# Adjustable Autonomy For Human And Information System Interaction

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**Abstract**

This paper is a position statement regarding the role of autonomy in information systems and human/system interactions. It describes some of the domain applications of interest to The Boeing Company in which autonomy is an important component and points out how the acquisition, fusion and dissemination of information is a common underlying thread for each of them. It then discusses the role autonomy plays in that activity with particular emphasis on balancing system autonomy with human oversight and some of the important issues involved.

## Background

Autonomous Agents is a critical technology for the Boeing Company. Our products and services, particularly in military and space applications, will have increasingly capable autonomy components.

Autonomous surveillance aircraft are already providing a valuable tool to the military. Military services have plans for a wide range of next-generation unmanned air, ground, and underwater vehicles. These vehicles will need more advanced autonomy capabilities as a single person will often need to control multiple vehicles and tele-operation will not be possible for many missions. Autonomous behavior plays a significant role in Boeing's concepts for the control of unmanned vehicles. Autonomy even plays a role in the navigation and control of manned vehicles through advanced collision avoidance concepts (Rock 2000).

Space operations will also require more advanced autonomy. As one example, on the International Space Station, astronauts spend a majority of their time on "housekeeping" tasks that might be more efficiently accomplished with autonomous helpers. Boeing has a role in a NASA project exploring the use of Personal Satellite Assistants in such a context. As another example, the Pathfinder robot fascinated millions of people as it rolled across the Martian landscape, but it was limited in the area that it could explore because of the latencies in controlling it from Earth. NASA has plans to use far more advanced autonomous vehicles in exploration of Mars, including multiple vehicles that can work together to scale cliffs in the search for water. The search for life will be carried to Europa with underwater vehicles that will have to operate entirely autonomously.

Autonomous agents will find increasing use in "Immobots" that provide functions analogous to the human nervous, regulatory, and immune systems. These capabilities could be useful to Boeing in a variety of applications such as station keeping for satellite constellations, facilities management in buildings and factories, and network configuration, security and management.

Autonomous agents have moved beyond the early applications of vehicle guidance and control. They are becoming integral parts of both civilian and military software systems. They can function as our purchasing representatives in online shopping and auction environments or patrol distributed military computing networks for hostile intrusions.

But a thread common to each of the autonomous and semi-autonomous, hardware and software applications mentioned is the availability and flow of information.

## Agent-based Information Systems

The availability and flow of information has, historically, been a significant driver in the advance of technology and the improvement of people's lot in life. However, the advent of the Internet has created a torrent of information that threatens to inundate everyone. At the same time, that flow of information is something that few can live without from the individual who depends upon it for current events, shopping, and activity scheduling to corporations that depend upon it for inventory management, employee communication, and product development to governments that rely upon it for diplomatic relations, economic forecasting and the conduct of military campaigns. As just one example, a new era has begun in the domain of military engagement.

Conflicts will no longer be between large masses of opposing forces on a battlefield, but will instead be dominated by numerous targeted strikes on prearranged targets by air forces and small, fast-moving ground forces. The success of such engagements will rely on accurate, timely intelligence. But the information resources available to the military are numerous, diverse in nature and geographically dispersed. The major technical challenge facing the military is that of gathering information from its diverse resources and presenting the *right* information in a *useful* form, *where* it is needed, *when* it is needed. We in Mathematics and Computing Technology (M&CT) wish to explore the role of autonomy in the acquisition and dissemination of the very information that describes the environment and forms the context within which more specific hardware and software applications operate.

Simple distributed client-server technology is inadequate to the task of gathering, fusing and presenting the right information at the right time. A distributed network of cooperative software agents and associated enabling technologies is required to provide the sophisticated computational capability necessary to meet the information and knowledge management needs of the military. Software agents of this nature possess sophisticated characteristics. They have the ability to traverse the network in response to the requirements of their task objective or state of their operational environment. Sophisticated agents possess the ability to coordinate with other entities in the system to complete subtasks in a cooperative manner. They can negotiate with other entities for scarce or time-critical resources. Agents are able to engage in complex conversations with other agents and with humans with a high degree of semantic content. They contain complex algorithms enabling fully- or semi-autonomous operation. Increasingly, the systems that Boeing builds and uses are limited by the human role. This trend requires more sophisticated autonomy technology.

## Adjustable Autonomy in Information Systems

One aspect of the use of autonomy in the context of information systems, one that is central to working with autonomous agents with this degree of sophistication and interoperability, is timely and efficient communication and interaction between humans and agents. We believe that it is important to the goal of Anytime/Anywhere information systems to investigate and demonstrate methods of communication and interaction between humans and semi-autonomous software agents, with a particular focus on enabling "adjustable autonomy" for agents.

Agents are the natural evolution of object programming technology and are typically distinguished from "ordinary" objects by possessing one or more of the characteristics of *adaptability*, *cooperation* or *autonomy*. The ability to perform, without supervision, functions that would normally be performed by humans is a major reason for the interest in agent technology. Many autonomous systems are designed with fixed assumptions about what level of autonomy is appropriate to their tasks. But complete automation of complex tasks is sometimes impossible to achieve and often it isn't even desired. They execute their instructions without taking into account that fact that the optimal level of autonomy may vary by task and over time, or that unforeseen events may prompt a need for either the human or the system to take more control. The gathering, analysis and delivery of data and knowledge in the information systems of the future will very likely need to be performed in cooperation with humans and with other autonomous systems. Furthermore, these heterogeneous cooperating entities may operate at *different levels* of sophistication and with *dynamically varying* degrees of autonomy.

