Artificial Intelligence AND Virtual Or

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A VIRTUAL COMPANY HAS BEEN DEFINED AS ONE where "complementary resources existing in a number of cooperating companies are left in place, but are integrated to support a particular product effort for as long as it is viable to do so. . . . Resources are selectively allocated to the virtual company if they are underutilized or if they can be profitably utilized there more than in the 'home' company." [4]. In addition, virtual organizations are designed to facilitate three types of capabilities:

- Create or assemble productive resources quickly,
- Create or assemble productive resources frequently and concurrently, and
- Create or assemble a broad range of productive resources (such as research, manufacturing, and design).

Although the idea of virtual organizations is not new [4], recent developments in information technology capabilities, such as the World-Wide Web (WWW) and artificial intelligence (AI), allow the development of new implementations of virtual organizations that exploit the capabilities of those new technologies. Information technology can be used aggressively, replacing or supporting human actions. Information infrastructure, such as the WWW, facilitates communications between and within virtual organizations, allowing development of widely dispersed virtual organizations.

Since intra- and intercompany resource availability can change minute to minute, with advantage accruing to parties able to arbitrage resource availabilities rapidly, virtual organizations use information technology to supplement limited resources and cognitive capabilities. Humans have limited ability to keep track of what is going on in the broad range of virtual organization activities, given the tight time constraints and limited resources required and used by virtual organizations. This is exacerbated by frequent interruption of their work, with recent research indicating that white-collar employees receive a communication (electronic, paper, or oral) every five minutes. As a result, AI provides virtual organizations the ability to mitigate the limitations and constraints of human agents in order to monitor and control substantial resources without the time constraints inherent in human organizations.

The use of agents, facilitators, and knowledge query and manipulation languages, together with negotiated ontologies, can provide a workable, reliable, and flexible base of systems used in creating the platforms for virtual organizations. Virtual organizations may be the first large-scale industrial application of AI, beyond its fragmented use in knowledge-based systems and robotics. However, without the research that produced a theory of

Definitions of Terms

A **command center** provides interfaces and communication capabilities for human actors that allow them to monitor agent and virtual organization activity. In their classic form, they are like military war rooms, where agent activities can be watched.

A **computational agent** is a computer program that functions autonomously or semiautonomously in communication with other computational agents, programs, or human agents. Agents can respond to messages typically represented in a standard interchange format, such as knowledge interchange format (KIF), typically in the presence of a standard protocol, such as knowledge query and manipulation language (KQML). Agents have the ability to go-get resources, optimize the use of resources, and perform independently and rapidly under changing conditions, mitigating human limitations.

It takes much more than the World-Wide Web to run a virtual organization.

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agents, virtual organizations could not exist in the form presented in the applications examined here. Thus, we review the use of AI in virtual organizations.

A Survey and Analysis of the WWW

To study how AI has been used to facilitate virtual organizations, we used a twofold approach: A search was made of the WWW, and a survey was made of organizations that might be supporting AI integration with virtual organizations.

A search of the WWW helped us find a number of organizations that have been actively involved in the use of AI and virtual organization. (See Table for WWW addresses of the home pages.)

Goldman et al. [4] list 96 U.S.-based resource organizations for support of virtual organizations. In order to assess the extent to which AI is used in conjunction with virtual organizations, a survey was conducted that focused on trying to determine if organizations were facilitating virtual organizations using AI. Unfortunately, out of about 20 respondents to two different requests, only one additional organization (The Office of Computational and Technology Research of the Office of Energy Research) was found to be integrating AI. Further inquiries there found that usage had not yet advanced to the point where they have issued any reports that could be included in this discussion.

However, integration of AI and virtual organizations has occurred in a number of applications, including, virtual laboratories, virtual office systems, concurrent engineering projects, virtual manufacturing organizations, virtual classrooms and individualized learning, and virtual environments for training.

