From Definition to Deployment: What Next for Agent-Based Systems?

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Abstract

The rapid development of the field of agent-based systems offers a new and exciting paradigm for the development of sophisticated programs in dynamic and open environments, particularly in distributed domains such as web-based systems of various kinds and electronic commerce. However, the speed of progress has been such that it has also brought with it a new set of problems. This paper reviews the current state of research into agent-based systems, considering reasons for the way the field has grown and pointing at the way it might continue to progress. It pays particular attention to problems with defining the nature of agents, the technologies that have enabled the rapid progress to date, and ways in which work can be consolidated through the development of large-scale applications, and the integration with theoretical foundations.

1 Introduction

While it may be difficult to identify the critical point at which work on agent-based systems became a distinct and recognisable area of research in its own right, it is undeniable that this has been so for a significant number of years now. As has been pointed out on numerous occasions, for example by Howe and Parsons (1998), and clearly demonstrated by the recent special issue of The Knowledge Engineering Review on agent research, there are currently a large number of major conferences and workshops in this very dynamic field, covering a depth and breadth of research that points to some level of maturity. That there *is* some maturity is a testament to the way in which the challenge of agent research has been taken up in attempting to lay a foundation at the same time as developing applications and carrying out much experimental work, in a still relatively new and emerging field (Luck, 1997; Luck et al., 1998).

Therein lies much of the contradiction of agent research. It is a nascent field, but one which is already displaying a maturity that some might argue it should not have. It is still attempting to provide a sound conceptual foundation, yet application development is moving forward at full throttle. There are still disagreements over the nature of agents themselves, yet significant commercial and industrial research and development efforts have been underway for some time, and are set to grow further. Perhaps it is too early to say whether the reality will outdo the hype, or whether the predicted backlash (Crabtree, 1998) will stultify the present enthusiasm, but for the moment, the prospects remain strong.

In this paper we examine some of the reasons for the rapid growth in agent research and take stock of the current state of play in the field, paying close attention to the driving forces in terms of applications and development. The paper ends with a brief consideration of the immediate needs for continued effective progress, and the dangers that might constrain future growth. First, however, we discuss the problems that face many new to the field — understanding the nature of agents and agent systems.

2 Beyond Definition

A recurrent theme that is raised in one form or another at many agent conferences and workshops is the lack of agreement over what it is that actually constitutes an agent. It is difficult to know if this is a help or hindrance, but the truth is that it is probably both. On the one hand, the immediately engaging concepts and images that spring to mind when the term is mentioned are a prime reason for the popularisation of agent systems in the broader (and even public) community, and for the extremely rapid growth and development of the field. Indeed the elasticity in terminology and definition of agent concepts has led to the adoption of common terms for a broad range of research activity, providing an inclusive and encompassing set of interacting and cross-fertilising sub-fields. This is partly responsible for the richness of the area, and for the variety of approaches and applications. On the other hand, however, the lack of a common understanding leads to difficulties in communication, a lack of precision in nomenclature and sometimes even confusion, vast overuse and abuse of the terminology, and a proliferation of systems adopting the agent label without obvious justification for doing so.

The discussion is valuable and important, for without a common language, there can be significant barriers to solid progress, but it is problematic to find a way to converge on such a language without constraining or excluding areas in the current spectrum of activity. There have been several efforts to address this issue, however, including encompassing agent frameworks (Luck and d'Inverno, 1995) and agent taxonomies (Franklin and Graesser, 1997) which go some way to identifying the key features of agent systems and the characteristics of the different branches of the field. The benefit of these is that the richness of the agent metaphor is preserved throughout its diverse uses, while the distinct identities of the different perspectives are highlighted and used to direct and focus research and development according to the particular objectives of a sub-area.

3 Enabling Technologies

Apart from the reasons why the agent metaphor has been extremely successful in engaging interest and research, there are also strong reasons why this interest has not simply been idle, and has been able to achieve substantial success on the development side.

Indeed, the swell of interest in agents has typically been attributed to key changes and advances in the technological landscape over a number of years in recent times. Perhaps the most dramatic of these changes has been the emergence of the World Wide Web, a double-edged sword which, on the one hand has opened up a wealth of resources in an accessible way and provided ready technologies for remote distribution of information that brings with it, on the other hand, a new set of problems relating to information gathering, for example. (That little more needs to be said about the Web itself is a mark of the impact it has made across technological domains and everyday life.) As far as agents are concerned, both the benefits and the difficulties that have arisen as a result of the Web are grist to the mill of agent research and development. The distribution of information and associated technologies lend themselves almost ideally to use by, in and for multi-agent systems, while the problems that arise as a consequence suggest no solution quite as much as agents. The dual aspect of this interaction with the World Wide Web has thus been a major driving force.

