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Defence Applications of Multi-Agent Systems

International Workshop, DAMAS 2005
Utrecht, The Netherlands, July 2005
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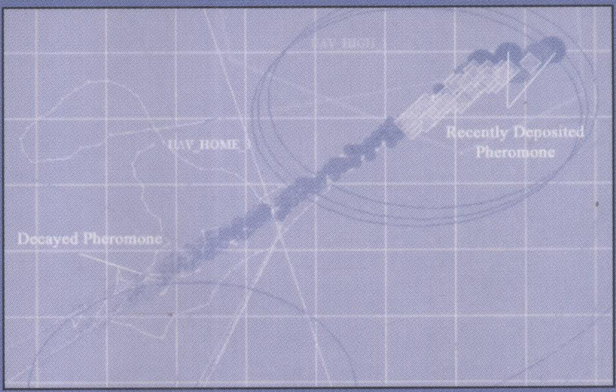

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Preface

The evolution of defense processes towards network-enabled systems and rapid deployment scenarios, as exemplified by the UK Network Enabled Capability (NEC) program or the US Network Centric Warfare (NCW) effort, is creating an urgent demand for highly adaptive and autonomous information support systems. These are large-scale organizational and technological transformational processes. There is therefore a requirement to create autonomous IT infrastructures with automated logistics and planning capability, all of which provides significant scope for an agent-based approach.

The emerging problem set in the defense ICT domain is also mirrored in the civil sector for enterprise scale systems, where cost reduction, legacy integration, scalability and security, are all significant problems to be addressed. To date, the civil sector has taken the lead on the application of agent systems, particularly in the manufacturing sector, (e.g., [Jennings & Bussmann 2003]). Recently, agent systems have become significant mainstream ICT technologies with the emergence of IBM's autonomic computing initiative and the integration of agent technology in various products for infrastructure management. Further information on civilian applications of agent technology can be found in the AAMAS industrial applications conference proceedings [Pechoucek et al. 2005].

Of course, the defense domain has the additional problems resulting from hostile actors and environments. However, it is precisely this aspect that makes a multi-agent system (MAS) approach attractive as it offers increased resilience, run-time flexibility, and embedded intelligence. In addition the key factors in the evolution of MAS have been the advent of service-oriented computing, high-power computing capability, and high-speed ubiquitous networks, which have finally created a suitably rich electronic environment for MAS to be deployed to full effect.

The defense domain therefore covers a broad spectrum of applications that will benefit from an agent approach, including:

ISTAR – sensing and information fusion management
C3 – agent-based command and control support and analysis
NEC/NCW – agent-based middleware and P2P networks
UAVs and Autonomous Robots
Self-Organizing Systems and networks
Simulation and Scenario Engines
Real-time Logistics and Planning support

As we enter the next phase of networked warfare up to 2020, the need for self-organizing, self-healing and intelligent ICT support systems and networks will become paramount. The roadmap to achieve this vision of NEC/NCW is heavily reliant on the fullest utilization of multi-agent systems.

This book is a post-proceedings for the Defence Applications of Multi-Agent Systems (DAMAS) workshop held at the Autonomous Agents and Multi-Agents System conference (AAMAS) in Utrecht in June 2005 (http://www.aamas2005.nl). It contains versions of selected papers presented at the workshop which have been updated and extended by the authors in the light of the comments and discussion of their work.

The workshop was cross-disciplinary in nature, bringing together researchers from academic, industrial, and defense teams. The goals of the workshop were to explore the value of agent technology in defense applications and to review example agent systems applied to defense applications. The book therefore represents a cross-section of the current state of the art in defense applications of agent systems.

The workshop featured several lively discussions on the presentations and the challenges that the defense domain held for agent technology. These are summarized in the first invited paper in this collection, by Beautement et al.

