Applying a hierarchical multiprocessing architecture to computer integrated manufacturing

by Roen Stephen Hogg

A thesis submitted in partial fulfillment of the requirements for the degree 'of Master of Science in Computer Science
Montana State University

Abstract:
A hierarchical multiprocessing architecture is an organizational paradigm that can be applied to the class of problems that involve organizing asynchronous processes via abstraction and localization of information. Within the domain of Computer Integrated Manufacturing (CIM), one such problem is the integration of manufacturing constraints into the product design process. Though most companies perform some degree of design optimization, it is often achieved via an ad hoc system of people and computers. This thesis discusses the application of a hierarchical multiprocessing architecture to this ad hoc system in an attempt to provide the design engineer with timely estimates of the economic impact of various design alternatives. In particular, a hierarchical organizational system, based on Factor and Gelernter's [1988] process lattice, was developed and tested.

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ABSTRACT

A hierarchical multiprocessing architecture is an organizational paradigm that can be applied to the class of problems that involve organizing asynchronous processes via abstraction and localization of information. Within the domain of Computer Integrated Manufacturing (CIM), one such problem is the integration of manufacturing constraints into the product design process. Though most companies perform some degree of design optimization, it is often achieved via an ad hoc system of people and computers. This thesis discusses the application of a hierarchical multiprocessing architecture to this ad hoc system in an attempt to provide the design engineer with timely estimates of the economic impact of various design alternatives. In particular, a hierarchical organizational system, based on Factor and Gelernter's [1988] process lattice, was developed and tested.

INTRODUCTION

A recent trend in Computer Integrated Manufacturing (CIM) research has been the development of process and data management systems. These systems are intended to manage the entire engineering release system of a product. Though such systems are useful, management of the product development process is not sufficient. A product is more cost effective when manufacturing constraints, such as material and machining cost, are considered while the product is being designed. Though most companies perform some degree of design optimization, it is often achieved via an ad hoc system of people and computers. This thesis discusses the development of a Constraint Monitor that provides the design engineer with timely estimates of the economic impact of various design alternatives by imposing an organizational paradigm on this ad hoc system. The driving force behind the design of the Constraint Monitor is the recognition that the problem domain, since it directly interacts with the physical world by the continual input of new information from a variety of sources, is an open system. Any design for an integrated product development system, therefore, needs to address the properties of open systems. A paradigm that is well-suited for an open system is Factor and Gelernter's [1988] process lattice since it provides a flexible method to organize the flow of information within a system that consists of a diverse set of functions. This hierarchical organizational paradigm is used to develop the Constraint Monitor.

Though the Constraint Monitor developed in this thesis does not demonstrate actual manufacturing constraints, it does illustrate how different constraints could be organized in a hierarchical fashion based on a process lattice. In order to apply this concept to an actual product development system, a thorough analysis of the different manufacturing constraints and their relationships must be performed.

This thesis first presents an overview of current CIM systems. Following this overview, the need for a Constraint Monitor that integrates manufacturing constraints into the design process is discussed. An argument is then made that a hierarchical multiprocessing architecture is a well-suited organizational paradigm for the development of a Constraint Monitor. This is followed by a specification of the particular architecture used to design the Constraint Monitor, namely the process lattice paradigm. This discussion of the design and implementation of the Constraint Monitor is then followed by an overview of related areas of future research.

COMPUTER INTEGRATED MANUFACTURING

In this chapter an overview of Computer Integrated Manufacturing (CIM) is presented followed by a brief review of several existing systems that provide data and process management. The functional components of these systems are abstracted and the limitations of such a functional design are discussed. A case is made for CIM systems that incorporate manufacturing constraints into the design process.

CIM Overview

Automation of the manufacturing process has been a research concern for a number of years. In 1974, Harrington defined "Computer Integrated Manufacturing" (CIM) in his book by the same name. Since then, the concept of what exactly constitutes a CIM system has been disputed. In particular, the terms "manufacturing" and "integration" remain controversial. This section discusses the various interpretations of these two terms and their relevance to this thesis.

Manufacturing

Manufacturing systems, as noted by Chang and Wysk [1985], can be classified into two major categories: continuous process manufacturing and discrete parts manufacturing. The former involves the production of a continuous product; for instance, the process of refining crude oil into gasoline.