Virtual Organizations

A number of firms have actively pursued the use of virtual organizations. For example, Lockheed has developed the Agile Cable Production Service (ACaPS) virtual organization in order to offer cable production facilities over the Internet. By focusing on a virtual organization design that exploits Internet capabilities, Lockheed hopes to improve quality and reduce cycle time between delivery and order. Other firms on the WWW also employ virtual organizations. In addition, practitioners have begun to develop a basic set of support organizations for virtual organizations, such as the Agility Forum at Lehigh University. Further, basic organizations supporting commerce by virtual organizations has been developed (e.g., CommerceNet and Part.Net). Many of the developments are designed to function in the CommerceNet environment, where commerce can take place with respect to parts listed in Part.Net—a forum consisting of organiza-

Facilitators are programs that provide a communication coordination intermediary between agents. As used in PACT [2], facilitators provide a reliable communication layer, route messages among agents based on the content of the messages, and coordinate control of multiple agent activities.

An **ontology** is an explicit specification of a conceptualization [5] and a knowledge-based specification that typically describes a taxonomy of the tasks that define the knowledge. Ontologies are specifications of discourse among multiple agents in the form of a shared vocabulary.

A **conceptualization** is an abstract, simplified view of the world we wish to represent for some purpose. Every knowledge-based or knowledge-level agent is committed to some conceptualization explicitly or implicitly [5].

tions providing transaction exchanges with or for virtual organizations. Others on the WWW, like Sandia National Laboratories, have described necessary communications structures.

Virtual Laboratories

Research information, such as remotely sensed data, is increasingly available over the WWW. Indeed, Hubble telescope data is made available over the Internet. Cameras and robots are controlled by actions over the Internet. Loosely coupled research teams are then expected to analyze data from these sources. Such interest in remote collaboration hase led to the National Virtual Laboratory (NVL) and to Virtual Lab Notebook (VILAN).

At the AI level, some of the primary technology issues associated with virtual laboratories relate to *reactive software agents* that could be part of a toolkit for such virtual organizations. In particular, VILAN used two types of agents: data source *wrapper* agents, which encapsulate various heterogeneous data sources, and a *broker* agent, which brokers requests from users through knowledge about and transactions with data source agents. The purpose of the wrapper agents was to enable the ability to plug-and-play third-party software in the agent environment. Wrappers provided the agents with the ability to communicate on some general level with other agents while still being able to fully exploit domain specific software. The purpose of the broker agents was to find information that would enable satisfaction of user requests. The initial design of data brokers included the following basic capabilities:

- Exhibit goal-directed behavior by accommodating single-occurrence requests,
- Service recurring behavioral goals,
- React dynamically to changes in goals,
- Persist indefinitely, and
- Interact with other agents.

The initial design of wrapper agents sought to meet many of the same requirements as those of the broker agents, but a wrapper also needs to be able to advertise its capabilities, and interface with its wrapped tool so it can receive the task results or feedback using the tool.

Data brokers and wrapper agents play a critical role in virtual laboratories. They communicate among heterogeneous distributed agents to locate, identify, examine, and use information.

Virtual Office Systems

Almost all organizations use relatively generic processes for procurement, sales and collection, payroll/personnel systems, and other processes. Virtual office systems have been developed recently to treat business processes as having boundaries that include vendors, customers, intermediary organizations, and regulatory organizations.

The business process system receiving most of the attention to date is the procurement process. Historically, procurement systems are steeped in bureaucracies of interlinking departments and companies. Accordingly, there are typically long chains of approvals for buying goods and they can result in long delays. With the advent of "just-in-time" inventory and "just-enough-inventory" systems, there is a need to cut through the time required under classic procurement, using redesigned procurement systems.

SmartProcurement (developed jointly as a prototype system by the National Institute for Standards and Technology and Enterprise Integration Technologies) employs autonomous intelligent agents over the Internet or other networks to facilitate procurement. The system is designed deployment in conjunction with CommerceNet. In this system, procurement information, such as part information, can be located throughout the world in heterogeneous databases. SmartProcurement allows a purchaser to execute procurement electronically. A typical SmartProcurement process is initiated with either an electronic or human request for quotation (RFQ). A purchasing agent then acquires a list of agents who have been registered as vendors for the requested item. The RFQ is sent to those agents, who then decide whether or not to bid. Each bid is independently sent to the purchasing agent, who accumulates the bids submitted before the deadline. The buyer then selects from the set of bids submitted. After a bid is selected, the winning vendor agent is notified.

