Mobile Agents in Network-Centric Warfare

Marion G. Ceruti, Ph.D., Senior Member, IEEE
Space and Naval Warfare Systems Center, San Diego,
Code D4121, 53560 Hull Street, San Diego, CA 92152-5001, USA
Tel. (619) 553-4068, FAX (619) 553-5136, ceruti@spawar.navy.mil

Abstract
This paper describes agent technology and the various ways in which it can be applied to command, control, communications and intelligence in general, and to network-centric warfare in particular. The paper provides a brief overview of agents, their properties, and their advantages. It covers the concept of the current military trend, network-centric warfare. Problems associated with agents are described, including the conflict between security and autonomy in a distributed environment. The paper concludes with a discussion of research trends in mobile agents, particularly with regard to applications in the Department of Defense.

Keywords — command and control, communications, heterogeneous distributed information systems, intelligence, Internet, mobile agents, network-centric warfare

1. Introduction

Network-centric warfare is defined as warfare in which the issues in network utilization among various platforms and shore-based installations, the interoperability of new and legacy systems, and the reuse that the networks enable become more significant than they were with platform-centric warfare [2]. “Platform centric” means that the purpose of a ship, submarine, airplane or tank is defined and limited by its own sensor capabilities and ranges [2]. The network enables access to aggregate capabilities that provide warfighters access to considerably more information than that available on their own platform [18].

Decentralization in computing and in information management is making a significant impact on today’s military and how the armed services will conduct warfare and peacetime operations in the future. This impact is evident in the area of command, control, communications, and intelligence (C3I). For example, the Internet is available on Navy ships. Marine Corps infantry troops are being introduced to personal computers for C3I purposes.

The Department of Defense (DOD) endorses and plans to utilize the general industry trends toward increased intelligent automation and decentralization of information, including mobile agents and systems of agents interacting with each other and with other software in complex, distributed systems. Although the concept of network-centric warfare is not based on the use of mobile agents per se for information exchange, agent-based approaches will contribute to the evolution of network-centric warfare [2] into knowledge-centric warfare. As agents in military systems become more widely used, they will enable or, at least, stimulate advances in other areas of technology, such as information display, database maintenance and integration, data mining, and communications.

This paper is organized as follows. Section 2 introduces basic concepts and characteristics of agents in general. Section 3 describes mobile agents in particular. Section 4 covers some commercial and research agent tools. Section 5 introduces the notion of network-centric warfare. Section 6 suggests ways in which the military can use mobile agents in the evolution toward knowledge-centric warfare. Section 7 concludes with a discussion of current and future research and development in agent technology.

2. Agents and their characteristics

Because the research field of agents is young, emerging and evolving rapidly, a standard, unique and precise definition for “agent,” with which all researchers agree, is not available [7], [9]. Agents have been defined in various ways by various research groups [7], [8], [11], such as “an autonomous software object that performs tedious and repetitive computer-based operations on behalf of a human user or another agent” [4]. Another definition [16] is “a persistent computation that can perceive its environment, reason, and act alone with other agents.” A general definition has been suggested as “any continuously running software that communicates with others” [11].

The essential concepts in most definitions are interoperability and autonomy, which also serve to distinguish agents from ordinary search engines [16]. In fact, the notion of interoperability is so closely associated with “agenthood” that a proposed test of whether or not a software program is an agent is to observe how the system changes when another reputed agent of the same architecture and functionality is added to the system [8]. That is, agents are expected to interact with each other and modify their behavior accordingly [8].

Knowledge acquisition implies a higher level of structure and representation than the mere information retrieval [3] that is performed commonly by search engines. Agents can perform knowledge acquisition in a way that commercial search engines so far have not. The notion of a “software agency” implies the characteristics of flexibil-
ity, autonomy, intelligence, adaptability, and high-level communication [3]. Persistence is another quality for an agent to possess that is at least desirable [8] and possibly necessary [16]. Artificial intelligence techniques in the design and implementation of agents are either stated explicitly or implied by the complexity of the task. (See, for example, [3], [4], and [16]).

Four main categories of agent functionality are described below [7]. Problem-solving agents often resemble expert systems because they encode domain-specific information to achieve their functionality, sometimes using rule-based approaches. User-centric agents assist users in their interactions with computers. Control agents provide control services to other agents in multiagent systems. Translation agents provide bridges between systems that use different data standards and help users cope with the increasing heterogeneity in distributed systems.