The latter involves the production of a product that undergoes a finite number of production operations. CIM research has generally focused on this latter case. In particular, it has focused on the manufacturing of machined parts which is also the focus of this thesis.

Integration

As illustrated in Figure 1, integration can differ in terms of type and degree, which produces confusion regarding what constitutes an integrated system.

Integration		
Type	Control limited to actual production activities	Incorporation of preproduction activities
Degree	Loosely coupled	Tightly coupled

Figure 1. Types and Degrees of Integration.

Research in integrating the process of manufacturing machined parts can be delineated into two areas with respect to type: (1) the control of actual production activities, i.e. the actual manufacturing of the product, and (2) the incorporation and synchronization of preproduction activities such as product design and analysis. The former limits manufacturing in the strict sense of the word. Such a view is unnecessarily limiting; since other aspects of the product development process must be considered to achieve true integration.

The degree of integration is a continuum defined by the amount of coupling. For instance, a loosely coupled system (as illustrated in Figure 2) might encompass the interface and coordination of information that occurs throughout the entire organization.

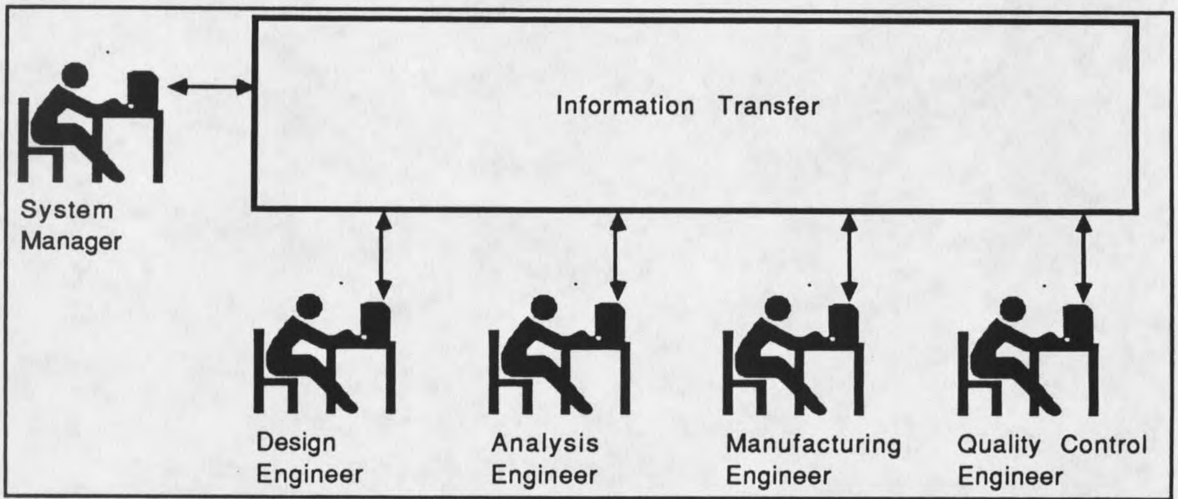

Figure 2. Loosely Coupled CIM System.

The solution requires integration of organizations that are currently "islands of automation". Though this solution has technical consequences, it is less a technical problem than political. As noted by Appleton [1985] and Savage [1985], policies need to be defined by upper management which will bring members of the engineering release system into a closer relationship.

A more tightly coupled system (Figure 3) extends this concept of information integration to include, for instance, the data and process management of the engineering release system of a product. Such a CIM system provides procedures, methodologies, and application programs to aid people in developing a product. This includes providing authorization control (controlling who can use the system) and process control (controlling when the next process in the product development process can be executed). This ensures an effective and accountable product development process (also referred to in the literature as a product's life cycle).

