# Distributed Agent Systems for Intelligent Manufacturing

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## Introduction

Les architectures pour la fabrication intelligente formant des sociétés d'agents coordinateurs sont devenues un sujet de recherche important au cours de la dernière décennie. Pendant cette même période, la recherche sur les systèmes de fabrication intelligente a connu une collaboration internationale plus grande, ainsi qu'une coordination accrue des sociétés de chercheurs à travers le monde. Les modèles et les technologies de coordination distribuée d'agents en cours de développement pour gérer la fabrication, s'appliquent aussi bien à la gestion de la recherche en collaboration distribuée. Le programme de recherche international des Systèmes de fabrication intelligente tente de systématiser et de rendre opérationnel le savoir mondial sur les systèmes avancés de fabrication en vue de générer de nouveaux paradigmes [3]. Cet article met l'accent sur la recherche sur les systèmes de fabrication intelligente à base d'agents effectuée à l'Institut de la science de la connaissance et à la Division d'ingénierie de la fabrication de l'Université de Calgary pour supporter le cycle de vie de fabrication dans une entreprise distribuée. On y décrit des applications à la coordination de recherche en fabrication et à des activités et procédés de fabrication spécifiques.

## Introduction

Architectures for intelligent manufacturing systems as societies of coordinating agents have become a major research theme in the last decade. At the same time, research activities on intelligent manufacturing systems have increasingly involved international collaboration and the coordination of societies of human research agents world-wide. The distributed agent coordination models and technologies being developed to manage manufacturing are also applicable to the management of distributed collaborative research. The international Intelligent Manufacturing Systems (IMS) research program is an attempt to systematize and make operational world-wide knowledge of advanced manufacturing systems as a basis for new paradigms [3].

This article focuses on agent-based IMS research undertaken in the Knowledge Science Institute and the Division of Manufacturing Engineering at the University of Calgary to support the manufacturing life cycle in a distributed enterprise. Applications to the coordination of manufacturing research and to specific manufacturing activities and processes are described.

The following describes two multi-agent systems embodying new approaches and for which working prototypes have been developed. The first of these is a high-level Mediator agent system which supports the coordination in concurrent fashion, of geographically distributed application processes via Internet communication [4]. The second multi-agent system is a concurrent engineering application which supports coordinated simultaneous design, process planning, routing, and scheduling activities [7].

## Mediator

Mediator is an agent-based, open-architecture information and knowledge management system designed to provide a flexible technology to support the management of complex manufacturing environments. A heterogeneous environment is assumed in which the sub-systems are geographically dispersed and involve different application packages, not necessarily designed to work together, multiple platforms,