3. Mobile agents for the Internet

An agent is considered a "mobile agent" if it migrates and if it is prepared for transfer over a network in a manner that allows its state to be recovered [4]. Mobile agents are self-contained programs that move within a network and act on behalf of the user or another entity [15]. The advantages of mobile agents are summarized as follows:

- Agents can automate otherwise manual operations [4].
- Agents process data on remote computers thus reducing overhead on the user's local machine [4].
- Agents can save bandwidth by transferring only aggregated data over the network instead of high-volume raw data [1], [13]. (On Navy ships, lack of bandwidth can become a problem during wartime.)
- Mobile agents can be spawned in parallel to accomplish many tasks simultaneously [13].
- Preparing a system to accommodate the level of interoperability that will optimize the utility of mobile agents will also increase efficiency and accuracy of other aspects of the system.

Mobile agents also have these disadvantages:

- An agent developer must specify programatically where an agent will go and how it will interact with its target environment(s) [13].
- Systems provide little support to encourage interactions and coordination between multiple mobile agents [13], a deficiency discussed in section 5.
- Developers must write agents in a programming language that the execution environment supports [13].

The system architectures and designs of mobile agents are based on agent models, which are conceptual views [17] of how the network behaves, the tasks the agent is supposed to perform, and the relationship between the agent, the network and other agents.

4. Agents tools

Many multi-agent and mobile-agent tools are used today. Tools have been used in connection with an architecture and system for visualizing and controlling distributed multiagent applications. The development of mobile-agent technology has progressed to the point where commercial products are available. (See, for example, [1], [10] and [12]). Some of these tools are available as Java-based software that a user can download [10].

Researchers recognize the importance and the need for new tools to help users with agent technology. For example, the Iconic Modeling Tool [4], allow users to generate agents in a few minutes and to reuse and manipulate them efficiently. Kiniry and Zimmerman [10] present a good review of both commercially available and research-based agent system. Military personnel need to be able to use agents to obtain information on the Web without extensive familiarity with technical implementation details, such as data formats [12]. Commercial agent tools, as they mature, will provide this user-friendly implementation environment that is necessary for widespread acceptance in the operational military.

5. Network-centric warfare

DOD agencies conduct research and development programs to enhance information-systems access over the Internet for sharing data and knowledge among service components [2]. Future platforms will support network-centric warfare, which provides enhanced capabilities to the warfighter at significant cost savings.

In the Navy, network-centric warfare refers to the ability to expand each ship's horizons by using computers to enable an intelligent, fast, flexible network of sensors, shooters, and command centers. New networks make command systems orders of magnitude more effective. These systems are designed to assist commanders in coordinating the widely dispersed forces that are expected to dominate future warfare because of the increased speed at which command decisions will be made. The global military multimedia network will support voice, video, data, text, graphics and imagery transfer between all nodes, both afloat and ashore sites. Networks have been proven to provide a significant improvement in efficiency and accuracy over paper and diskette-based planning [2].

6. Military use of mobile agents

The four most frequently mentioned reasons for the use of the mobile-agent paradigm are intelligent information retrieval, network and mobility management, electronic commerce, and network services [10]. Whereas the military has some interest in all of these uses for non-tactical purposes, intelligent information retrieval is of the greatest interest from a tactical perspective.

Network-centric warfare implies that all platforms in the theater are aware of and contribute to the total information available to all platforms, such as ships, aircraft and tanks, as well as ashore command centers. Agents are well suited for the collaborative environment [11] that is necessary to support network-centric warfare.
Mobile agents can enhance the utility of the networks and information systems that enable network-centric warfare. In some circumstances, a commander could even deploy assets based on another ship. One way to accomplish this is with the help of mobile agents. Network-centric warfare implies that the volume of the information available to warfighters on a theater-wide basis will keep growing [2] as more units contribute the information they acquire. Mobile agents provide an intelligent means to use of both readily available and otherwise overwhelming information as well as knowledge hidden in the data.

In the future, military personnel will be able to use mobile agents in battlefield command and control, in communications systems, and for intelligence acquisition. The military often participates in missions other than war, such as disaster relief and emergency management. Mobile agents will be useful in that area as well.

Mobile agents actively change their executing environment as they transfer to new environments [1]. A mobile agent can switch context from intranet to Web, manage remote resources, such as those on a distant ship or command center, and return to the original user an integrated report of information found or of tasks performed.

Launching a mobile agent to gather military intelligence on the World-Wide Web is very different from using an ad hoc query in a database system. A mobile agent can perform routine tasks recursively with minor variations and integrate disparate information into a single report [12]. Also unlike a database query, mobile agents can perform on-line functions that carry out specific actions in addition to gathering web pages, either on demand or on a scheduled basis [12]. Mobile agents retrieve information in a manner that also differs from that of general search engines, which can be of limited use because they lack task relevance, structure, and context [3].

Software agents that automate interactions with Hypertext Markup Language pages and forms provide flexibility in the usage, display, and modification of this information for other applications [12]. On ships and in ashore command centers, mobile agents can automate information interactions on intranets at all security levels.

