Guest Editors' Introduction

Computer Support for Concurrent Engineering

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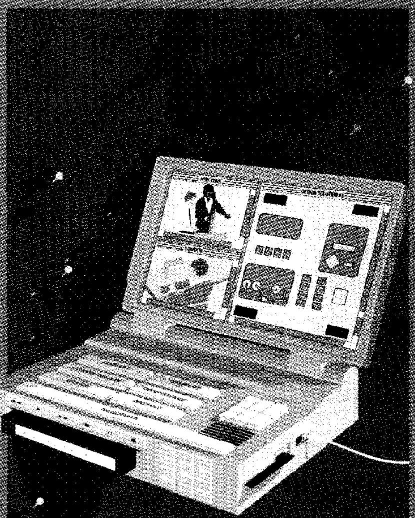

In all concurrent planning, effective collaboration among team members is the key to success, whether they are a group of physicians planning a medical procedure or a team of engineers designing a new VLSI chip. Numerous US government initiatives in Total Quality Management, Integrated Product Development, Concurrent Engineering, and the Virtual Enterprise, all emphasizing teamwork, demonstrate the acceptance of this idea.

Concurrent Engineering (CE)[1] is a systematic approach to integrated product development that emphasizes response to customer expectations and embodies team values of cooperation, trust, and sharing. Decision-making in CE proceeds with extended periods of parallel effort synchronized with comparatively brief exchanges between participants to produce consensus.

While teamwork has been acknowledged as an effective approach, its wide-scale adoption has been impeded by the rigid hierarchical structures of most organizations. There is also a dearth of tools for enabling real-time communication among team members working in a heterogeneous, geographically distributed environment.

To overcome the barriers of hierarchical structures, the notion of *tiger teams* has been proposed. These interdisciplinary human teams are physically collocated to enable concurrent product development. The concept was extended to *virtual tiger teams* by the DARPA (Defense Advanced Research Projects Agency) Initiative in Concurrent Engineering (DICE). A virtual (tiger) team consists of a geographically scattered team of experts who use a computer-supported environment to collaborate over a network, as shown in Figure 1.

Enabling technology

Advances in database and networking technology, groupware, multimedia, and graphical user interfaces, and a precipitous drop in the cost of computing, all point the way to creating a truly collaborative environment to transcend the barriers of distance, time, and heterogeneity in computer equipment. The ideal collaborative environment would enable any team member to spontaneously communicate (and thereby collaborate) with any other member (or group). Figure 2 shows a layered architecture of different types of computer technology that must come together to

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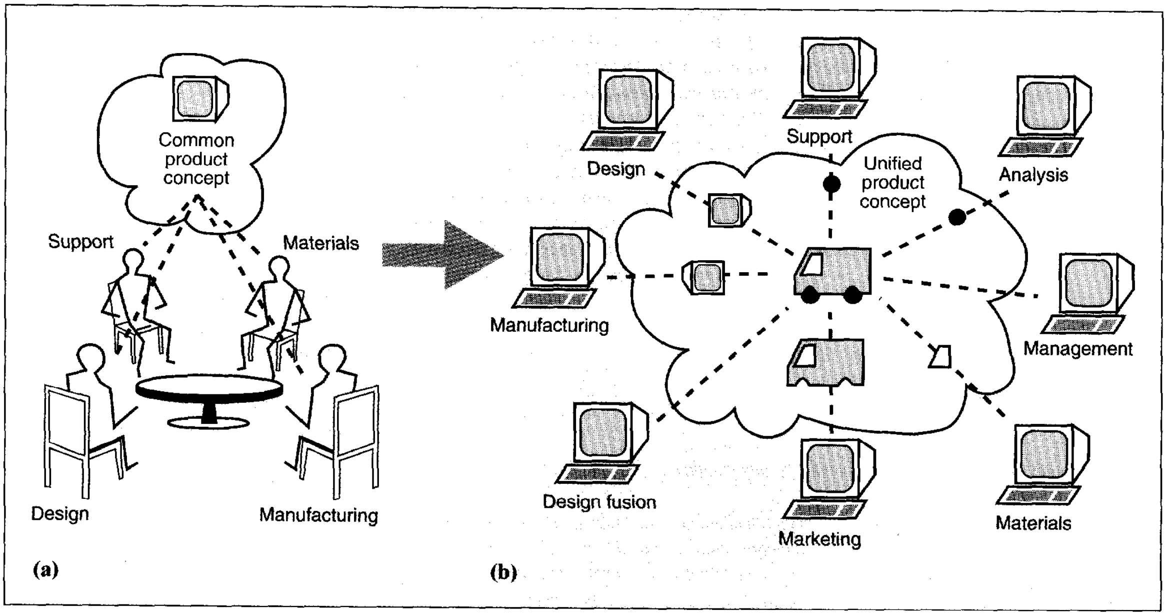

