Distributed data base technology—An interim report of the CODASYL systems committee

by The CODASYL Systems Committee

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INTRODUCTION

The purpose of this paper is to present to the computing community an interim report (as of January 1978) on the work of the CODASYL Systems Committee in analyzing the relationship between database technology and distributed processing. This paper discusses the following topics:

- The motivations for incorporating one or more data bases into a distributed processing environment.
- The current objectives of the Committee’s work.
- The network-oriented and database-oriented components, and their relationships.
- The design choices available to the architect of a distributed database environment.
- The technical and administrative issues which arise in such environments.

The Committee hopes that this paper will evoke thoughtful comments from its readers. These will greatly aid the Committee in the preparation of its final report. Comments should be directed to:

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PURPOSE/SCOPE OF COMMITTEE’S CURRENT WORK

In accordance with its charter, the CODASYL Systems Committee, in January of 1977, undertook a two-year task examining the implications of database technology in a distributed environment. The Committee is focusing its attention primarily on the impact of extending database management techniques to distributed processing environments.

The scope of this effort is the establishment of a framework for examining these issues, and the formation of baseline concepts and guidelines which will support the continuing development of distributed database management technology. The results of this work will be published at the end of this two-year effort as a Systems Committee Technical Report.

MOTIVATIONS FOR THE DISTRIBUTED DATABASE ENVIRONMENT

In today’s evolving data processing technology, a number of factors have generated a trend from centralization toward distribution of data processing functions. Of major importance to the end user is faster, easier access to the data needed for decision making, a need essentially unchanged from earlier, more centralized environments. A further concern of the end user is reliability and security. These user motivations, coupled with the increasing geographic dispersion of the end users within an organization, are generating pressures on data processing and corporate management to distribute data processing and storage capabilities to the location of data origin and/or use. The major benefits derived by distributing these functions focus on increased data availability to the end user and reduced exposure to total system failure due to hardware/software failure.

Historically, the application of computer technology to the information processing needs of an organization have
tended toward the centralization of data processing and storage facilities. Motivations for such centralization of data processing functions have focused on the following:

- **Economies of Scale**—the cost of processing and storage facilities sufficient to handle the local processing requirements of the end user generally exceeded the combined cost of large, centralized computer facilities and a communications facility to provide user access to the central facility.
- **Control**—security, data integrity, and standards administration in a centralized environment generally were less complex than in a decentralized environment.
- **Availability of Data to the Corporate Level**—Although not fully satisfying the needs of the distributed end user, the centralized environment provided easier generation of and access to summary data.

Today, organizations have grown in size and complexity, the users have become more sophisticated in their information needs, and the geographic locations of the origin and use of data have become increasingly dispersed. As a result, the strategy of centralizing the EDP function may run contrary to the objective of availability of data to the end user. Further, a number of technological factors encourage the distribution of data processing and storage facilities.

These factors include:

- **Lower Cost of Processing and Storage Facilities**—recent advances in computer technology and a rapid decrease in hardware cost have reduced or eliminated the cost advantages experienced through centralization.
- **Cost of Communications**—relative to the price/performance gains achieved in computer hardware, communications cost, in terms of price/performance, have remained fairly stable, further motivating decentralization of data processing and storage facilities in order to minimize communications traffic and associated costs.
- **Improvements in Communications Hardware and Software Technology**—though not as dramatic as witnessed in computer hardware and software technology, certain developments in communications technology are motivating factors in the trend toward distributing the data processing function. For example, the needs for control a motivating factor for centralization, can now be accommodated with facilities to "down load" control, software, standard application software, or special procedures to the local processing nodes from a central or controlling node. Additionally, communications technology today readily accommodates the need to access one or more nodes in a distributed environment from a central or controlling node in order to gather summary data.

In summary, technological and price/performance developments in recent years are tending toward distribution of data processing and storage facilities to the geographic location of the origin and/or end use of data. From the perspective of end users, distribution of the data processing function accommodates the need for accessibility to data critical to their decision making responsibilities. This is likely to represent a major motivating factor on the part of management. Further, a move to a distributed database environment may realize real hardware/software cost savings to organizations. Such savings may represent an additional, or perhaps the only, motivating factor.

