SHORT PAPERS

Integration and Collaboration Models*: An Overview

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1. Introduction

The purpose of this introductory chapter is to define several important types of integration and collaboration issues and describe briefly some research efforts to model them.

Integration is an intelligent response to an increasing fragmentation of distributed organizations. Information integration is necessary to gain better control over the different units or functions of an organization, leading to improved performance and, potentially, better results. With the advent of computer and communication techniques, information integration has become more feasible, but at the same time, also more necessary. Increasing amounts of information are generated and handled over complex networks of users, clients, and servers. As a result, successful integration is viewed as a useful competitive ability.

Typical examples of integration are on-going design revisions and process improvements that are integrated with previous product information to produce a more desirable product model; integration of sensory information from multiple sensors; integration of several expert systems embedded in microprocessors; integration of distributed human and machine function in a factory or a service organization.

INTEGRATION: Integration is a process by which sub-systems share or combine physical or logical tasks and resources so that the whole system can produce better (synergistic) results. *Internal integration* occurs among sub-systems of the same system, and *external integration* is with sub-systems of other systems (as in customers-supplier relations). However, integration always depends on a cooperative behavior.

CO-OPERATION: The success of any integration is a function of the degree of co-operation among the integrated sub-systems. Without co-operation, integration is impossible. Co-operation is defined as the willingness and readiness of sub-systems to

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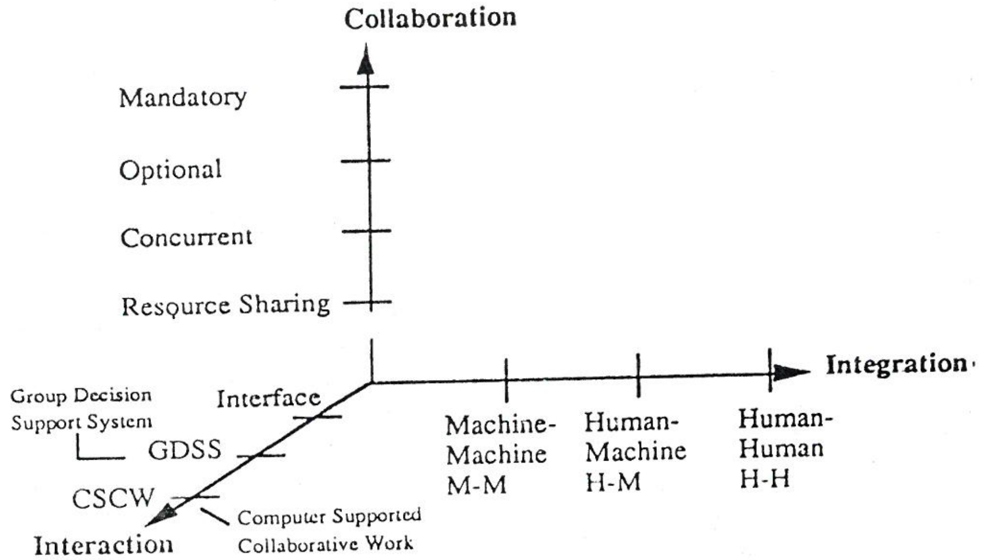


	M-M	H-M	H-H
Interface	I/O, PLC	Display	Fax; E-mail
GDSS	Negotiated Scheduling	Flexible Manufacturing Control	Decision Room
CSCW	Intelligent Control	Engineering Integration	Computer Mediated Collaboration
Example	Multiple Robots	Supervisory Control	Team Work

	Integration Problem	Integration Example *		Collaboration Type
1	Processing of task without splitting and with sequential processing	Concept design followed by physical design	H-H	Mandatory, sequential
2	Processing of task with splitting and parallel processing	Multi-robot assembly	M-M	Mandatory, parallel
3	Processing of task without splitting. Very specific operation.	Single human planner (particular)	H-M	Optional, similar processors
4	Processing of task without splitting. General task.	Single human planner (out of a team)	H-M	Optional, different processor types
5	Processing of task, can have splitting	Engineering team design	H-H	Concurrent
6	Resource allocation	Job-machine assignment	M-M	Competitive
7	Machic substitution	Data base backups	M-M	Cooperative

* For every problem, examples exist for H-H, H-M, and M-M; only one was arbitrarily given.

