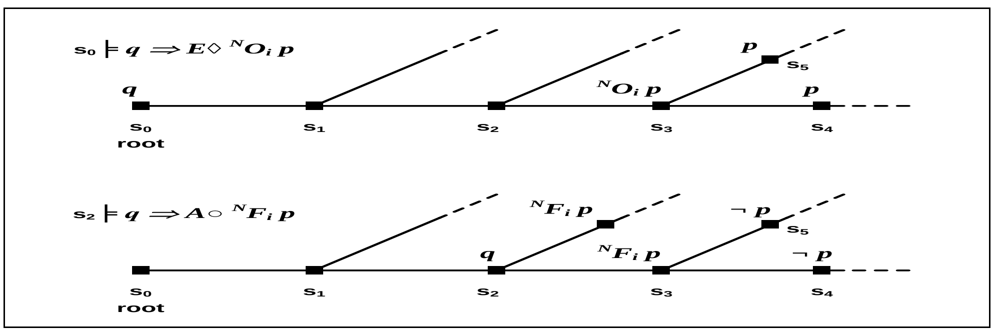

Figure 1: Branching time and Deontic CTDL Structures

The interpretation of extended modalities can be intuitively defined. For example, the meaning of $^{N}\boldsymbol{O}_i\ \boldsymbol{\varphi}$ is that *"for agent i and according to a society in N, it ought to be the case that φ"* where $\boldsymbol{\varphi}$ may represent a possible world state in which $\boldsymbol{\varphi}$ holds. In a similar fashion, the formula $^{N}\boldsymbol{P}_i\ \boldsymbol{\varphi}$ expresses the fact that *"for agent i and according to a society in N, it is permitted that φ"* . Finally, formula $^{N}\boldsymbol{F}_i\ \boldsymbol{\varphi}$ reflects the following interpretation *"according to a society member of N for agent i, it is forbidden that φ".* This means that a society of which agent i is a member, prohibits agent i to reach a possible world-state in which the fact $\boldsymbol{\varphi}$ is true**.**

3.2 Examples

In order to demonstrate our intuitions we will now provide two simplified examples based on the concepts presented so far. In fact, this will allow us to see how normative aspects can be expressed in the proposed framework. For this reason, let us consider an obligation of an agent which is a member of a society s ∈ N. In order to provide clear understanding, we also need to make use of Figure 1. The behaviour of an agent, from the normative point of view, should be expressed as a rule:

formula that expresses present situation ⇒ formula that expresses future aspects

For example, consider an agent, *i*, which is a member of a society or some organisation s ∈ N and is currently at state i.e. s_0. The formula below, where ***p, q*** reflect propositional statements:

$$\boldsymbol{s_0} \models \boldsymbol{q} \Rightarrow \boldsymbol{E}\Diamond\ {}^{N}\boldsymbol{O}_i\ \boldsymbol{p}$$

expresses that if $\boldsymbol{q}$ holds at present time (state s_0) then at some future state along some branch, agent *i*, according to the rules of the society $s \in N$, should be obliged for reaching all future states, in which the atomic propositional variable $\boldsymbol{p}$ should be satisfied. More intuitively, for example, if agent Tom borrows 10 pounds from his bank, at a possible future state, he will be obliged to return them back to the bank. In fact, this obligation directs Tom's behaviour to reach this future state that allows him to fulfil his obligation.

The second example is also based on Figure 1. Let us assume that we wish to express the fact (obligation) that if something is currently true then something else should be forbidden at the next moment in time:

$$s_2 \models q \Rightarrow A \circ {}^{N}F_i\, p$$

Indeed, this formula expresses that if $\boldsymbol{q}$ holds at a state (s_2) then for all future paths at the next moment, for agent *i*, it is forbidden to reach a state in which p holds. Note that in both examples, we did not explicitly mention the accessibility relation of the deontic modalities. However, we just assumed that s_4, s_5 world-states are accessible from s_3. Let us recall agent Tom, as it is currently borrowing money from a teller machine, at the next moment in time he is forbidden to leave, in some sense. In fact, as the teller machine is keeping his debit card, Tom shows a preference of staying there instead of moving away.

4. Applications

Without any doubt, multi-agent systems offer strong models capable of dealing with complexity, uncertainty, volatility and unpredictability. Their key qualities such as autonomy, responsiveness, adaptation, distribution, and proactive-ness make them applicable in a wide spectrum of real-world applications. These range from manufacturing and industrial domains in which automation is a matter-of-fact to simulation of economies or even societies where complex behavioral patterns emerge through interactions among autonomous entities. Despite of their classification into four thematic areas (Luck et al. 2003), these domains also share common ground. For example, agents coordinate their activities in a cooperative or competitive fashion while they may also have common or conflicting interests. However, both fashions do not consider the aspect of factuality. In fact, they lack a kind of reasoning that differentiates ideality from actual behavior (Wieringa et al. 1993) as means for regulating their autonomy.

Our framework considers this issue by two different standpoints. The first is the adoption of the deontic logic as a mean to represent normative aspects i.e. obligations that may eventually lead to morally better worlds (Chellas 1980).The second refers to the dynamic aspect of these application domains and the changes that happen over time. In fact, the dual aspect of our framework allows us to cover a depth and breadth of application domains. These include the traditional use of deontic logic to analyze the structure of the normative law and normative reasoning in terms of automating legal issues. In addition, as the notion of time is an essential element for representing contracts, in terms of meeting deadlines, our framework can be bent to support automating contracting between participants. Here possible application domains include the design, implementation and automation (automated social reasoning) of e-organizations, e-institutions (societies) as a set of constraints and distributed knowledge management systems.

From the theoretical point of view, our specification language can be bent in modeling a wide range of social environments in which complex patterns of behavior can be detected as an emergent outcome of simple rules. This for example can lead to the formulation of theories that attempt to find out a link between individuality and overall system behavior (Taylor 2003). It can also study social order and anticipate types if events and the likelihood, they may occur.

5. Concluding remarks and future work

In this paper we have discussed a number of aspects of the applicability of agent technology. We based our analysis on a formal framework for the development of artificial social systems, with the main problem of the formalization of social determination and autonomy in a normative environment. We have introduced an expressive specification language which captures both the normative and the dynamic aspects of agents' behavior. This allows us to apply the resolution technique as a verification method for such specifications. Due to the highly abstract level of our specification language, these developments can be applied to a wide range of social environments including business environments and are useful from theoretical and practical points of view. Our future work will be aimed at the justification of the correctness properties of the introduced formal techniques.

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