The CODASYL Systems Committee, recognizing the above factors and concerned with the prevailing perception that database technology is applicable and consistent only with the philosophy of centralization, has undertaken a study of the implications of database technology in a distributed processing environment.

**WHAT IS A DISTRIBUTED DATABASE ENVIRONMENT**

Considerable attention has been given recently to computer networks and to database technology, but little to the application of database technology in a network environment. The traditional single-site orientation of DBMS and databases must be extended to operate in the context of a network of computer facilities. To provide a basis for discussion and investigation, the committee first laid a careful foundation of terminology. The following paragraphs define network and database related aspects of a distributed processing environment.

The network provides the underlying configuration of computer systems and communication facilities within which data is stored, DBMS's operate, and users access data. A node in the network consists of computer processing facilities (ranging from a large multiprocessor computer to an intelligent terminal) and an associated operating system sufficient for executing user and DBMS processes (programs, queries, etc.). In addition, data and its definition may be stored at a node. The precise structure of a node is an architectural design choice independent of the manner in which the node is connected to other nodes and the extent of geographical separation.

A communications facility is the collection of processes and physical facilities which interconnect the nodes. The communications facility includes knowledge of the physical location of each node, the physical path connections between the nodes, and the protocols to be used in sending messages between nodes. Processes in the communications facility will accept a message from one node and deliver it to another node or broadcast it to some or all other nodes. Two nodes may be connected directly or indirectly through other nodes. A network access process (NAP) exists at every node as the interface between processes at the node and the communications facility. The NAP is that portion of the communications facility which executes on the processing facilities of a node.

A traditional single-site database environment (See Figure 1) consists of a database, a DBMS, a database definition ("schema"), and a user schema. Placing these data-related

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* User schema broadly refers to the user's view of the database. CODASYL has called this a "subschema", but, in general, the only requirement is that a mapping exist between the user schema and the "schema." It is not strictly a subset of the schema.
Process
Data, System Information (userschema need not physically exist)
direct transfer of data/language statements/control
additional transfers (of less interest to us)
relationship

Figure 1—Conventional single-site database environment
components at the nodes in a network environment produces a distributed database environment. The primary architectural design choices relate to the distribution of databases, and the distribution of DBMS functions. All the databases may be stored at one central location (the traditional single site), they may be stored at different nodes, a given database may be broken down into pieces ("partitioned") with the pieces stored at different nodes, or finally, multiple copies of a database or its pieces may be stored at multiple nodes ("replicated"). Whenever a database (or part thereof) is stored, there also must exist appropriate data definition and DBMS capabilities to access and process the data. When the user request and the target database exist at different nodes, DBMS functions can also be distributed and performed at multiple nodes.

The integration of database technology and a network environment leads to new problems and the need for new functions. Perhaps the most important need is for some network-wide intelligence concerning the node location of all the databases in the system, their partitions and their replications. The network data directory serves this function.

When the system receives a user request to access data, a new DBMS function must first determine what data must be accessed and the node or nodes on which it resides. Then it must communicate with another DBMS. Increased heterogeneity within the distributed database environment, i.e., multiple different DBMS's, necessitate a translation of the request. Data conversion may also be necessary if the data is stored in different forms, according to different data structure models or on different hardware/storage devices. These are some of the key technical problems to be addressed by the data processing community in the coming years.

DESIGN ALTERNATIVES

Three levels of perspective

The Committee recognizes three distinct, but nevertheless interdependent, perspectives in providing design alternatives for a distributed database environment.

- Each component of the environment and the interrelationship of components. (See Figure 2)
- The study, in static state, of a node in the distributed environment including its various alternatives for configuration. (See Figure 3)
- The specification of user interaction in a distributed environment, emphasizing the sequence of events and the execution of functions, creating a dynamic model of the environment.

Components and interrelationships

There are five major components within a node of a distributed database environment as illustrated in Figure 2. Non-distributed databases have three of these—the database, the DBMS, and the user process. A distributed database environment requires two additional components—a network DBMS and a NAP. Figure 2 shows three types of nodes:

- A "complete" node with all five basic components.
- A "user" node with only a user process accessing data in the network.
- A "data" node with only those components necessary for data to be made available throughout the network.