However, the Web in itself is not the only factor, though its sudden and dramatic appearance, and its pervasive nature might mask other issues. In particular, advances in object technology, and more specifically distributed object technology, have provided an infrastructure without which the development of large-scale agent systems would become much more difficult and less effective and, without a doubt, agent techniques and technologies would become less transferable. For example, the CORBA distributed computing platform to handle low-level interoperation of heterogeneous distributed components, is a valuable piece of technology that can underpin the development of agent systems without the need for re-invention of fundamental techniques. Moreover, as Wooldridge and Jennings (1998) point out, related developments in other fields can, and have, also contributed to the development of agent solutions. In a very effective paper, they make a reasoned and sensible assessment of nature of agent-oriented development and, in addition to highlighting the fundamental (if sometimes obscured) observation that this is a special case of software development, identify its relation to existing and more general technologies and techniques.

In fact, it might be argued that the success of agent systems is due to the timely coincidence of a maturity in some related fields and specific developments in others that have converged in a particular way, catalysed by the agent metaphor, to describe the current state of the art.

4 Agents Out of the Laboratory

With this maturing of the technology, and the increasing acceptance of agents and their deployment in commercial and industrial applications, agents can be regarding as moving out of the laboratory. The adoption of agent technology for use in fielded applications is an important milestone in the development of the field, and marks the start of the transition from prototypes and demonstrators to the commercial products that can provide further impetus.

In the early days of the field, a number of archetypal problems suited to the application of agent technology achieved high visibility and were responsible to some extent for driving the field forward. For example, agents for traversing and searching the web as discussed above, and email and news filtering agents exemplified a large body of work at one end of the spectrum. These kinds of systems were not the only agents being developed, but occupied a central position in the perception of the work being done.

The application of techniques developed for these relatively well-defined problems, however, has transferred into more general areas, and in more sophisticated and extensive systems. Electronic commerce is just one example of the natural extension and elaboration of earlier work and its application to an exciting new domain of activity (Guttman et al., 1998).

Perhaps more important to the long term prospects of agent systems, though, are application domains that are less intuitively obvious possibilities for agent systems deployment, but no less deserving or appropriate. This is because the successful development and use of agent systems by those who are unaware of the hype, and less concerned with the issues of the technology *per se* but more concerned with the benefits that it delivers, is more likely to sustain the agent paradigm in the longer-term. In this respect, work on the development of agent systems for electricity distribution management through the ARCHON project (Jennings and Wittig, 1992), and more recently on business process management in ADEPT (Jennings et al., 1996), for example, provide good illustrations. Similarly, the application of agents to problems in protein analysis and genome structure prediction, in order to make sense of the vast amounts of genomic data that are being generated at an ever-increasing pace and stored at globally distributed but accessible sites [1], demonstrates the suitability of the agent paradigm in yet another very different domain.

[1] `http://globin.bio.warwick.ac.uk/geneweaver/`

The particular value of these latter efforts is in solving problems that have not been created by the very technology (or related technology) that is being used to solve them. These problems and domains are pre-existent and *decoupled* from the solutions, and consequently provide what might be considered an objective demonstration of the utility of agent systems. For the cynics — and there are many — this is an acid test.

5 Theory and Practice

To this point, the general tone of this piece has suggested that good progress is being made at a reasonable pace and, though this is true to a large extent, there are nevertheless significant obstacles to be overcome. In particular, the rapidity of progress has led to the emergence of distinct threads of research concerned with what might coarsely by grouped under headings of *theory* and *practice* (as it has led to the difficulty with definition as discussed earlier). In simple terms, and in a gross misrepresentation of the field, but one which illustrates a valid point, much work has tended to focus on either the development of practical applications of agent systems on the one hand, or the development of sophisticated logics for reasoning about agent systems on the other. Certainly, both of these strands of research are important, but it is crucial for there to be a significant area of overlap between them for cross-fertilisation and for one strand to inform the other. Unfortunately, however, there has been a sizable gap between these formal models and implemented systems.

For example, implementations have typically involved simplifying assumptions that have resulted in the loss of a strong theoretical foundation for them, while logics have had small relation to practical problems (Rao, 1996). Though this fragmentation into theoretical and practical aspects has been noted, and several efforts made in attempting to address this fragmentation in related areas of agent-oriented systems by, for example, Goodwin (1995), Luck et al. (1997), and Wooldridge and Jennings (1994), there remains much to be done in bringing together the two strands of work.

Some progress has been made with BDI agents (Bratman, 1988) in particular, a well-known and effective agent architecture, and Rao has attempted to unite BDI theory and practice in two ways. First, he provided an abstract agent architecture that serves as an idealization of an implemented system and as a means for investigating theoretical properties (Rao and Georgeff, 1992). Second, he took an alternative approach by starting with an implemented system and then formalizing the operational semantics in an agent language, AgentSpeak(L), which can be viewed as an abstraction of the implemented system, and which allows agent programs to be written and interpreted (Rao, 1996).

