On Intentional and Social Agents with Graded Attitudes.

PhD Thesis submitted by: Ana Casali
Universitat de Girona - España
Advisors: Lluís Godo and Carles Sierra
Institut d'Investigació en Intel·ligència Artificial- CSIC - España

Extended Abstract

The agent research community holds that there are some application domains where agent technologies will play a crucial role in the near future. In order to achieve the full potential of agent approaches the research and development resources should be focused along several key directions. One of them, is the development of different theories, architectures, technologies and infrastructures required to specify, design, implement and manage agent based systems. The work reported in this Thesis can be placed within this direction.

The central contribution of this dissertation is the proposal of a graded BDI agent model (g-BDI), specifying an architecture capable of representing and reasoning with graded mental attitudes. We consider that making the BDI architecture more flexible will allow us to design and develop agents capable of improved performance in uncertain and dynamic environments, serving other agents (human or not) that may have a set of graded motivations.

This work is an important contribution to the agent architectures field, because of the relevance of the BDI architecture and because some of our ideas may be adapted to other agent architectures. Moreover, we dealt with the operational semantics of the agent model as a first step towards a g-BDI agent interpreter and we also developed a methodology to engineer multiagent systems composed by g-BDI agents. In summary, the Thesis contributions are situated on the following diverse fields:

1. **Agent architectures:** *a general graded BDI agent model is proposed.*

   In this model, the agent graded attitudes have an explicit and suitable representation. Belief degrees represent the extent to which the agent believes a formula to be true. Degrees of positive or negative desire allow the agent to set different levels of preference or rejection respectively. Intention degrees also give a preference measure but, in this case, modelling the cost/benefit trade off of achieving an agent's goal. Then, agents having different kinds of behaviour can be modelled on the basis of the representation and interaction of their graded beliefs, desires and intentions.

The specification of the g-BDI agent model is based on Multi-context systems (MCS). These systems were introduced by Giunchiglia et al. [12] to allow different formal (logic) components to be defined and interrelated, and Parsons et al. in [16] firstly used them to formalize BDI agents. The MCS specification of agents has several advantages both from a software engineering and a logical point of view.

In order to represent and reason about graded notions of belief, desire and intention, in the g-BDI model we followed the approach developed by Godo et al. [13] where uncertainty reasoning is dealt with by defining suitable modal theories over suitable fuzzy logics. This formalization permits us to represent the different mental attitudes within the same well-founded logical framework. The evolution of the g-BDI agent model, can be seen in [3],[4] and [5].

2. **Knowledge representation and reasoning:** *a logical framework with a sound and complete axiomatics for representing beliefs, desires and intentions is presented.*

Looking for suitable logical systems for representing and reasoning about beliefs, desires and intentions in the g-BDI agent model is a knowledge representation problem. The question of how to deal with uncertain beliefs has been widely studied in the AI community and several approaches to approximate reasoning have been proposed. The problem of preference representation (i.e. desires and intentions) has been also approached previously. Considering the agent desires in our g-BDI model, besides representing graded positive desires our agent model includes the formalization of graded negative desires, to represent respectively the agent desired and rejected states. We based our work on the bipolar model due to Benferhat et al. [1] and we extend the state of the art by giving a sound and complete axiomatics and defining different logical schemas to represent some additional constraints over preferences. In addition, we present a logical system for intentions and we show that the framework is expressive enough to describe how desires (either positive or negative), together with other information, can lead agents to intentions. Recent work in this direction was presented in [10].

3. **Process calculi:** *a Multi-context calculus (MCC) to define operational semantics for multi-context systems is developed and we use it for giving semantics to the g-BDI agent model.*

In order to cope with the operational semantics aspects of the g-BDI agent model, we first defined a Multi-context calculus (MCC) for Multi-context systems (MCS) execution. The calculus proposed is based on Ambient calculus [2] and includes some elements of the Lightweight Coordination Calculus (LCC) [17]. We expect that MCC will be able to specify different kinds of MCSs. Particularly, we have shown how graded BDI agents can be mapped into this calculus. Through MCC semantics we give this agent

model computational meaning and in this way, we move one step closer to the development of an interpreter of the g-BDI agents. Preliminary results on the language for the execution of g-BDI agents can be seen in [9]. Although process calculi have been mainly used in the past to model multiagent systems, we have considered that the modular structure that MCS provides to the architecture of an agent would permit a similar treatment of single agents as well. We think that the implementation of agent architectures using process calculi, in particular ambient calculus, would give a uniform framework for agent architectures, multiagent systems and also electronic institutions.

4. **Agent based software engineering:** *a methodology for engineering agent based systems composed by agents designed as g-BDI agents, was presented.*

We have proposed a software engineering process to develop graded BDI agents in a multiagent scenario. The aim of the proposed methodology is to guide the design of a multiagent system starting from a real world problem. The methodology presented has been built by adapting and extending previous approaches [14, 15] in order to engineer agents with a more complex internal architecture. In our work the social aspects of design are also considered, and the System Design phase is clearly separated from the Agent Design phase. Then, the proposed methodology is composed by two fundamental phases: the System Design phase, that has the purpose of determining the agent types composing the system and the Agent Design phase that is focused on modelling g-BDI agents. We extract the necessary elements from the System Design phase to design the different types of agents using the proposed architecture. This process is done in two stages. The first one, deals with the logical skeleton of the multi-context specification of g-BDI model. The second one, complete the agent design, filling the contents (theories) of the different contexts.