Figure 1. How a collocated human team using a computer network (a) translates into a virtual team collaboration (b).

provide such collaborative environments.

Activity layer. This layer represents the activities undertaken by CE teams. A team is involved in a continuous cycle of planning, implementing, monitoring, and improving the collection of activities vital to the success of a given project.[2]

Transaction layer. To understand how individuals work in an integrated computer-supported environment in large distributed organizations, consider the six fundamental activities performed by any member of the virtual team: *look-up*, *compute*, *communicate*, *negotiate*, *decide*, and *archive*. These simple transactions become powerful when performed in the context of a heterogeneous distributed environment (see sidebar on page 14).

Collaboration services layer. One can envision a variety of services to support fundamental CE transactions and the day-to-day activities of team members. These services can be categorized as those for collocation, coordination, information sharing, corporate history management, and integration.

Collocation. Lack of communication among geographically dispersed team members is a major obstacle to cooperative work. Effective communication between members can be facilitated by enabling them to share applications. Multimedia desktop conferencing using text, graphics, audio, and video is also needed.

Coordination. Coordination is critical for effective functioning of multidisciplinary product-development teams. These teams must influence each other so that a high-quality product is produced within a short turnaround. These services provide computer support for group decision-making and negotiating solutions over a geographically dispersed network. In particular, common visibility of activities and data, planning and scheduling of activities, notifying team members of changes, and managing constraints across multiple perspectives are some of the needs to be addressed by these services.

Information sharing. Information generated by an enterprise is stored in heterogeneous data formats and in

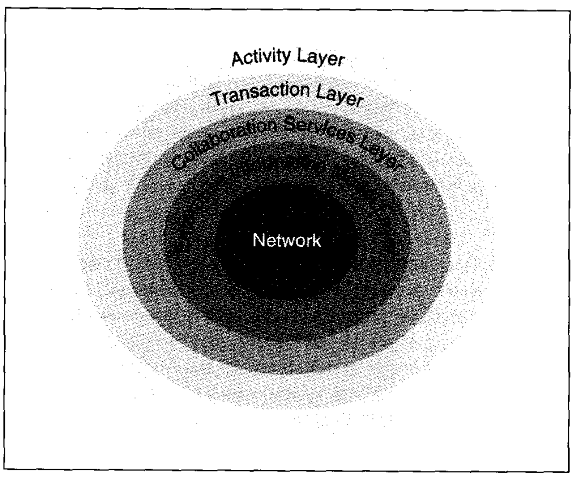

Figure 2. Layered architecture of technologies that enable a virtual team.

various legacy databases scattered across the organization. Information sharing involves developing common data representations and providing transparent access to information in a distributed heterogeneous system. Problems arising in the management of replicated data, version and concurrency control, and change management in distributed databases are important here.

Corporate history management. In a CE environment, it is desirable to electronically capture the design intent and evolution of a product from conceptual design to retirement. Corporate history is useful for designing future products and documenting existing ones. Indexing, linking, and storing various types of documents (design, manufacturing, specifications, etc.), and archiving decisions reached in meetings among designers are some of the problems that need to be addressed in this context.

Integration. This service is the glue that holds all other services together. It also facilitates access to engineering tools and services in a transparent manner across the enterprise. To achieve this end, integration services comprise a number of capabilities. They provide mechanisms to describe what services are available to users and in what form. They also provide mechanisms to exploit the communication infrastructure. Finally, these services provide "wrapper generator" tools that encapsulate existing tools and services for use over a network.