Part 1 contains several papers on decision support and simulation. This includes a contribution on maritime situation awareness by Hemaissa et al., which present an innovative approach based on multi-agent negotiation to fuse classifiers, using the flexibility and reliability of a multi-agent system to exploit distributed data across dispersed sources. The following paper by Louvieris et al outlines the application of Bayesian technologies to CSF (critical success factors) assessment for parsimonious military decision making using an agent-based decision support system. This paper illustrates the application of CSF-enabled Bayesian belief networks (BBN) technology through an agent-based paradigm for assessing the likelihood of success of military missions. A paper by Wise et al. considers whether an agent-based autonomic network control system can provide the flexibility needed to allow an agile mission group to reconfigure their network, while maintaining a high tempo, yet minimize their demands on signals staff. Their architecture describes services that configure a device, and a hierarchy of networks, in terms of the contribution that each makes to networks of which it is a member.

The next paper in this section by Parunak et al. considers the importance of modelling emotion within a simulated combat environment in order to provide a realistic simulation of the likely behavior of forces in battle. The models developed simulate the propagation of emotion in combat units using concepts from Agent technology such as pheromones in a computationally tractable and realistic training simulator.

Part 2 looks at UAVs and starts with a paper from Han et al. which discusses how three technologies can be combined to achieve the UAV functionality needed for coordinated autonomous operation, from building up accurate beliefs, efficiently gathering information, to acting rationally. It discusses how, in order to facilitate the target-tracking activity, a reliable information provisioning network can be constructed by selecting the most appropriate information sources and using trust evaluations to perform belief revision. Also, a macro-based action selection scheme is deployed for efficient coordination of target-tracking activity among agents.

This is followed by a paper from Dasgupta et al. on the interesting problem of automatic target recognition using a multi-agent swarm of unmanned aerial vehicles.

The aim being to avoid a centralized approach to UAV direction. The UAVs employ a swarming algorithm implemented through software agents to congregate at and identify targets.

Part 3 considers wider system management issues such as security and the logistics domain. The paper by Janicke et al. presents a security model that allows the expression of dynamic access control policies that can change on time and events. A simple agent system, simulating a platoon, is used to show the need and the advantages of our policy model. The paper finally describes how existing tool-support can be used for the analysis and verification.

A paper by Greene et al. covers the critical topic of intelligent logistics support using an agent approach. They present a novel cognitive agent architecture and demonstrate its effectiveness in the sense and respond logistics (SRL) domain. Effective applications to support SRL must anticipate and adapt to emerging situations and other dynamic military operations. SRL transforms the static, hierarchical architectures of traditional military models into re-configurable networks designed to encourage coordination among small peer units. This is followed by work from Carvalho et al., who present a mobile agent-based middleware that supports both point-to-point message and hierarchical data-stream communications in these environments. Two infrastructure technologies (Mockets and FlexFeed) are introduced as service providers for messaging and publish-subscriber models for data streaming. Opportunistic resource allocation and monitoring are handled by distributed coordination algorithms, implemented here through two complementary technologies (Stand-In Agents and Acquaintance models).

The final paper by Allsop is an invited contribution that considers the technical challenges that remain in realizing the potential of agent-based technologies in the defense arena.

Organizing the DAMAS workshop and producing this volume of proceedings was a difficult, time-consuming, but ultimately very rewarding exercise (or so we hope). It would have been far harder without the support, advice, and assistance of others. Most significantly no event of this type can occur without the support of the community in the form of contributed papers and presentations, and in the form of reviewing. All the presented papers at DAMAS were reviewed by at least two anonymous reviewers in the Program Committee, and we would like to take this opportunity to thank them for the quality of the reviews they produced and for the timely fashion in which they produced them. It is worth stressing that the nature of the DAMAS Program Committee makes this an even more noteworthy point than would normally be the case in a workshop. The DAMAS PC was made up of members that are all actively involved in defense projects and many of the members are senior people in major commercial organizations, and the demands made on their time make taking on a duty like reviewing for a workshop especially onerous.

In addition we would like to thank Nick Jennings and Mark Greaves for their assistance in organizing the workshop and acting as senior Program Committee members. Both of them were instrumental in making the event happen, and their advice and council did much to shape the workshops character and content. Andre Meyer provided us with much-needed support in making the necessary local arrangements for the workshop and we would also like to thank him for his diligence and for the support he provided.

Finally we would like to thank the organizers of AAMAS 2005 for agreeing to host DAMAS, in particular Frank Dignum and Rino Falcone.