Virtual office systems based on intelligent agents expand the boundaries of organizations, facilitating interactions with a broader range of business than under traditional approaches. In addition, agent-based approaches speed business processes and facilitate commerce by being opportunistic in their solicitation of RFQs from a broad range of processes.

Concurrent Engineering Projects

Researchers argue that in the future much engineering, software development, and similar activities will be done by groups or organizations that are loosely coupled and widely distributed, such as virtual groups and organizations. As a result, substantial research effort has been devoted to the generation of virtual organizations for concurrent engineering.

Manufacturing Automation and Design Engineering (MADE) is an ARPA program supporting research in the development and demonstration of next-generation design environments, specifically for electromechanical

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systems. MADE emphasizes *tag teams* so designers perform the functions at which they are most expert. Enough information is left behind in a design information web so other designers can continue the design process. The program goal was to develop enabling tools and technologies to provide engineers with cognitive support to facilitate generation, tracking, storage, and analysis of different design alternatives. MADE used an approach that included developments in knowledge sharing and interchange, planning, scheduling, and intelligent agents.

ARPA's Palo Alto Collaborative Testbed (PACT) [2,7] was designed as a testbed for cooperative research and knowledge sharing in concurrent engineering. Research on PACT found that designing an ontology for concurrent engineering was the most difficult task. PACT employed an informal and ad hoc approach to ontology development, in which the ontology was implicit and generated through a number of email messages among agent developers. Knowledge sharing in PACT was done using encapsulated models and tool data, freeing development of each agent to use the most appropriate representations. Then, to let encapsulated agents communicate, PACT used a shared language called the Knowledge Query and Manipulation Language (KQML) and a standard Knowledge Interchange Format (KIF) (e.g., [3]).

PACT uses facilitators, local agents, and remote agents in its design. Facilitators are responsible for providing an interface between local agents and remote agents. The four purposes of facilitators include:

- Providing a reliable layer of message passing
- Routing outgoing messages appropriately
- Translating incoming messages for local agents
- Initializing and monitoring agent execution

In PACT, communications occur between agents and facilitators, and between facilitators, but not between agents. The PACT demonstration involved 31 different agents on 15 different workstations and microcomputers. There were six different engineering-based groups of agents: digital circuitry agents, software control agents, power systems agents, physical plant agents, sensor agents, and parts catalog agents, although all but the last two existed before PACT was built.

ARPA's Shared Dependency Engineering (SHADE) [8] was primarily concerned with information sharing and access to information, extending some of the work done in PACT. The approach used in SHADE was to provide a medium in the context of the Internet allowing designers to accumulate and share engineering knowledge in a distributed environment. In particular, the SHADE vision is based on an intelligent broker of information between consumers and providers of information, matching them up through a knowledge-based analysis of messages between these sets of agents. The matchmaking service allows efficient communication by mitigating the message traffic bottlenecks through a central facilitator.

One of the primary concerns of SHADE was investigation of shared ontologies, since SHADE was designed for a shared environment. In order for the multiple agents in SHADE to communicate effectively, they had to use similar ontologies. SHADE defined engineering ontologies within widely accepted and formally defined representations and a modular, hierarchical vocabulary.

Knowledge-based agents interact in the same conceptual manner as PACT. Consumer agents send requests to a matchmaker facilitator agent, and provider agents evaluate them. Provider agents advertise capabilities to matchmaker agents, and consumer agents compare those capabilities to their needs. SHADE researchers found it was easier to have consumer agents express a need than to have provider agents summarize their capabilities. Whereas consumer agents will have specific interests, provider agents may have many capabilities.