Figure 1. Integration taxonomy

share or combine their tasks and resources as in "open systems".

COLLABORATION: Even with co-operation, there is still the issue of how to perform the process of integration effectively. Collaboration is defined as the active participation and work of the sub-systems towards accomplishing collaborative integration. Collaboration can also be characterized as *internal* or *external*. Usually, collaboration is the opposite of competition among sub- systems, although there can be situations of competitive integration. An important function of collaborative integration is to overcome conflicts among the sub-systems.

2. Types of Integration and Collaboration

An attempt to provide an integration taxonomy is shown in Figure 1. The taxonomy is along three main axes: integration, interaction and collaboration. Examples are also given to illustrate the different types of integration and collaboration. Recent research has focused on two main types of integration:

(1) coordination and collaboration among distributed, often remote, teams, facilities, suppliers, and clients;

(2) integration of software tools. By co-ordination and collaboration, distributed workers or processors can integrate information via a network of workstations (Eberts and Nof, 1993). In software tool integration, information and programs are combined to provide a smooth transition of information between them to increase overall computational effectiveness (Weston, 1993).

Several attempts to develop a theory of integration have been reported, e.g. Papastavrou and Nof (1992), in the area of decision integration. We can define the integration process with six elements of integration as follows:

$$\textbf{Integration: } (I, IP, I/O, S_i\ (i=1,\ldots n), t, IM) \qquad (1)$$

where

(1) I is the *Integration Operator*, e.g. $I(Y_1,Y_2)\rightarrow u$ means that two input streams, Y_1 and Y_2, are integrated to produce output u; $I(Y_1, Y_2) \rightarrow u = Y_1$ or Y_2 means that one of the inputs is ignored and the other accepted, etc.

(2) IP is the *Integration Procedure* or algorithm which specifies *how* the integration process is realized, e.g. the collaboration type and the interaction protocols that are applied.

(3) The *I/O streams* indicate the information inputs and outputs.

(4) S_i is a *sub-system* of a distributed organization defined by G = (N, A), a directed graph of the message flow diagram specifying the A arcs architecture and communication among the N S_is.

(5) t is the *Integration Time*, a time function specifying the durations and timing of integration tasks and events.

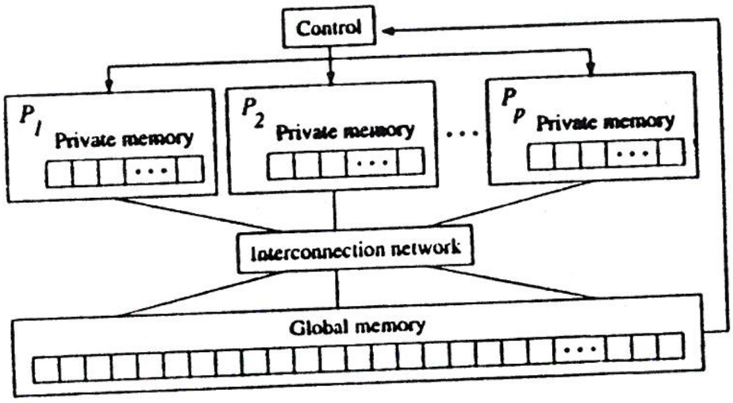
(6) IM is the *Integration Model*, the model of the integration which can be used to analyse, design, test, evaluate, or operate the integration process.