January 2006

Robert Ghanea-Hercock
Simon Thompson

N. R. Jennings and S. Bussmann (2003) "Agent-based control systems" *IEEE Control Systems Magazine* 23 (3) 61-74.
Pechoucek, M., Steiner, D. Thompson, S.G. (eds) *Industrial Applications of Autonomous Agents.* ACM July 2005.

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Part III: Systems and Security

Invited Paper

Autonomous Agents and Multi-agent Systems (AAMAS) for the Military – Issues and Challenges

Patrick Beautement[1], David Allsopp[1], Mark Greaves[2], Steve Goldsmith[3], Shannon Spires[3], Simon G. Thompson[4], and Helge Janicke[5]

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Abstract. The military domain is a very challenging environment and human endeavour in this domain is characterized by uncertainty and the need to be able to deal with significant and disruptive dynamic changes. In addition, activities are driven by human decision-makers who need support in making sense of the environment and with reasoning about, and effecting, possible futures. Hence, various unique factors need to be taken into account when considering the provision of applications, tools, devices and infrastructure for the military domain. This paper will itemize and discuss some of these factors in the context of autonomous agents and multi-agent systems. This paper is a desiderata for the research space.

1 The Military Context

The military domain is a very challenging environment characterized by uncertainty and the need to be able to deal with significant and disruptive dynamic changes. Despite an increasing trend towards adopting approaches from the commercial domain, military activities are different in one key respect - there are opponents who are doing their best to frustrate or destroy friendly activities and to deflect or subvert allies or neutral actors. This means that nothing can be relied upon and that therefore key capabilities include: the ability to dynamically adapt to (or shape) change; to be agile (and grasp fleeting opportunities) and be robust (in the face of potentially catastrophic disruption). Anything that inhibits these capabilities is unacceptable.

In addition, military activities are driven by human decision-makers who need support in making sense of the environment and with reasoning about, and effecting, possible futures. Conflict is, essentially, a human activity. Admittedly, all creatures on the planet are involved in a competition for resources including all those involved in commerce. Conflict, however, is different in that it always involves the purposeful disruption / destruction of the affairs of your opponents - driven by the intent of a

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state, group or individual. Consequently, when supporting these human-led endeavours, the primacy of the human must always be kept at the forefront. Three other key aspects of the military domain are:

1. the certainty of uncertainty;
2. the inherent heterogeneity and complexity of the environment; and
3. the increasing blurring of boundaries between self and non-self (including friends, foes and other actors).

When reasoning about conflict one should always start by embracing the realization that nothing will be absolutely predictable and that being able to cope with uncertainty should be a fundamental capability. An aspect of this is the heterogeneity and complexity of the environment. Conflict with an opponent on a 'standardized' battle space will end up being an attrition war in some limited part of the conflict space. Instead, finding asymmetries (where you are strong and so can wield decisive advantage against an opponent) is an important strategy. This involves working with anything in the battle space which can be wielded as a weapon, including exploiting (even deliberately increasing) the complexity of the environment to undermine the opponent. The key is to always retain as big a range of options as possible (from which to generate novelty) as this is the counter to uncertainty. Finally, cyberspace is a battlespace in its own right (not just a conduit for communication between people). It is a domain closed to humans and so 'cyberspace dominance' can only be obtained by using proxies to wield power on our behalf – those proxies are software agents.

2 Previous Work

Autonomous Agents and Multi-Agent System (AAMAS) are computer software systems that exhibit one or both of the following two tightly coupled behaviours. An Agent is exhibiting Autonomous behaviour when it makes a decision as to what goals it will attempt to fulfil, or when it is able to choose between a number of different strategies to fulfil those goals. Multi-Agent behaviour is exhibited when Agents co-ordinate their behaviour in order to achieve their common or separately held but coupled goals. An extensive literature is available which describes work that has been undertaken with the object of understanding and developing such systems (for example Rosenschein et-al 2003; Jennings et-al 2004; Dignum et-al 2005, Pechoucek et-al 2005).