Translator agents are put on the network to enable otherwise segregated agent interaction. The agent commits to a specific engineering mathematics ontology, using that vocabulary for inputs and outputs. Translator agents are not hardwired into particular ontologies but must be given an ontology.

Taken together, MADE, PACT, and SHADE provide a

Virtual manufacturing organizations must be able to sell as well as procure, and they must be able to determine how much to produce.

glimpse of the way organizations can organize and employ agent-based, virtual organizations for concurrent engineering and such related activity, as software development. Development of ontologies for multiple agents is a necessary process but a difficult one, requiring agreement by developers. Although an ad hoc process was used here, for larger projects a more formal approach may be appropriate.

Virtual Manufacturing Organizations

Manufacturing organizations can experience peak-and-valley demands for resources that are substantially different. As a result, there is incentive for those firms to seek out resources that can be used to meet peak demand or to make excess resources available during valley demand times. Typical of this scenario are firms that traditionally do manufacturing for military purposes. As demand for military goods decreases, these firms need to use available unused resources for alternative production.

Probably the most visible effort in this area has been the ARPA Agile Infrastructure for Manufacturing Systems (AIMS) project; participants are Enterprise Integration Technology, Lockheed, General Motors, and Texas Instruments. AIMS builds on the results from the SHADE pro-

Some URLs That Address Virtual Organizations

Background on Virtual Organizations

Agile Cable Production Service (ACAPS)
http://hitchhiker.space.lockheed.com/~acaps/

Examples of Virtual Companies
http://www.wordsimages.com/virtcorp.htm

Agility Forum at Lehigh
http://absu.amef.lehigh.edu/

CommerceNet
http://www.commerce.net/pr/041094-sjmn.html

Part.Net
http://part.net/about.htm

Advanced Manufacturing Technology Network (AMTnet)
http://amtnet.sandia.gov/htdocs/amtnet.html

Agile Manufacturing Networks
http://elib.cme.nist.gov/edl/html/agile/network.html

List of Government Projects
http://elib.cme.nist.gov/msid/projects.htm

Capabilities of AI on Internet

ARPA — AI Capabilities
http://www.arpa.mil/sisto/symp/Demos/Demos.html#intelligent

Lockheed AI Center
http://hitchhiker.space.lockheed.com/aic/

Virtual Laboratories

National Virtual Lab
http://www.cs.brown.edu/research/robotics/software/nvl.html

Virtual Lab Notebook
http://hitchhiker.space.lockheed.com/VLAB/htdocs/vilan-overview.html

Virtual Office Processes

SmartProcurement—ECS (Electronic Commerce Supporting Agile Manufacturing)
http://www.arpa.mil/sisto/symp/Demos/Agile/PR_ECAGI.html

Collaborative Engineering

MADE (Manufacturing Automation and Design Engineering)
http://elib.cme.nist.gov/made/made.html
http://www.eit.com/creations/research/made/background.html
http://www.arpa.mil/sisto/symp/Overview/MADE.html

Shared Dependency Engineering(SHADE)
http://www.arpa.mil/sisto/symp/Demos/I3/DE_SHADE.html
http://www-ksl.stanford.edu/knowledge-sharing/papers/shade-overview.html
http://www.arpa.mil/sisto/symp/Demos/I3/PR_SHADE.html
http://hitchhiker.space.lockheed.com/aic/shade/demos/

ject and is designed to integrate with the MADE project. The two primary purposes for the AIMS pilot program are to create a technological infrastructure based on the Internet to enable complementary companies to share resources, and to devise a set of business practices to facilitate virtual organization.

At least two AI developments have been explored in the AIMS project, beyond virtual office systems, such as SmartProcurement: autonomous intelligent agents and knowledge-based systems. AIMS features Mediator Tool Kits that allow development of customizable agents to function as intermediaries between clients and servers. Mediators are viewed as essential for creating large-scale federated systems, such as those envisioned under AIMS. In particular, intelligent agents have multiple roles in the AIMS setting [11] :

- Information agents (*facilitators*) route requests for part information to the appropriate engineering databases.
- Aggregator agents combine multiple orders into a single request.
- User programmable agents can automate routine work-flow tasks, such as forwarding mail or invoking programs.
- Engineering database agents notify each other of design changes affecting other members.