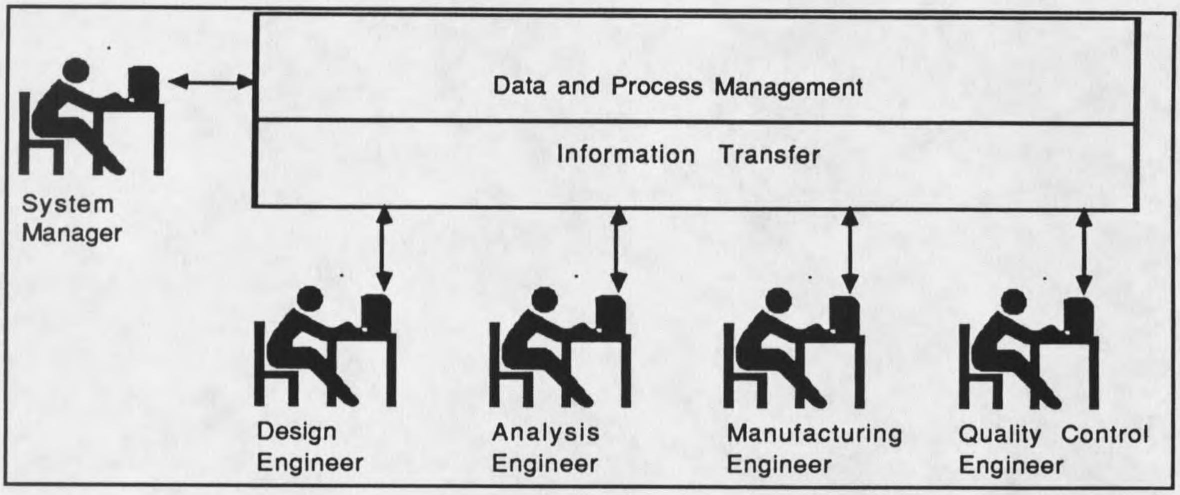

Figure 3. Tightly Coupled CIM System.

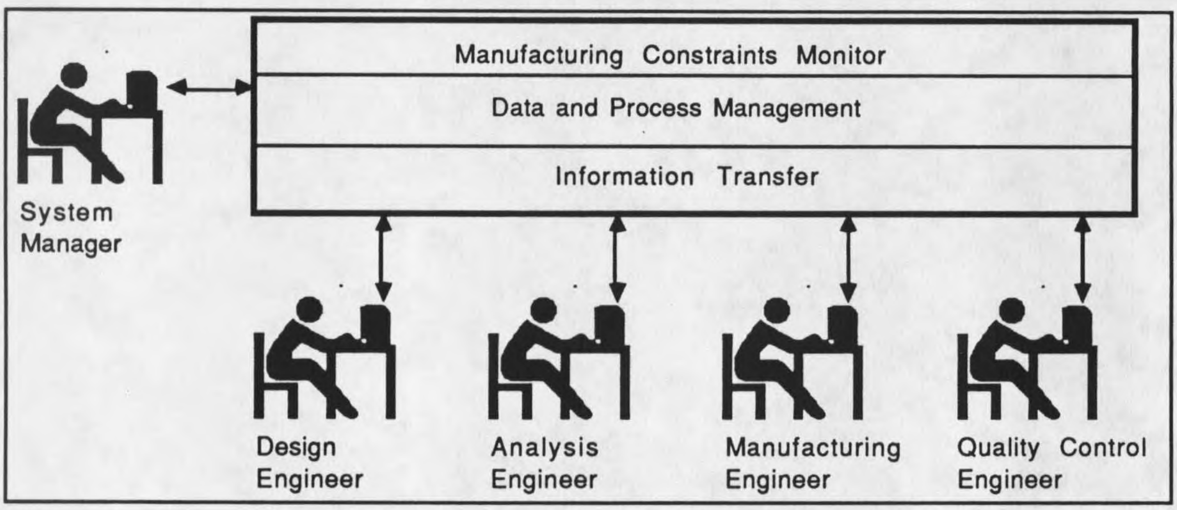

Figure 4. More Tightly Coupled CIM System.

A more tightly coupled system (Figure 4) extends this concept of data and process management to include, for instance, the integration of manufacturing constraints during the design process.

This research considers developing such a tightly coupled system. Methods are investigated to organize the preproduction tasks so that the product is manufactured at the optimal production rate and cost. Before this research approach is discussed, it will be helpful to describe current CIM data and process management systems.

Current CIM Data and Process Management Systems

Developing a CIM system that performs data and process management is not technically difficult. In fact, several such systems that provide some degree of data and process management currently exist: (1) Sherpa's DMS, (2) SDRC's (Structural Dynamics Research Corporation) DMCS, and (3) IBM's DCS. These three products can be categorized into two distinct groups: Those that offer an integrated system and those that offer a collection of software tools. Sherpa and SDRC are of the former, IBM of the latter. In other words, Sherpa and SDRC offer an integrated system that has predetermined data structures and predetermined functions that operate on this data. IBM offers a set of software tools which the user must integrate into a unified system.