3. Modelling Research

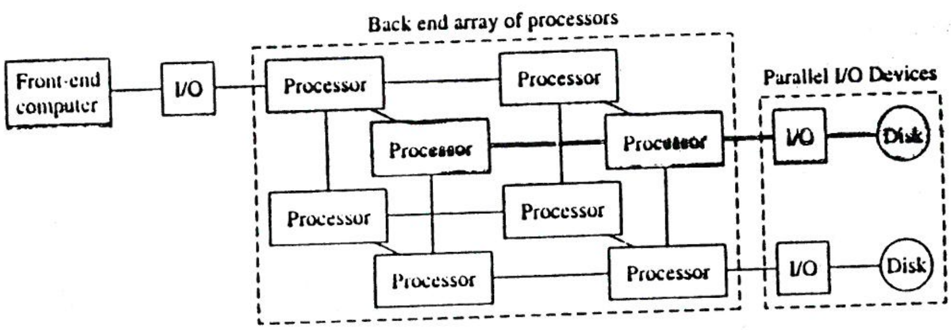
A variety of modelling approaches has been researched and developed for integration and collaboration, depending on the application area. *Planning* and *design models* have included enterprise information flow models, software tool integration models, operational models such as CRP (Collaboration Requirement Planning), game-theoretic models, and reasoning models such as multi- agent models and DPS (Distributed Problem Solving) models. *Enabling models* have included interface models and interface generators, GDSS/CSCW models, and object-oriented integration models.

Some specific modelling examples:

- *Organizational integration*: e.g. to evaluate the impact of integration on organizational models (Sproull and Kiesler, 1991).
- *Database integration*: e.g. by federated databases with loose coupling and database



a) The Parallel Random Access Memory model of parallel computation (Quinn, 1994). The PIE Simulator applies the Pi's to parallel workers.



b) Block diagram of an nCUBE 2 multicomputer, for communication-based simulation of concurrent work.

Figure 2. Parallel Computing Models of Engineering Tasks Integration.

schema integration models (Sheth and Larson, 1990).

- *Semantic integration*: Here, the focus is on semantic models for unifying and agreeing on terms, and resolving semantic conflicts (Sciore et al, 1993).
- *Task integration*: e.g. integration and collaboration models for multiple machines and FMS based on game theory and decision models (Nof, 1992); distributed hypothesis testing models for decision task integration (Papastavrou and Nof, 1992); computer mediation models for decision integration by large, distributed, loose teams (Sudweek and Rafaeli, 1994).
- *Computer integrated engineering*: e.g. software design tool integration in a simulation/emulation workstation (Nof, 1994); parallel simulation and parallel computing models of engineering task integration (Nof and Fortes, 1994); (see Figure 2).
- *Computer integrated manufacturing*: e.g. use of neural networks and object-oriented models to integrate horizontal and vertical information flows in distributed manufacturing organizations (Eberts and Nof, 1993).
- *Enterprise integration*: e.g. information models are used to design integration of information flows for functional integration throughout the whole enterprise (Petrie, 1992).

Measures and limits of integration and collaboration

An essential objective of the above models is to provide measures or metrics of integration and collaboration and identify their theoretical limits. Examples of some initial efforts in this area include the MRC, multi-robot co-operation measures, and CCC, Collaborative Coordination Control performance measures (Nof, 1992).

Current and future work on the PIE (Parallel Integrated Engineering) communication-driven simulator addresses the evaluation of alternative integration organizations by measuring speedup, number of errors, and quality of the integrated results (Nof, 1994).

4. Conclusions

The competitive benefits of integration and collaboration are significant: *Flexibility* by utilizing the right information and resources at the right time and place and responding correctly to change; *Reliability* by mutual backup, substitution, and recovery, by conflict resolution, and by look-ahead, predictive planning; *Quality* by responding correctly to evolving client needs, and by creative, synergistic solutions to new problems; *Quality of worker life* by well-managed, computer-supported teamwork.

We further observe that computer-based integration and collaboration can support the development of Asimov's Gaia (in Italian, happiness), an organism living by combining many collaborating individuals. But we also observe that integration and collaboration occur as a looping phenomenon of organizations, as follows:

$$\textbf{Conflict} \rightarrow \textbf{Negotiations} \rightarrow \rightarrow \textbf{Compromise} \rightarrow \textit{New}\ \textbf{Conflict...} \quad (2)$$

Hence, we face the following challenging issues:

- How many individual processors, databases, machines can/should be included?
- How much effort and time should be devoted for negotiations as part of the integration?
- How shall we negotiate and mediate?
- How good is the compromise, and how long will it last?
- How can information gaps and conflicts be minimized in number and in severity?

These issues and related interesting questions about integration and collaboration, as intelligent features of civilization, merit additional investigation.

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