In addition, knowledge-based systems are planned for use in assessing manufacturability, matching process capabilities and needs with production planning, and scheduling. Generally, these systems will be implemented as agents to coordinate production scheduling and dynamically balance loads.

AIMS-like environments can also make use of a *command center* design to monitor and control agent activity and firm resources. Since leveraging resources is so critical and time constraints are so tight, graphic representations can be used to monitor agent commitments and activities in a virtual manufacturing war room.

Virtual manufacturing organizations extend the use of agents beyond basic office processes, integrating them with manufacturing processes and coupling procurement with manufacturing needs. Virtual manufacturing organizations must be able to sell as well as procure, and they

Palo Alto Collaborative Testbed(PACT)
http://www.eit.com/creations/papers/pact/
http://hitchhiker.space.lockheed.com/aic/kcd/parman/parman.html

Virtual Manufacturing Systems

Agile Infrastructure for Manufacturing Systems (AIMS)
http://hitchhiker.space.lockheed.com/~aims/
http://www.eit.com/creations/papers/DMC93/

Defense Manufacturing Conference
http://picard.ml.wpafb.af.mil/DMC/dmc94.html

ARPA
http://www.arpa.mil/sisto/symp/Overview/Agile.html

Ontology

What is an Ontology?
http://www-ksl.stanford.edu/kst/what-is-an-ontology.html

Ontology for Engineering Mathematics
http://www-ksl.stanford.edu/knowledge-sharing/papers/engmath.html

Virtual Classroom

Computer Aided Education and Training Initiative (CAETI)
http://www.arpa.mil/sisto/Overview/CAETI.html
http://www.cs.unc.edu/caeti

Virtual Environments for Training

Virtual Environments for Training
http://128.9.176.20/isd/VET/vet.html
http://vet.parl.com/~vet/
http://www.brooks.af.mil/HSC/AL/HR/HRT/HRTI/vett.htm
http://cwis.usc.edu/dept/News_Service/chronicle_html/1996.02.26.html/Computers_learn_to_match_.html

JACK
http://www.cis.upenn.edu/~hms/jack.html

Uses of AI on the Internet

AAAI
http://www.aaai.org/Publications/TechReports/Papers/nii.html

ARPA Systems
http://www.arpa.mil/sisto/symp/Demos/

must be able to determine how much to produce. Under the AIMS structure, agents are used to capture these business processes and execute transactions in real time.

Virtual Classrooms and Individualized Learning

The WWW and AI also have been used to facilitate training through the development of virtual classrooms that allow students to learn on their own with the assistance of intelligent agents to guide them through the learning process. Virtual classrooms provide intelligent tutoring capabilities in an Internet infrastructure. ARPA's Computer Assisted Education and Training Initiative (CAETI) is concerned with the expansion and customization of intelligent access and integration of digital resources. It supports individualized learning regardless of the availability of local resources, as well as enhancing group training and education through multiuser environments and simulation. Three initiatives in CAETI are:

- *Expert Associates Guide to Individualized Learning* (EAGIL), which encompasses intelligent guides, tutors, and associates that adapt to student learning styles, respond to student progress, and support individualized learning.
- *Collaborative Applications for Project-based Education Resources* (CAPER), which includes authentic multimedia, synthetic environments supporting involvement, experimentation, exploration, and collaboration in cross-disciplinary projects.
- *Smart Navigators to Access and Integrate Resources* (SNAIR), which uses intelligent agents for students, and instructors that access, mediate, tailor, and integrate networked data and computational resources.

Agents play a critical role in each of these virtual classroom environments. Agents limit the need for students to be present at some central location. Instead, agents facilitate off-site intelligent tutoring. Agents allow student experimentation with Web-available resources, such as telescope time.

Virtual Environments for Training (VETs)

Virtual environments for training are another type of virtual organization activity. Virtual environments integrate virtual reality and intelligent tutoring. Students can either watch or participate in the simulations.