Furthermore, the proposed process to develop g-BDI agents contributes to bridge the gap from the external functionalities assigned to a particular agent (in the System design phase), to the elements that composed the architecture (in the Detailed design stage). Besides, we have designed and implemented a case study in the tourism domain so as to show how the proposed methodology works.

Through the design and implementation of a Tourism recommender system, where one of its principal agents was modelled as a g-BDI agent, we have come all the way from the formal g-BDI model to a concrete agent implementation. The Tourism recommender design and implementation was presented in [6, 8].

Finally, the validation and experimentation of g-BDI agents was carried out by using this case study (detailed in [11]). First, the results of the validation performed allowed us to conclude that g-BDI agents are useful to build concrete agents in real world applications. Second, we have also performed a sensitivity analysis that

showed that a g-BDI agent architecture can engineer agents having different behaviors by suitably tuning some of its components. The results of a third experiment gave support to our claim that "the distinctive feature of recommender systems modelled using g-BDI agents, which is using graded mental attitudes, allows them to provide better results than those obtained by non-graded BDI models".

References

[1] Benferhat S., Dubois D., Kaci S. and Prade H., Bipolar possibility theory in preference modeling: Representation, fusion and optimal solutions. *Information Fusion*, Elsevier, 7, 135-150, 2006.

[2] Cardelli L. and Gordon A. D., Mobile Ambients. In (Maurice Nivat, ed.) *Foundations of Software Science and Computational Structures*, number 1378 in LNCS, 140–155. Springer-Verlag, 1998.

[3] Casali A., Godo L. and Sierra C., Modelos BDI Graduados para Arquitecturas de Agentes. In *Revista Iberoamericana de Inteligencia Artificial, AEPIA*, N° 26, Vol. 9, 67-75, 2005.

[4] Casali A., Godo L. and Sierra C., Graded BDI Models For Agent Architectures. In (Leite J. and Torroni P., Eds.), *CLIMA V, Lecture Notes in Artificial Intelligence* LNAI 3487, 126-143, Springer-Verlag, Berling Heidelberg, 2005. Also in *Proceedings of EUMAS'04*, Barcelona, Spain, 2004.

[5] Casali A., Godo L. and Sierra C., Multi-Context Specification for Graded BDI Agents. In *Proceedings of the Doctoral Consortium - CONTEXT-05* Research Report LIP 6, Paris, Francia, 2005.

[6] Casali A., Godo L. and Sierra C., Modeling Travel Assistant Agents: a graded BDI Approach. In Max Bramer (Ed.), *IFIP-AI, WCC. Artificial Intelligence in Theory and Practice.*, 415-424. Springer Verlag, 2006.

[7] Casali A., Godo L. and Sierra C., A Methodology to Engineering Graded BDI Agents. In *Proceedings WASI-CACIC 2006*, 12pg. Potrero de Funes, Argentina, 2006.

[8] Casali, A., Godo, L., Sierra, C., A Tourism Recommender Agent: From theory to practice. In *Inteligencia Artificial* AEPIA 40(2008), 23:38, 2008.

[9] Casali A., Godo L. and Sierra C., A Language for the Execution of Graded BDI Agents. In *Proceedings de Formal Approaches to Multi-Agent Systems FAMAS'007*, 65-82, Durham, UK, 2007.

[10] Casali A., Godo L. and Sierra C., A Logical Framework to Represent and Reason about Graded Preferences and Intentions. In *Proceedings of the 11th*

International Conference on Principles of Knowledge Representation and Reasoning, KR 2008, 27-37, Sydney, Australia, 2008.

[11] Casali A., Godo L. and Sierra C., Validation and Experimentation of a Tourism Recommender Agent based on a Graded BDI Model. In *Proceedings of 11th International Conference of the Catalan Association for Artificial Intelligence (CCIA 2008)*, 41-50, IOS Press, 2008.

[12] Ghidini C. and Giunchiglia F., Local Model Semantics, or Contextual Reasoning = Locality + Compatibility *Artificial Intelligence*,127(2):221-259, 2001.

[13] Godo L., Esteva F. and Hajek P., Reasoning about probabilities using fuzzy logic. *Neural Network World*, 10:811-824, 2000.

[14] Jo Ch. H., Chen G. and Choi J., A New Approach to the BDI Agent-Based modelling. *ACM Symposium on Applied Computing SAC'04*, ACM 1-58113-812-1/03/04, 1541-1545 Nicosia, Cyprus, 2004.

[15] Padgham L. and Winikoff M., Prometheus: A Methodology for Developing Intelligent Agents. Proceedings of the first international joint conference on Autonomous agents and multiagent systems, 2002.

[16] Parsons S., Sierra C. and Jennings N. R., Agents that reason and negotiate by arguing. *Journal of Logic and Computation*, 8(3): 261-292, 1998.

[17] Walton C. and Robertson D., Flexible multi-agent protocols. *Technical Report EDI-INF-RR-0164*, University of Edinburgh, 2002.