On Agent-Specific Formal Methods

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1 Introduction

Over the past ten years, the field of agent-based systems has grown rapidly and
dramatically to become one of the most dynamic and significant areas of com-
puter science. Perhaps as a result of this speed of progress, the field has developed
along two largely distinct lines, corresponding to empirical and formal research.
While there is beginning to be some interaction between these two areas, there
is still a danger of fragmentation into isolated groupings. Both approaches are,
however, vital to sustained progress in work in agent-based systems. Arguably,
the most important aspect for the future of formal approaches to agent-based
systems lies in its ability to inform and contribute to practical systems develop-
ment. In that context, this contribution reviews the role of formal approaches
to agent-based systems to date and outlines some further directions, describes
some concerns that are likely to provide further impetus to future work in the
area, and highlights the overarching principles that must direct such work.

We can begin by summarising the aim of work in agent-based systems as
being to build systems capable of flexible and autonomous decision-making, with
multiple systems interacting and cooperating with each other. Formal work in
support of this goal of agent-based systems has reflected more general work in
artificial intelligence by being focussed in three key ways [1].

- First, logic has been used to axiomatise common-sense reasoning such as
  Cohen and Levesque’s theory of intention, and the more practically focussed
  BDI theories of Rao and Georgeff [5].
- Second, logic has been used as a knowledge representation language, for
  example to provide formalisms for modelling belief (eg [3]).
- Finally, logic has been used as a programming language to implement agents,
  with examples including Fisher’s work on Concurrent MetateM [2].

2 Formality in Relation to Agents

In the context of agents, we can consider the contribution that formal methods
can make in support of the further development of the field. First, we can describe
the uses to which we might put formal approaches to investigate and underpin
the foundations of the field and, second, we can describe the agent applications
that demand the use of formal approaches and provide the impetus for work at
the intersection of both fields. Each is considered briefly below.
2.1 Agent Requirements

In relation to agent-based systems in particular, there is a need for formal theories to express such components as perception, action, knowledge, belief, goals, motivation, desire, intention, and so on. The difficulty with representing such components is that while it provides useful agent theories, it is likely to produce complex theories that are not tractable. We also need languages with appropriate abstractions for programming agents — high-level languages such as Java are inadequate for a specifically agent approach because they don’t support the particular kinds of abstractions that give value to the agent metaphor. These new languages can then also provide a way of implementing formal agent theories. Finally, theories and languages for multi-agent systems are needed in addition to single-agent systems, incorporating multiple agents, common knowledge, joint intention, cooperation, coordination and communication.

Typically, efforts to address these concerns have produced formalisations of idealised or abstracted systems so that there is still a significant gap between the theory and implementations. Narrowing that gap is a key area of current work.

2.2 Agent Applications

On a related note, and as pointed out by d’Inverno et al. [1], “at least 90% of the next 700 formalisms for reasoning about agents will have no impact whatsoever on the development of the field.” Yet many applications may demand a formal analysis, in particular areas of concern that are additional to the more general issues relevant to mission-critical systems as a whole. For example, agents have been touted as an effective means of interaction in e-commerce and e-business systems. Here, agents might negotiate on behalf of a user or organisation, or they might participate in auctions, or otherwise engage in transactions on behalf of others. In such cases, users will need assurances about agent behaviour that can be provided by formal approaches. In a similar respect, perhaps the biggest barrier to the uptake of mobile agents has been concerns over security; when your mobile agents execute at remote hosts, or when other mobile agents execute at your host, security guarantees against malicious behaviour, for example, will be necessary. Despite the suspicion over formal approaches, these kinds of concerns are likely to drive forward work on the application of formal approaches to agent-based systems.

3 Formality in Support of Practice

More generally, formal agent theories can be regarded as agent specifications; they describe and constrain agent behaviour, and provide a base from which to design, implement and verify agent-based systems. The last of these, verification, has been the traditional focus of formal approaches, but the first two concerns of design and implementation are also vital and can benefit from the incorporation of formal methods. Indeed, there is a need for formal approaches to support the
movement from specification to implementation, and for formal theories to be
guided by the practical applications of agents.

In particular, for work on the development of agent-based systems to be
sustained, accessible and easy-to-use methodologies for the refinement and im-
plementation of formal agent specifications, for example, are required. This
might be achieved through the adaption of existing techniques such as UML to cope
with agents, or through methods similar to the familiar routes offered by Z speci-
fication and refinement for agents. Some current work seeks to do exactly this
in analysing the key characteristics of agent-based systems and then trying to
extend existing methods to deal with the particularly agent aspects that are not
adequately addressed already (eg. [4]). In this way, the concerns of empiricists
and formalists can be brought together, to support practical development and
deployment in pursuit of the ultimate goal of building systems.

4 Conclusion

The value of formal approaches to agent-based systems lies in their contribu-
tion to the broader goals of building agent systems. This is not to say that
system building is the only concern, but for the continued success of the agent
paradigm, real-world practical problems must be addressed. With agents, there
are numerous theoretical issues to consider, but there is also a whole new set of
problems that arise when considering systems that are delegated to act on be-
half of others in foreign environments. Certainly there are theoretical problems
here, but the commercial imperative for such systems today demonstrates a real
need for practical solutions that may be delivered by formal methods. In all of
these areas, however, there are two key questions that must be considered. First,
what is unique about agents and multi-agent systems that has implications for
formal approaches? Second, how can we tailor formal approaches to deal with
agents, be that through the development of new techniques, or the adaptation
of existing ones? While the discussion above suggests some ways in which the
future of the field might develop, these questions suggest many others.

References

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