Figure 3 provides a more detailed picture of "complete" node. To convert a conventional database environment (See Figure 1) to a distributed database environment requires the addition of the following components:

- Network DBMS
- Network Data Directory
- NAP (described above)

With a centralized database, which is the case in a single-site data processing environment, all the intelligence relating to the database is in one place. A conventional data definition can provide all the information needed for a DBMS to locate and process the stored data. As soon as data becomes distributed—single, whole databases at different nodes, partitioned databases, or replicated databases—there must exist some information within the system which indicates where the different databases, their partitions, and their replications are stored. This is the primary role of the network data directory.

Network data directory

The network data directory contains information indicating the nodes at which the various units of data reside within the distributed processing environment. For example, given a file name, the network data directory provides the node or an indirect reference to the node(s) at which the file resides. It does not contain information about the physical location of nodes or the routing between nodes; this information is part of the communications facility.

Network database management system

If we assume that a DBMS only includes those functions which relate to a local database and that it has no cognizance of any other data nodes (i.e., a conventional, single-site DBMS), then all other new functions needed in a distributed environment can be packaged in a new system called the Network Database Management System (NDBMS). In the development of a distributed processing environment, it may be desirable to integrate the NDBMS functions with the DBMS, with the NAP, or leave as a separate package. We will be more concerned with the nature of the function and its information inputs, than with any particular packaging approach.
Figure 2—Data and users in a distributed database environment
Process
Data, System Information (userschema need not physically exist)
direct transfer of data/language statements/control
additional transfers (of less interest to us)
relationship

Figure 3—A "complete" node in a distributed database environment
The network DBMS includes at least the following functions:

- Intercept a user request and determine where to send it for processing, or what nodes must be accessed to satisfy the request.
- Access the network directory or at least know how to request and use the information in it.
- Coordinate the processing and response to a user request if it spans nodes, that is, the target data exists at multiple nodes.
- Function as the communication interface between the user process, the local DBMS, and DBMS's at other nodes (via the NAP).
- Provide data and process translation support in a heterogeneous distributed database environment.

Design choices and distribution alternatives

The specification of design choices and distribution alternatives for various distributed database architectures requires a model that will facilitate the study of database related distribution alternatives. If a major component does not exist as a single copy at a single node, then there are multiple alternative design choices as to its distribution to nodes.

- **Replication Versus Partitioning of Components**—the replications of a distributed component (or any piece of a component) are functionally identical copies of the component. Replication introduces the issue of update synchronization.
  
  The partitions of a distributed component are different and non-overlapping. Under partitioning, the whole of a component consists of multiple pieces which the system must be able to associate. The system must know the relationships among the pieces and be able to manage the whole component and its pieces.

- **Homogeneous Versus Heterogeneous Implementation**—a central issue relative to the replicated and partitioned distribution alternatives regards the relative degree of homogeneity/heterogeneity of the supportive components (namely the DBMS, schema, non-schema and system information) across nodes. If the corresponding supportive components at each node are different (heterogeneous) then the complexity and technological difficulty implementing the system increases. If all components are the same (homogeneous) then it is easier to implement and operate the environment.

These simple rules are complicated by observations of existing distributed environments.

- Hybrid distribution alternatives are possible as are time variant ones.
- Not all distribution alternatives are relevant to realistic systems.
- Not all combinations of component distributions are internally consistent or useful.
- Complex interdependencies exist.

**TECHNOLOGICAL AND ADMINISTRATIVE ISSUES**

Benefits from the distribution of data and its management are not without cost. Benefits resulting from the dispersal of data processing and DBMS capabilities must be balanced against the new technological and administrative problems which result in costs. The solution of these problems will demand a significant cost commitment in terms of additional hardware, software and communications facilities. Similarly, distribution will impact at the administrative level. Data control is complicated since the distributed environment and administrative control must be more highly coordinated. For the purposes of its report, the Committee distinguishes between technological and administrative implications.

The Committee has thus far in its deliberations identified a number of issues which sharply focus the technological implications of distribution. Each of these is briefly described.