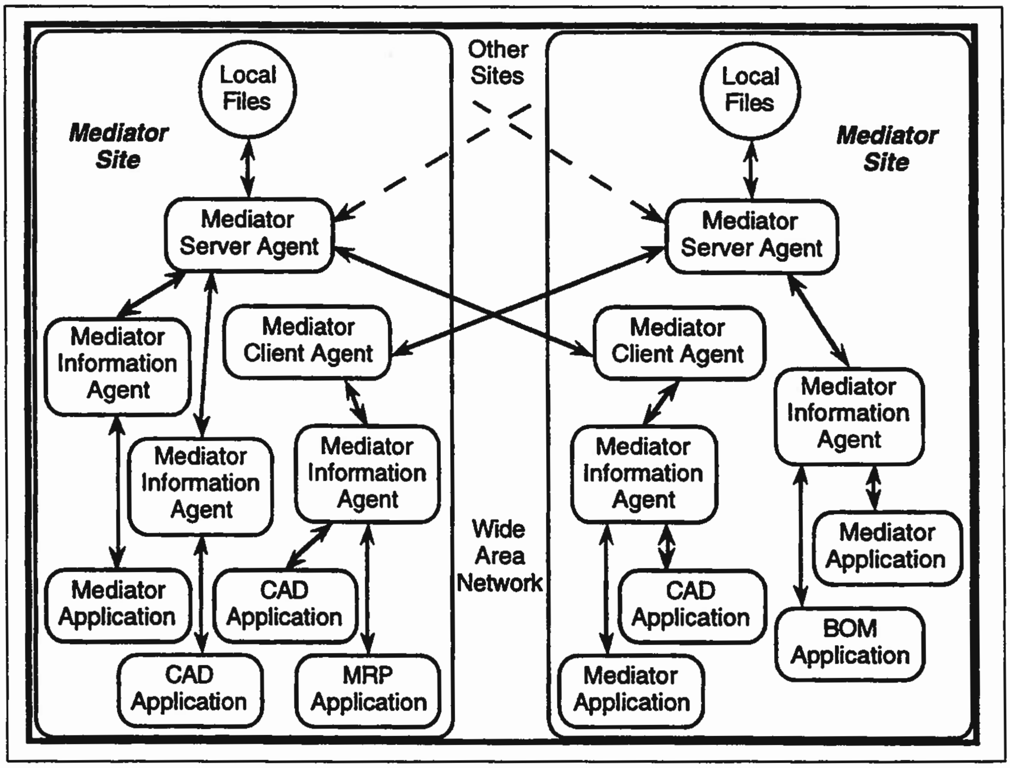


*Figure 1. Mediator Operation Over a Network*

protocols and forms of user interface. The function of Mediator is to provide a knowledge support system for the managers and system operators involved in running a virtual factory. It is designed to facilitate communication, compliance with constraints including physical restrictions and legal obligations, and to generally represent knowledge about any activity or sub-system relevant to the manufacturing process.

Figure 1 shows the way in which Mediator operates over a network. A server agent at a site manages a knowledge base consisting of a set of files from different applications. Concept maps are used to represent the files and relations between them. Files may be opened from the maps in the appropriate applications. Since the maps and hypermedia documents of Mediator are also files, the system can be used to support large-scale linked knowledge structures. Client agents at remote sites connect to server agents across the network and allow files to be accessed remotely in the same way as they are locally.

### Concurrent Engineering MAS

The architecture of this concurrent engineering application is based on a heterogeneous agent paradigm in which every physical or other entity in the system, such as design features, parts, and manufacturing shop floor machines, is associated with a reasoning agent. These design, resource, part, and coordination agents are integrated into an open ended system in which dynamic virtual clusters of agents interact to carry out the necessary concurrent engineering activities [8]. Novel features are: dynamic system organization through virtual clustering (the clusters are created, coordinated, and destroyed as required for task accomplishment); agent reasoning through an asynchronous message-triggered inferencing process quite different from conventional inferencing techniques; specially developed mechanisms to provide each agent with its own independent thread of execution control and to dynamically coordinate these. The system has been tested when distributed across three workstations connected by a local area network.

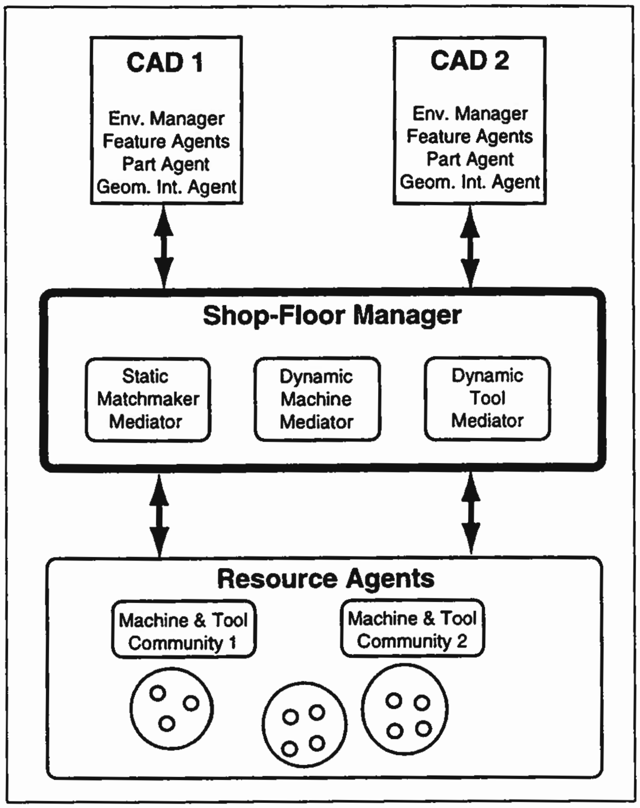


*Figure 2. System Architecture*

Figure 2 shows a simplified view of the architecture. The components include a CAD sub-systems, a Shop-Floor Manager, and Resource agent communities. These multi-agent composite components have reasoning, control, and communication capabilities for both their internal activities and their collaborative actions with other agents. This synergy achieves flexibility, expandability, fault tolerance, and reconfigurability on a real-time basis.