There are advantages and disadvantages to each approach. The advantage of the integrated system approach is that it reduces the cost to install a CIM system. The disadvantage is that because it is an off-the-shelf system, it is difficult to tailor the system to match the user's particular needs and ways of doing business. The software tools approach is flexible and can be tailored to the user's particular requirements. However, more time (and money) is required to integrate these flexible software tools into a unified system. Based upon this categorical distinction, the following sections examine in more detail the three products.

Sherpa DMS

Sherpa DMS is a software system that runs on the VAX series of computers. This system manages both data and the development process for engineering organizations. Once the user gathers the design process data, Sherpa offers a Macintosh-style interface that allows one to enter this data into DMS. Once this data is entered, the system provides several predetermined functions that facilitate management of the design process. In addition, DMS allows users to tailor these functions to match their particular needs and way of doing business. This is done by using DMS's alert facility to define alerts. The alerts can be used to notify users of database activity or to activate a computer process based on a database activity. The capability to define alerts enhances the flexibility of the system. For the alerts enable the user to customize the system to perform those actions deemed necessary. In addition to allowing the user to tailor the system functions to match his needs, DMS offers two other useful features: distributed file storage and distributed user access. Distributed file storage allows files to be stored on any node in the network, but still be controlled by DMS from a central location. Distributed user access provides users with transparent access to DMS from any node in the network.

SDRC DMCS

SDRC DMCS is in many ways similar to Sherpa DMS. DMCS, like DMS, is a software system that runs on the VAX series of computers. Once the user gathers and inputs the design process data, DMCS keeps track of product data creation, revision, and movement. DMCS, like DMS, supports distributed file storage. In fact, in DMCS, file storage is based on user rules that allow files to be stored on any node in the network. And like DMS, DMCS provides several predefined functions that facilitate management of the design process. However, unlike DMS, DMCS does not allow users to tailor these functions. That is, DMCS is an application, not an operating system. Thus it is designed to be used as delivered. Though the user can change data values, the user cannot add additional functions or modify existing functions. To do this, the application code itself must be modified. As such, DMCS does not offer the flexibility of DMS alerts.

IBM DCS

IBM DCS, unlike DMS and DMCS, is not a software system. Instead, IBM offers several software tools which the user would then integrate into a software system to support engineering design and manufacturing. However, this integration is only the first step since these tools must be tailored to meet the user's specific needs. In particular, the user must define and write ISPF panels, define data elements for DCS (Data Communication System) and for CDF (Consolidate Design File), write EXEC's to perform necessary functions for each panel, and implement user security.

Though these three systems provide some degree of data and process management, none of these systems is a turn-key system. Before such a system can be used, a company must determine the method by which it develops a product. This method should include the phases through which the product passes, the conditions and approvals that are required, and the personnel that are involved. Furthermore, a company must tailor any purchased CIM system to match its particular needs and ways of doing business.

Functional Description of CIM Data and Process Management Systems

Though the three products differ in particular details, functionally they all provide some degree of data and process management (in particular, they all support authorization control, process control, life-cycle definition, and message notification). In Figure 5 these CIM data and process management systems are functionally abstracted.

In this CIM model, User Control Knowledge is used to verify each requested user action. If the user has authorization to perform the action, this request is transferred to the Action Controller which sequences all requested actions. This list of sequenced actions is then sent to an Execute Action module which executes each requested action. In addition to user requested actions, there are system initiated actions. The Determine CIM System Action module uses CIM System Control Knowledge to determine whether any CIM action should be initiated based on information in the Product Definition Data Base. Such system initiated actions include the automatic notification of individuals based on an event within the CIM system as well as automatic execution of processes defined within the CIM system based on a set of conditions, such as the automatic promotion of the product through its life cycle.