Enterprise information model layer. The services discussed above rely on the availability of enterprise information. Access to such information is facilitated by enterprise information models, which characterize the product an enterprise is building, the processes it adopts to make such products, and the resources available to the organization. Collocation services rely on knowing which computer facility is available to whom, that is, these services require a resource directory. Coordination services rely on a process model of how teams work and how organizations chart team activities. Information services that provide access to heterogeneous databases rely on a model that tracks information storage. Corporate history-management services need a model of the kinds of information that should be archived to facilitate reuse during product development. In addition to supporting collaboration services, organizations should develop models to understand how companies currently do business and how it can be improved. In fact, this particular need is leading to the development of a separate field.

Network layer. Computer networking is the foundation for implementing the virtual team environment. This kernel represents advances in communications technology and distributed computing. Examples include directory services, interprocess communication, and remote procedure calls.

CE transactions

Any member of a virtual team needs the following transactions:

Lookup: Information is scattered throughout an organization, stored in media ranging from file cabinets to knowledge bases. Team members need an *information server* that provides a *single point of inquiry* for information. Work in the area of integrating heterogeneous data and knowledge bases is proceeding in this direction.

Compute: The information gained by lookup or other means is subjected to computation to add value. The main obstacle for computation at will is the heterogeneous and distributed nature of the computing environment for software applications. A *distributed yellow pages* coupled with a tool that distributes the load among various computers would enable transparent computing, but it has not yet been implemented.

Communicate: Sharing information is the key to effective concurrent engineering. However, the low bandwidth of the current networks and the difficulty in integrating various media have limited effective real-time communication over a wide area. We believe that present initiatives such as the gigabit networks and various projects on multimedia conferencing systems will help achieve this goal.

Negotiate: Concurrent engineering is predicated on the ability of each virtual team member to negotiate with the group and reach consensus. This means that the evolving design must be visible globally and its ramifications to any member's interest must be highlighted. Blackboard technologies and research on constraint management are potential enablers in solving this problem.

Decide: During the course of product development, various decision-making tools will be required by different members of the team. However, most of the present decision-support tools are centered on a single perspective. Team members need advances in the area of group-decision support, design assessment, and quality function-deployment tools to assist in group decision-making.

Archive: The *intellectual enterprise* of a realized product should be captured and subsequently exploited during the redesign or development of related products. Considerable work is going on in conceptual structures for design rationale, efficient retrieval of corporate history, and the building of hypermedia-based *electronic notebooks* to substitute for the engineer's current paper-based notebook. We believe that synthesizing all these ideas will result in viable tools for corporate history capture.

The CEphone

One can visualize future support for concurrent engineering through a proposed artifact we call the CEphone. Such a device could combine the capabilities of a number of commonly used communication and computational devices into a single artifact. Just as one uses a phone to conduct day-to-day activities, the virtual team member would use a CE phone to carry out all collaborative transactions. This electronically networked artifact would combine the capabilities of an ordinary phone, a TV, a VCR, a videoconferencing facility, and a computer. In addition, the environment would be cognizant of the impact of evolving decisions and the overall goals of the project, alerting responsible team member(s) at appropriate times. Because the environment *sees* the activities of all team members, it would know more than any one member and thus could provide intelligent assistance to all members.

The CEphone would essentially support the CE transactions discussed earlier. Such a device will be the cornerstone for tomorrow's dynamic organizations and enable the development of *virtual enterprises*. These future enterprises will operate in a global marketplace, with participants collaborating dynamically to produce goods and services. ■

Additional information

The July 1991 issue of *IEEE Spectrum* featured the subject of concurrent engineering, providing a perspective not restricted to computer-enabling technologies.

The Standard for Exchange of Product Data (Step) effort and the Computer-Aided Acquisition and Logistics Support (CALS) program of the Department of Defense promote electronic exchange of product information.

The Open System Architecture for Computer-Integrated Manufacturing (CIM-OSA) is the focus of a project of European Strategic Programme for Research and Development in Information Technology (Esprit). CIM-OSA includes an integration infrastructure and an enterprise model, thus enabling CE.

An annual conference on CE and CALS takes place in June in Washington, D.C. The first ACM International Conference on Multimedia will be held in Anaheim, California, in August 1993. *Computer* covered related topics in 1991: multimedia information systems in October and heterogeneous distributed database systems in December. The Concurrent Engineering Research Center (CERC) at West Virginia University is organizing a second workshop on CE in April 1993 with IEEE Computer Society sponsorship.