Autonomy, including in the context of agents, has been a major focus of academic research for several years. In recent years, a significant portion of autonomy research has moved in the direction of adjustable autonomy, also known as mixed-initiative autonomy. But most of the work has been performed in the context of robotic control and autonomy. In general, software autonomy implies the ability for a software program to receive a goal to achieve, devise a plan for achieving that goal, define a set of action primitives sufficient to carry out the plan, and oversee the execution of the plan. This implies a series of significant questions that need to be answered:

***What is the role of autonomy in information systems?*** How can autonomous behavior be employed to enhance the function of information systems, the tasks they need to perform and amount of oversight required by a human operator? Of particular interest, in the context of this whitepaper, is the access, acquisition, fusion and timely dissemination of the information necessary for the execution of domain-specific applications.

***What are the appropriate representations for stating a goal to be accomplished?*** Autonomous behavior generally manifests itself in the process of achieving a goal. The goal may be presented to the system by a human or by another software agent. This implies a need to represent goals in a manner that is understandable and processable by both humans and machines.

***What mechanisms can be used to go from goal representation to plan to actions?*** These mechanisms might be constrained by certain factors such as required response time, security, available resources or necessary interaction with a human operator.

***How is the appropriate level of autonomy determined?***

The goal of adjustable autonomy is to make sure that for any given situation and task the system is operating at the correct boundary between the initiative of the user and that of the system. People want to maintain that boundary at the optimum point in the tradeoff curve that minimizes their need to attend to interaction with the system while providing them a sufficient level of comfort that nothing will go wrong. The actual adjustment of autonomy level can be performed by a person or a program, or by the agent itself.

***How is decision authority transitioned between human and machine?*** A system's level of autonomy can be varied along several dimensions such as: 1) type or complexity of the commands it is permitted to execute, 2) which of its subsystems may function autonomously, 3) circumstances under which the system will override manual control (e.g., if a human operator is about to place classified information in an unclassified area), and 4) duration of autonomous operation. Different dimensions may require different transition mechanisms and choice representations.

***What kind of generic programmatic support for adjustable autonomy can be provided in an agent-based architectural framework?*** It isn't expected that all agents developed for Boeing applications will be developed by a centralized "agent development organization" or even by software engineers with years of agent development experience. Agent development frameworks providing support for advanced agent-related capabilities is an important component of Boeing's agent development strategy. Inclusion in a framework of "generic" algorithms supporting the implementation of autonomy in agents would be an important addition, if possible.

It is our goal at M&CT to pursue projects aimed at investigating these and other questions related to the use of autonomous agents in Boeing products and processes.

## Summary

This paper has laid out the general framework for investigating the use of adjustable autonomy in information gathering, fusion and dissemination and some of the important questions that need to be answered.

The use of autonomy in this context will not be an easy task. Ideally, the system will function with as much autonomy as possible, however, achieving results of sufficient accuracy and reliability to overcome the human operator's reluctance to "turn up the autonomy knob" will be difficult.

Accuracy and reliability are further complicated by a requirement for increasing breadth of information covered. Imagine a small system with tightly focused topical information requirements. The acquisition and fusion of information from different sources is likely to yield high-quality results. But imagine a large, enterprise-wide system with requirements for information covering a broad range of topics. Semantic differences are much more likely to occur with a corresponding degradation in result quality. Data fusion and the semantic integration of information from multiple sources are research topics in their own right, but they have direct implications on the successful implementation of autonomy in this context.

Nevertheless, as these questions are answered, autonomy in information acquisition and dissemination will enable efficient and effective system integration. Ultimately this will lead to more sophisticated unmanned vehicles, enterprise systems and other domain-specific applications.

## About M&CT

The Boeing Phantom Works Mathematics and Computing Technology (M&CT) organization has an active research effort in agent technology that has been at the forefront of the field for several years and an established core of technology experts. The work of the M&CT agent research team has been published in numerous highly respected technical journals and books. They have developed and continue to enhance a research-level framework for agent-based systems, Knowledgeable Agent-oriented System (KAoS). The M&CT Agents Research Team has a contract history of external research efforts for and with government agencies and various universities across the country.

In addition to agent-oriented knowledge and experience, M&CT is equally capable in the enabling technologies that give an agent its "intelligence". M&CT represents an internationally recognized group of experts in a wide range of technical fields, including those agent-enabling technologies that are necessary for the development of sophisticated, highly-capable, domain-specific agent systems. M&CT has ongoing research in areas such as: autonomous systems, knowledge management and representation, semantic integration and ontologies, information access and security, collaboration technologies, reasoning methods, and more.

Both authors are Associate Technical Fellows of The Boeing Company. Mr. Kerstetter is the lead for agent research activities in M&CT and Mr. Smith is the lead for autonomy research activities in M&CT.

## References

Rock, Dennis. 2000. Agent Autonomy Adjustment for Mid-air Collision Avoidance Automation. In Proceedings of the American Institute for Astronautics and Aeronautics Guidance, Navigation, and Control Conference, August 10-12, 2000, Denver, Colorado. AIAA Paper: GNC-35, 2000-4480