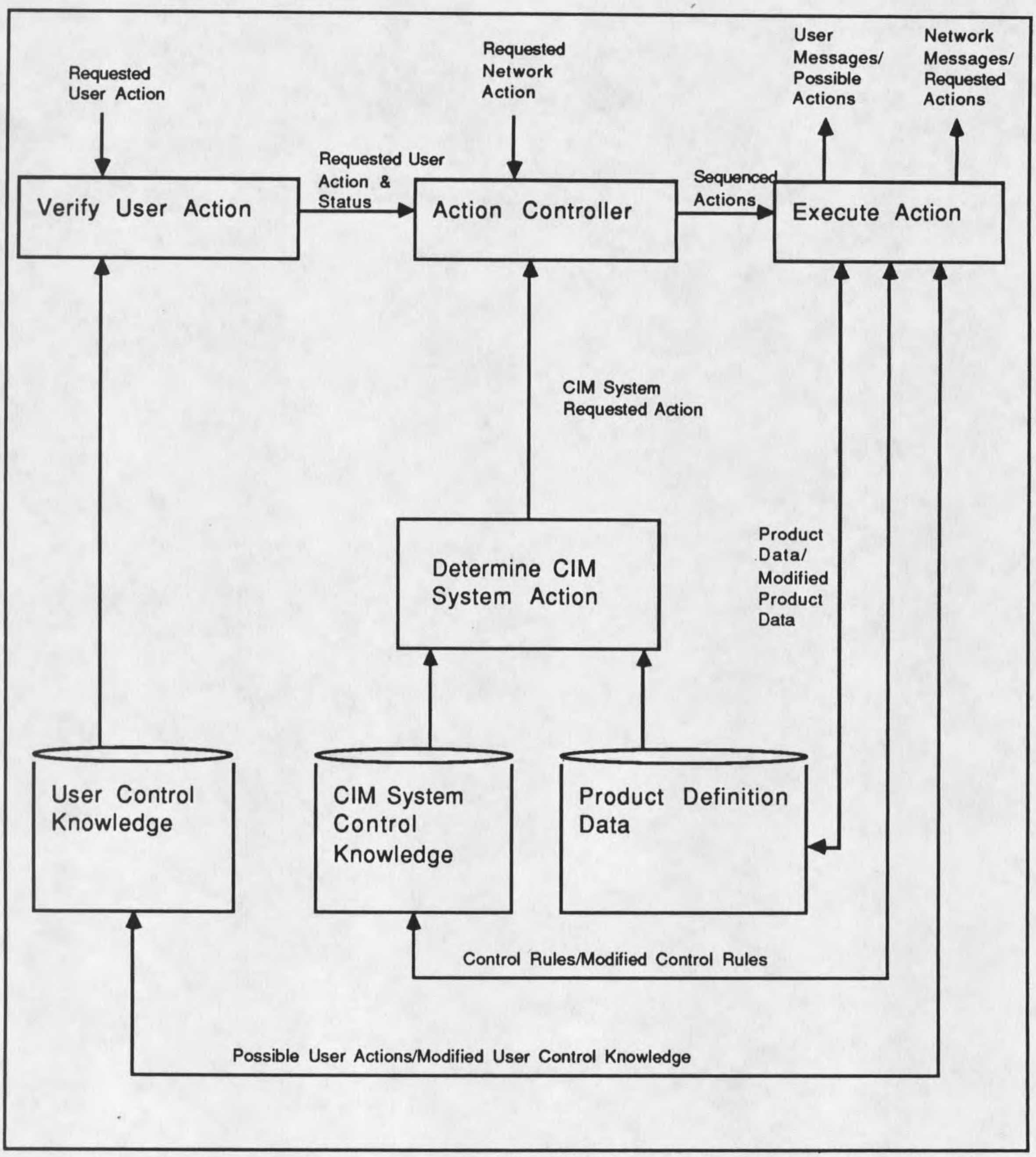

Figure 5. CIM Data and Process Management System.

Each of these functions is discussed in more detail in the appendix. In particular, the appendix describes the inputs, outputs, and driving requirements for each function.

Though these functions enable the system to provide data and process management, they do not integrate manufacturing constraints into the design process. The following section examines the need for such constraint integration.

Limitations of CIM Data and Process Management Systems

Though the three CIM data and process management systems described above support product development management, none incorporates manufacturing constraints into the design process. The incorporation of such constraints -- as noted by Fleischer and Khoshnevis [1986], Compton and Gjostein [1986], Suri [1988], Tipnis [1988], and Whitney et al. [1988] -- can result in substantial savings in product development cost. Such savings can be obtained since the design intent is often achievable in various ways. For instance, material type and tolerances can often be modified without impacting the design intent.

To achieve savings in the development of a product, the design engineer needs to be aware of the relationship between his design and the manufacturing process. This includes information on manufacturing constraints such as material cost, material attributes, and the production qualities of different machining processes.

The goal of this thesis is to propose an architecture that supports a formal interaction between design and manufacturing such that manufacturing