Readers can obtain CE-related information through CERCNet (a toll-free dial-up bulletin board service) and the *Concurrent Engineering Research in Review* newsletter from CERC. To gain Internet access to CERCNet, connect to babcock.cerc.wvu.wvnet.edu (129.71.14.1) and log in to cercnet (lower case). For modem access, dial 1-800-331-3808 with settings 1200/2400 baud, 8, N, 1, and log in to cercnet (lower case).

Acknowledgments

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2. E. Deming, *Out of the Crisis*, MIT Center for Advanced Engineering Study, Cambridge, Mass., 1989, p. 88.

Y.V. Ramana Reddy is professor of computer science and director of the Concurrent Engineering Research Center (CERC) at West Virginia University. He pioneered the development of knowledge-based simulation,

Conferences on concurrent engineering

ACM Multimedia 1993, First ACM International Conference on Multimedia, August 1-6, 1993, Anaheim, Calif.

CE and CALS Washington 1993, Conference and Exposition, June 28-July 1, 1993, Washington, DC.

Groupware 93, August 9-13, 1993, San Jose, Calif.

NGITS 93, International Workshop on Next-Generation Information Technologies and Systems, June 28-30, 1993, Haifa, Israel.

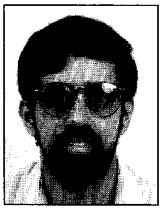
Second IEEE Workshop on Enabling Technologies Infrastructure for Collaborative Enterprises (WET ICE), April 20-22, 1993, Morgantown, W.Va.

Seventh Annual Engineering Database Symposium on "Engineering Data Management: Key to Success in a Global Market," August 9-11 at **13th Annual ASME International Computers in Engineering Conference,** August 9-11, 1993, San Diego, Calif.

For additional information, see the Calendar section of this issue.

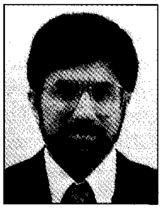
which combines knowledge representation and inference mechanisms with traditional simulation techniques. He has also worked on integration frameworks for collaborative environments (including the DICE architecture).

Reddy received BS and MS degrees in mechanical and production engineering from S. V. University and the Indian Institute of Technology, Kharagpur. He received the PhD from West Virginia University in the area of simulation of discrete systems.



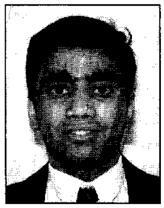
Kanakanahalli Srinivas is an assistant professor of computer science at West Virginia University and leads the multimedia conferencing effort at the Concurrent Engineering Research Center (CERC). His research interests are in multimedia conferencing, connectionist networks, and parallel processing.

Srinivas obtained the BSEE in electrical engineering from Bangalore University, India, the MSEE from the Indian Institute of Technology, Kanpur, and the PhD in computer science from New Mexico State University. He has authored or coauthored approximately 25 refereed papers in conference proceedings, journals, and books. Srinivas was awarded the Centennial Young Researcher Award from New Mexico State University and was an invited participant in the NSF Summer School on Parallel Processing.



V. Jagannathan is a senior member of technical staff at the Concurrent Engineering Research Center (CERC), where he directs research at the Enterprise Information Laboratory. Before joining CERC, he was the project manager for work done as part of the DARPA Initiative on Concurrent Engineering at Cimflex Teknowledge in Pittsburgh. He edited a book on blackboard systems through Academic Press and has published over 40 refereed papers in conference proceedings, journals, and books.

Jagannathan obtained the PhD in electrical engineering from Vanderbilt University in 1981. He is a member of IEEE, ACM, and AAAI.



Raghu Karinthi is an assistant professor in the Department of Statistics and Computer Science and the Concurrent Engineering Research Center (CERC) at West Virginia University. At CERC, he is involved in a project on enterprise integration. His current research interests include solid modeling, process planning, multimedia information systems, and concurrent engineering. He has written over 20 papers in concurrent engineering and related areas.

Karinthi received the BS degree in electrical engineering in 1984 from the Indian Institute of Technology, Madras, India. He received MS and PhD degrees in computer science from the University of Maryland at College Park in 1988 and 1990, respectively.

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