VETs have been used in such domains as orbital mechanics and fighter pilot training. At the core of VETs are autonomous intelligent agents. Typically, agents are used to represent or simulate other actors or other pilots. In the case of pilot training, the agents must provide three particular functions: a perception mechanism that lets them receive inputs, a range of their actions that lets them affect their environment, and the ability to analyze tasks and orchestrate actions in purposeful behavior. These capabilities translate into such actions as avoiding hillsides, flying in formation, and determining when to go into flying position.

One of the best-known environments for simulating human actors is *Jack*—a 3D environment featuring detailed human models with a wide range of capabilities so it can be used to model a diverse set of environments ranging from the space shuttle to tractors. Jack models human behavior with motion, hearing, voice, cognitive skills, and strength similar to those of a CAD model.

VETs allow a simulation of real-world environments with simulated actors. Computational agents provide human agents the ability to learn without actually experiencing the danger of certain activities or without having access to real environments.

Conclusions

Autonomous or semiautonomous agents are the dominant AI device in virtual organizations, proving to be a paradigm apparently suited to multiple, heterogeneous database structures. Agents have been given various roles within virtual organizations, ranging from purchasing to selling, and to facilitating communications with other agents. Interrelated projects, such as MADE, PACT, SHADE, and AIMS, have focused on the entire product lifecycle, going from product engineering to production and manufacturing.

In addition, these virtual organization projects illustrate some of the AI technologies that facilitate virtual organizations.

Wrapping and encapsulation architectures, as evident in VILAN and MADE, seem to provide a structure that facilitates interaction between agents and yet allows use of domain-specific software for virtual organizations.

Domain-dependent agent roles seem to be a critical feature of the virtual organization designs reviewed here. VILAN uses data broker agents; SmartProcurement uses purchasing agents and vendor agents; PACT uses facilitators, local agents, and remote agents; SHADE used translator agents, consumer agents, and provider agents; and AIMS uses facilitators, aggregators, and engineering database agents.

Ultimately, we would expect AI toolkits, as noted in VILAN and AIMS, and other studies to yield agents and related structures designed to facilitate virtual organizations.

One of the most difficult problems in using AI to facilitate virtual organizations is development of negotiated ontologies meeting the needs of virtual organizations. Although there are also examples of successfully adopted ontologies, there are a number of impediments to

ontology development. First, if multiple firms are involved, as is generally the case in virtual organizations, ontologies for agent communication are either negotiated or dictated. If the ontology is negotiated, some aspects of the ontology are likely to benefit each of the parties differently. If the ontology is dictated, the ontology likely benefits one party at cost to the others. O'Leary [10] developed an ontology impossibility theorem that shows it is impossible to choose an ontology that benefits all participants equally. Second, many ontologies are not stationary and thus need to change over time. Third, interfaces between ontologies for different products and activities make the process of scaling up ontologies a very difficult activity. Research in this area investigates many things including specification type, languages to accommodate diversity of agents and of databases, temporal issues, and constraint issues.

Communication among heterogeneous agents is another difficult issue that has received substantial attention from researchers using multiple approaches. One approach mitigates agent heterogeneity by using standards to facilitate interagent (and intercompany) interaction (e.g., [3]). Another approach tries to build agents that can communicate with agents of different types, using devices such as wrappings or development of so-called facilitator agents, as in PACT.

However, it is still difficult to assess whether using AI to facilitate virtual organizations is a success. We are certain that AI has been used to facilitate a number of virtual organization structures in a number of projects and that new projects continue to be implemented. We also know these projects are typically implemented in a WWW infrastructure using intelligent agents to facilitate communication among organizational participants. In addition, we have occasional news reports of the successful use of such intelligent agents in virtual organizations (e.g., [6]). For assessment purposes, however, firms have competitive reasons for not disclosing what works and what doesn't. If a project is successful, firms have incentives to not disclose that success for fear of increased competition. If a project is not successful, firms also have incentives not to disclose that fact, for obvious reasons.

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