**Initial implementation problem**

The first step in planning for a distributed environment involves careful engineering of the transition from existing operations to the new. Managing the conflicts of heterogeneity creates a significant problem. Often disparate database management systems may be in use, different processing hardware may be installed, and user languages may be incompatible. Conversion from the existing environment to a distributed environment is a technological issue.
Access control

A centralized DBMS facilitates the implementation of security restrictions. Through security mechanisms, protection is afforded against unauthorized, deliberate or inadvertent access to data in the system. One important mechanism used to achieve this goal is access control. In a distributed environment, access control is more difficult to implement because of the necessity of deciding where to locate the control mechanism. The vulnerability of dispersed data may be a real issue. In the extreme, it may be necessary to locate access control with each distributed component, a costly decision. On the other hand, centralizing access control may unduly burden the system with performance inefficiencies. However, if highly sensitive data is localized to specific nodes, higher assurances of strongest access control can be made.

Concurrency

A DBMS must include provisions for the control of concurrent multiple updates to a single record occurrence. In a distributed environment, the record occurrence itself may be partitioned across nodes. The control of concurrency can then become a more complex issue.

Synchronization

A DBMS takes into consideration the management of known redundancies such that a single update affecting multiple copies of the same record occurrence are effected in a manner transparent to the user and such that the database is always at the required level of consistency. The geographic dispersion of replicated copies makes this task more difficult.

Translation problems

In a distributed environment the number of conflicting logical views increases with the amount of heterogeneity in the network. The ability to effect the translation of data, processes, programs, user requests, and procedures from one node to another is a basic requirement of a distributed environment. The ability to implement transparent translation mechanisms presents a technological challenge.

Continuity of operation

An integral part of a DBMS’s objective is the ability to operate continuously. This entails specific provisions for the recovery of data and the restart of operations. In a distributed environment this task becomes more difficult when applied to partitioned distribution, and when considered in conjunction with the synchronization issue.

Performance issues

The ultimate goal is to provide information services to the user. Success is measured, in part, in terms of delivery of timely results. The underlying rationale of distribution is availability of data. If the implemented system cannot perform efficiently enough to meet response requirements, the service goals are not met and the system fails. When distribution of components is achieved, there is a risk that the communications overhead incurred in the interest of system integration and control will degrade performance sufficiently to cause the user to question the responsiveness of the system as a whole. The balance between distribution and control will thus be a key performance issue.

Administrative issues

The design, implementation and operation of a distributed environment will be impacted by a number of administrative issues. The fact that these issues cannot be resolved at a technical level make them all the more important and deserving of attention.

Constraints on data flow

The distributed environment introduces the potential for increased amounts of data storage and flow at and across geographically dispersed locations. The assumption that data can be moved subject only to economic considerations is no longer valid. Constraints on the storage and flow of data may be expected from a number of sources, such as:

- Legal—governments will legislate constraints on data flow in the form of tariffs and regulatory law.
- Privacy—privacy requirements and restrictions will have an effect on the storage and flow of data.
- International Law—the flow of data across international boundaries is just beginning to be examined. Responsibility for control, authorization, nature of transmission, rights to impose legal restrictions, traffic constraints, etc., remain to be established.

Coordination and control of data

The administration of data resources is recognized as an important prerequisite for successful implementation of shared use of data. Distribution of data complicates this issue. The development and enforcement of standard practices is more difficult with dispersion, the coordination of common data descriptions is a problem when users are geographically dispersed, and the resolution of conflicting data needs becomes more tedious and time-consuming with distribution.

Organizational issues in administration of data

The emergence of an organizational entity (Data Administration) to address the foregoing issues has provided users with an administrative mechanism to deal with the problem.
In a centralized database implementation, the data administration function has often been organized to be controlled by a senior level data processing officer. In a distributed environment, however, data administration may be potentially exercised at each node in the network. Issues of organizational placement, interaction and coordination must be carefully scrutinized.

User acceptance

The distributed environment must, in the final analysis, serve the user. There are a number of phenomena which may cause concern in this regard.

- Resistance to change.
- Conversion from existing user procedures.
- Potential risk of complexity.
- Organizational realignment.

In a distributed environment each user at every node must find it attractive to participate or the system will fail.

CONCLUSION

The impact of "distributed processing" is already manifested in many sectors of the EDP community. The impact on database technology is significant; the subject of current deliberations of the CODASYL Systems Committee is forging a framework for dealing with these new architectural concepts and is establishing a basis for dealing with the topic on common ground and with clear understanding of the issues and considerations.

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