Domains which are particularly amenable to solutions that use AAMAS technology have been categorized (Jennings & Wooldridge 1998) as being :

- open systems : systems with structures that evolve over time, are unknown in advance and are heterogeneous (the result of the actions of different actors independently and dependently)
- complex systems : characterized by Jennings and Wooldridge as systems that are too complex to understand without modularization
- ubiquitous computing systems : which require interaction with all other actors in their environment in various contexts. Systems of this sort require interaction interfaces that go beyond the enumeration of the required behaviour and instead co-operate with users to achieve goals.

All of the elements of this categorization intersect with the military context described above, so it is no surprise that there have been a number of attempts to utilize AAMAS technology in the Military Context, for example:

- CoABS / CoAX (Allsopp et-al 2002) : A project to develop AAMAS technology into an integrated environment to provide adjustable interoperability between disparate information systems and to support distributed mixed-initiative decision-making with acceptable agent behaviour (Bradshaw 2004). It used the CoABS Grid which is a well developed infrastructure that has been evaluated and tested in several operational military settings.
- DAML: The DARPA Agent Markup Language. DAML is a project to develop data, information and knowledge formats for exchange between systems. The DAML+OIL language has been extended and refined into the OWL ontology language adopted by the W3C and used in projects like the AKT (Shadbolt et-al 2004).
- UltraLog (Bates 2005) utilizes agent technology to provide highly survivable information and logistics systems. UltraLog was independently verified as being able to offer a high degree of robustness while solving problems of a realistic size and nature. The Cougaar agent tool kit (Helsinger & Wright 2005) was a result of the UltraLog program and is now opensource and widely used.
- FCS Command and Control Study (Potok et-al 2003) analyzes the current state of agent-based technology applied to C2 functions for the Future Combat System and net-centric warfare in general. The study concludes that advances are required in the areas of scalability, mobility and security of agent systems before the command and control problem can be suitably addressed.

But it is our contention that the uptake and impact of AAMAS technology in the military domain remains disappointing. In particular it is a puzzle as to why AAMAS technology, which is aimed at providing abstractions and tools for handling open, pervasive and complex situations has not become the technology of choice to implement new doctrines which advocate ad-hoc, agile and decentralized organization. Also, the missions that the military now face (including small scale short notice deployments, complex coalition force structures, counter terrorism and disaster relief) all seem to require from information systems the kind of behaviours that AAMAS technologies offer.

The rest of this paper in part attempts to explain this situation, and in part attempts to provide a list of pitfalls and pratfalls that the developers of military applications (who want to exploit AAMAS technologies) should consider.

3 General Issues Around Agent and AAMAS Implementation

This paper is aimed specifically at the military context, but lessons from AAMAS development in commercial and scientific applications must not be ignored by teams focusing on military requirements. Pitfalls identified in this area (Wooldridge and Jennings 1998) can be summarized as:

Political:
  overselling,
  dogmatic commitment to AAMAS technology.
User context:
  failure to understand the military domain,
  failure to address scale and tempo of real operations,
  failure to match the technology to the constraints of a real military environment.
Management:
  lack of technical appreciation of AAMAS technology,
  lack of application understanding,
  failure to differentiate between prototypes and systems.
Conceptual:
  using buzzwords without understanding them,
  AAMAS as a silver bullet.
Analytical:
  over genericism,
  a failure of analogy.
Agent level:
  failure to reuse architectural principles,
  inappropriate emphasis on problem solving as opposed to usability,
  over-simplification (assumptions about clear boundaries and identification of self and non-self),
  failure to use proper granularity to model the system.
Implementation:
  legacy system integration,
  failure to abide by de-facto standards.

These strap lines highlight "anti-patterns" of AAMAS development that have become well known to commercial developers. In addition we would add that in recent years it has become clear that a lack of trained development staff, a lack of systematic methodological tools and a lack of case studies that could be used to enable and support business cases, have also hampered military and commercial development. The rest of this paper focuses on the issues that are particularly significant when attempting to transfer AAMAS technology to the military sphere.

4 Key Issues

Given the context described above it is clear that there will be some key challenges and issues for anyone wishing to employ agents (of any type) in the military domain. These arise from the need to embrace uncertainty, lack of boundaries, complexity and heterogeneity and to recognize the primacy of the human in military endeavours. In this part of the paper we itemize and comment on some of these key issues, indicating some of the factors which apply to them.