Agents can be used to perform intelligence gathering from unclassified Web-based sources. Whereas much of the intelligence world operates at classified levels, there is still a great deal of knowledge that can be inferred from monitoring and correlating information from unclassified sources. Agents can automate this process.

For example, a mobile agent can be enabled to access password-protected news or weather Web pages to obtain a variety of multimedia information. This information can be used to support weekly intelligence and operations briefings to a commander. A report or a group of reports sorted by topic would be made available to the command centers where the briefing officers could use these finished products rather than raw data. This would save time for the briefing officers, who then could perform additional duties that are not easily automated.

Mobile agents, when used efficiently, can transform network-centric warfare into the knowledge-centric warfare mandated for the next-generation military forces. Connecting military information systems in a network and providing a unified, integrated display of battlespace information to all echelons is only the first step toward knowledge-centric warfare. A significant evolutionary step in this progression is to develop and use mobile agents to build and maintain knowledge bases. The most successful mobile agents interoperate with other AI technologies, such as inference engines, natural language, and robotics. An architecture was suggested that employs Internet agents to construct ontologies and acquire knowledge [3].

The distribution of agents in space and time, and their logical and semantic separation, can be utilized to cope with the scale and the distributed, dynamic, and unreliable nature of information on the Internet [3]. Similarly, mobile agents can be used to provide domain-specific knowledge to cope with uncertainties in the battlespace, commonly called the "fog of war."

7. Research and development with agents

The use of agents to interact with the Internet as surrogate users for knowledge discovery is an active topic of current research. (See [1], [3], [4], [12] and [15]). Optimal solutions have yet to be devised for the design and implementation of mobile-agent system architectures [15]. A particularly challenging area of research is the coordination among agents and between agents and other software applications (See [1], [4], [5], [8], [13], and [14] - [16]).

Several targets for future research stem from the challenges that remain in the area of agent modeling, particularly with regard to agent communication [17] and graphic representations. For example, one important obstacle is how to control message flow and migration in a multiagent system [4]. The main difficulty is in the ability to model complex agent scenarios that are not easily modeled with interaction diagrams [4].

Users and developers alike have considerable difficulty visualizing overall system behavior in distributed, multi-agent systems and distributed agent workflow and operations using a set of icons [4]. Since an agent's physical behavior is so difficult to specify and control, visual languages for program control will remain an active area of research in modeling mobile agents [4].

Agent interoperability continues to be a key area of research. Fundamental issues must be resolved to improve inter-agent communication languages so that agents developed by different organizations can interoperate without over-constraining an agent's design [16]. Standards are essential for interoperability in any area of technology. Emerging knowledge standards, such as Knowledge Interchange Format (KIF), Knowledge Query and Manipulation Language (KQML), Extensible Markup Language (XML) [17] and Java provide a certain level of interoperability in architectures such as Internet-based Multi-agent Problem Solving architecture [3] and the
Open-Agent Architecture [13]. KIF and KQML are de facto agent-communication standards although a successor to KQML based on lessons learned was proposed in [5]. KQML, which specifies interaction protocol, is the most widely used foundation technology for agent-based software engineering [13]. KIF likely will be the most widely used neutral message-content format for agent communication due to its rich expressive power and simple syntax [14]. KQML is used often with KIF [13]. Java will play a key role with platform-independent agents [10].

More work is needed in agent security, which is a very active area of research [15]. In the mobile-agent paradigm, the network is treated as a collection of multiple "agent-friendly" environments and the agents are considered to be programmatic entities that move from location to location, performing their tasks [15]. However, an environment that provides considerable capabilities and autonomy to beneficial agents also invites the use of malicious agents that will exploit for evil purposes the information retrieved [1]. Malicious agents also can damage a visited site [1]. Mobile agents increase the efficiency of all kinds of production, including the production of security breaches [6]. Therefore, it is not wise for agents and visited sites to assume that they can trust one another [15].

Most of today's host-protection techniques alone are insufficient for the majority of applications because the computing environment has expanded beyond the scale that easily lends itself to human surveillance [6]. Traditional security mechanisms that rely on cryptographic techniques to implement authentication, authorization and access controls also have applications in protecting agent-execution environments from hostile agents [15]. However, no satisfactory solution has been offered to protect a friendly agent from the tampering that may occur at a hostile site [15]. Further research is needed to detect and prevent security violations from malicious mobile agents and hostile sites. Therefore, future DOD Internet security policies must address the control of agent interactions. Future studies need to identify ways to provide technical support for a comprehensive agent-security policy that will not reduce significantly the unique advantages of mobile agents.

Network-centric warfare is still in its infancy. Serious challenges remain due to complexities in the area of integration and interoperability. A substantial amount of research, experimentation, and analysis is needed to realize the full potential of network-centric warfare across all DOD components.

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