The system has been implemented on a network of HP 9000/715 machines running HPUX 9.01. The CAD sub-systems have been implemented using AutoCAD R12, Advanced Modeling Extension V2, a light-weight process library developed for this purpose, and C++. The Shop-Floor Manager and resource agents have been implemented using Smalltalk VisualWorks 2.0. Every agent in the system has an independent thread of execution control. The HPUX communication capabilities have been used to provide an asynchronous messaging mechanism for communication among the sub-systems. The constituent individual agents use facilities provided by their respective local environment, namely, the light weight process library and Smalltalk.

The CAD sub-system provides facilities for feature-based design and comprises Part Agents, Feature Agents, a Design Agent, a Geometric Interface Agent, and an Environment Manager. A part is designed by repeated instantiations of features on a blank geometry. The Part Agent is the repository for both product data and knowledge, and dynamically updates itself as the design progresses. Every feature type present in the design system and every feature instantiated in the design process is represented by a Feature Agent. The design system has more than twenty-five non-degenerate feature types for prismatic components.

The Design Agent here is the human expert. The Geometric Interface Agent acts as an intermediary for translating information between the graphical display, the constructive solid geometry manipulation front end, and other agents. The Environment Manager coordinates the activities of the agents in the design system by acting as a message redirector. It also interfaces local agents with manufacturing resource agents through shop-floor manager.

The Shop-Floor manager plays a vital role in shop floor control by establishing and maintaining virtual agent communities and by redirecting messages. It imposes an adaptive hierarchy within a resource community as required. The Shop-Floor Manager is comprised of multiple components, namely, a Static Matchmaker mediator, and a number of dynamic machine and tool mediators. The mediators have a generic coordination architecture [9] and provide facilities for matchmaking, cloning, clustering, dynamic coordination, and arbitration.

Each machine on the shop floor is represented by an autonomous machine agent which has knowledge of its own machine's physical and process capabilities, potential or assigned tooling, and production schedule. Each tool in the shop floor is represented by an autonomous tool agent which has knowledge about the tool's shape, and its tolerance capabilities in combination with a particular machine and work material under standard operating parameters. It also maintains a record of the schedule for the tool's use.

## Other Agent Research at the University of Calgary

Other agent projects related to manufacturing include a development system for agent software [6], planning and control of autonomous guided vehicles (AGVs) [5], and intelligent control [1].

The applications of agent-based systems to manufacturing are part of a long-term program of research into the fundamentals of intelligent, adaptive agents, including communities of agents in human society and their interactions with technology.

The collective stance model [2] views the human species as a single agent recursively partitioned in space and time into sub-agents that are similar to the whole. These parts include societies, organizations, groups, individuals, roles, and neurological functions. Notions of expertise arise because the species adapts as a whole through adaptation of its interacting parts. The phenomena of expertise correspond to those leading to distribution of tasks and functional differentiation of the parts. The mechanism is one of positive feedback from parts of the agent allocating resources for action to other parts on the basis of those latter parts past performance of similar activities. Distribution and differentiation follow if performance is rewarded and low performers of tasks, being excluded by the feedback mechanism from opportunities for performance of those tasks, seek out alternative tasks where there is less competition. The knowledge-level phenomena of expertise, such as meaning and its representation in language and overt knowledge, arise as byproducts of the communication, coordination, and modeling processes associated with the basic exchange-theoretic behavioral model.

The collective stance model has been applied to many areas of human-technology interaction, including educational systems and the use of Mediator to support a learning web [10].

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Copies of these papers and other relevant articles may be found at: http://ksi.cpsc.ucalgary.ca/articles/ and http://www.ucalgary.ca/~norrie/

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*Systems and, in particular, in Multi-Agent Applications in Manufacturing. Contact: http://www.ucalgary.ca/~norrie/*

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