An alternative effort with BDI agents has been made made by d'Inverno et al. (1998a; 1998b) in providing formal computational models of implemented systems and idealised systems, using the Z specification language (Spivey, 1992), a standard (and commonly-used) formal method of software engineering. The benefit of this work is that the formal model is much more strongly related to the implementation, in that it can be checked for type-correctness, it can be animated to provide a prototype system, and it can be formally and systematically refined to produce a provably correct implementation. In this vein, related work has sought to contribute to the conceptual and theoretical foundations of agent-based systems through the use of such specification languages (used in traditional software engineering) that enable formal modelling yet provide a basis for implementation of practical systems, as has been done by several researchers (Craig, 1991; Goodwin, 1995; d'Inverno and Luck, 1998).

In contrast to these approaches, some work aims at constructing directly executable formal models. For example, Fisher's work on Concurrent MetateM (Fisher, 1995) has attempted to use temporal logic to represent individual agent behaviours where the representations can either be executed directly, verified with respect to a logical requirement, or transformed into a more refined representation. Further work aims to use this to produce a full development framework from a single high-level agent to a cooperating multi-agent system. In a similar vein, Parsons aims to address the gap between specification and implementation of agent architectures by viewing an agent as a multi-context system in which each architectural component is represented as a separate unit, an encapsulated set of axioms, and an associated deductive mechanism whose interrelationships are specified using bridge rules. Since theorem-provers already exist for multi-context systems, agents specified in this way can also be directly excecuted.

As yet, the body of work aimed at bridging the gap between theory and practice is small. Fortunately, though, there seems to be a general recognition that one of the key roles of theoretical and practical work is to inform the other (d'Inverno et al., 1997), and while this is made difficult by the almost breakneck pace of progress in the agent field, that recognition bodes well for the future. Some sceptics remain, however, as Nwana made clear in the FoMAS'97 panel discussion on agent systems when he followed Russell (1997) in warning against *premature mathematization*, and the danger that lies in wait for agent research (Aylett et al., 1998).

6 Problems and Prospects

Beyond the somewhat higher level concern with the theory-practice divide, and despite the progress to date, some other key areas of more definite concern remain. Though we know, more or less, what agents are, the uses to which they might be put or are suited, and the component technologies that are necessary for their construction, the field as a whole is a patchwork of more and less critical areas of interest, each at a different level of maturity and with prospects for variable levels of progress. There are significant and very visible gaps here. This is partly due to the inconsistent views of what agent research entails, or perhaps just to the range of issues that remain to be addressed.

For example, the question of how important agent development methodologies are, and to what extent they are needed in addition to existing object-oriented methodologies, depends on the individual view of the agent field. If agents provide a programming paradigm to rival object-oriented programming, then this is clearly of central concern, but if they instead provide a paradigm or metaphor for design, then methodology is certainly important, but the nature of that methodology is likely to be significantly different (Fisher et al., 1997). In either case, however, methodology is an issue that merits much more attention than it has yet achieved. As Crabtree (1998) points out, some initial work resulting from major development projects such as ARCHON (Jennings and Wittig, 1992) has been done, and there are a few more recent efforts in this area, such as the work by Kinny et al. (1996), but these must be just the start of a much more sustained programme. Indeed, as the field matures, the broader acceptance of agent-oriented systems will become increasingly tied to the availability and accessibility of well-founded techniques and methodologies for system development.

The first wave of agent research might be over, but a second wave is now upon us. Arguably, this is the more difficult one, because it must be less concerned with the exciting and inspirational issues, and concentrate more on the mundane but fundamental issues of consolidation that underlie any serious technological effort. As described in this paper, these include the integration with, and use of, existing technology that is tried and tested, the application of agent solutions to pre-existent problems, the linkage of agent theory and practice, and the augmentation of the technology with facilities for development, of which methodolgy is a potent example. Arguably, the success of the last ten years is that they have defined some of the problems that need to be addressed over the next ten years.

Ultimately, the nature of agent research can be viewed in a similar way as has general artificial intelligence research by some. They argue that while the goals of artificial intelligence may or may not be achieved (whatever they may be), the pursuit of those goals and the endeavour to achieve them will unearth many useful and effective techniques and tools that address some relevant problems. Even if agents do not succeed in fulfilling the aims of those working in the field, the many and varied aspects of agent technology (in tools, techniques and also theory for negotiation, communication, protocols, and so on), will, nevertheless, contribute significantly to computing as a whole. Indeed, some would suggest it is fair to say that this has already been done.

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