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SPECIAL ISSUE ON DATABASE CONNECTIVITY

Data Engineering Bulletin is a quarterly publication of the IEEE Computer Society Technical Committee on Data Engineering . Its scope of interest includes: data structures and models, access strategies, access control techniques, database architecture, database machines, intelligent front ends, mass storage for very large databases, distributed database systems and techniques, database software design and implementation, database utilities, database security and related areas.

Contribution to the Bulletin is hereby solicited. News items, letters, technical papers, book reviews, meeting previews, summaries, case studies, etc., should be sent to the Editor. All letters to the Editor will be considered for publication unless accompanied by a request to the contrary. Technical papers are unrefereed.

Opinions expressed in contributions are those of the individual author rather than the official position of the TC on Data Engineering, the IEEE Computer Society, or organizations with which the author may be affiliated.

Membership in the Data Engineering Technical Committee is open to individuals who demonstrate willingness to actively participate in the various activities of the TC. A member of the IEEE Computer Society may join the TC as a full member. A non-member of the Computer Society may join as a participating member, with approval from at least one officer of the TC. Both full members and participating members of the TC are entitled to receive the quarterly bulletin of the TC free of charge, until further notice.

Letter from the Editor-In-Chief

I would like to announce changes to the editorial board effective June 1990. Dina Bitton, Michael Carey, Roger King, and Sunil Sarin have completed their two year terms as Associate Editors, and Rakesh Agrawal, Ahmed Elmargarmid, and Yannis Ioannidis have agreed to take their places on the editorial board. On behalf of the TC, I thank the outgoing Associate Editors for the fine jobs they did, and welcome the new Associate Editors.

Meral Ozsoyoglu is organizing the September '90 issue in cooperation with Zbigniew Michalewicz. The issue will feature selected papers from the 5th International Conference on Statistical and Scientific Database Management which was held in April in Charlotte, Noth Carolina. I will edit the December issue, which will be a special issue with ACM SIGMOD RRECORD on Directions for R&D Databases.

Won Kim
June 1990
Austin, TX

Letter from the TC Chair

This will be my last message to you as Chair of our TC on Data Engineering. I am happy to announce that the new Chair is Professor John V. Carlis of the University of Minnesota. Dr. Carlis has been active in our TC, having served as Program Chair and then General Chair of the Data Engineering Conferences. John and his group at Minnesota are doing some pioneering research in the relationships between knowledge and data engineering. Welcome aboard John!

We have seen several changes to the TC over the last couple of years. First, we initiated a dues policy in an effort to lead the Technical Activities Board — the governing body for the Technical Committees — toward a cost-center concept in which each TC is responsible for its budget. The dues are supposed to partially offset the costs incurred by the TC. In our case the major expenses are the publication of the excellent *Data Engineering Bulletin* and the sponsorship of the International Conference on Data Engineering. The *Data Engineering Bulletin* has an excellent reputation within the community. It has been ably guided by Dr. Won Kim.

There are several news items associated with the Data Engineering Conference. Next year, for the first time, the conference will leave the United States and travel to Kobe, Japan. Thereafter, it will be hosted in the US one year and outside the US the next, in a two year cycle. We are seeing the Data Engineering Conference become truly *international*. I hope our readership will continue to support the conference by writing papers, reviewing papers, and attending the conference. In conjunction with the Data Engineering Conference in Kobe, there will be an International Workshop on Interoperability in Multidatabase Systems, to be held April 8-9, 1991 in historic Kyoto, Japan.

Another important event has been the publication of the new *IEEE Transactions on Knowledge and Data Engineering*, under the expert guidance of Professors C.V. Ramamoorthy of UC-Berkeley and Benjamin Wah of the University of Illinois.

It has been a pleasure to have been able to work with you and to have served as TC Chair.

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Letter from the Issue Editor: From Theory to Practice in Heterogeneous DBMS Access

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This issue is an experiment, bringing together papers from both research and unabashedly commercial perspectives. This combination is particularly appropriate in the area of heterogeneous database access, which has been a lively and interesting research area over the past ten years, but which is now turning into a commercial reality, driven by the rapidly increasing connectivity of computer systems.

To a database user, the potential payoff is great in accessing and integrating diverse corporate, organizational, and workgroup data sources, and in broadening the "field of vision" to include related but separately-developed databases. To both researchers and commercial developers, the challenge has been equally great. Heterogeneous database systems are not just on different hardware and software platforms; they differ in connection protocols, data models, query languages, processing capabilities, and transaction models. Databases built on these systems have meta-data conflicts, where similar information is structured and defined differently, and data conflicts, where units and data values disagree. It is often non-trivial even to match up corresponding records on different systems.

The juxtaposition of research and commercial viewpoints in this issue is also an interesting reminder of some of their fundamental differences. I have learned though occasionally painful experience of the difficulties of moving from theory to practice, from research prototypes to viable commercial systems. Often it is a case of *depth* versus *breadth.*

Researchers tend to concentrate on one particular aspect of a problem, while making a number of simplifying assumptions about issues they see as tangential. The results can be valuable insights, representations, algorithms, heuristics, approaches, or proofs of concept. But they can also be idiosyncratic, isolated, or incompatible with related results, and consequently of sharply limited practical utility.

Commercial developers, on the other hand, are faced with multiple target platforms, a gallimaufry of standards, the need for compatibility with previous decisions, and the goal of hiding complexity from the user. Their concerns must be broader almost by definition, with at least some thought given to every issue. The

results can be intuitive and easy-to-use products that greatly increase productivity and solve real problems in an innovative fashion. However, products can also be non-rigorous or complex, with inconsistent user interfaces, narrow applicability, and feature sets driven more by deadlines and competitive checklists than by technical considerations.

Have I offended everyone by now? I hope not, for what the best efforts of researchers and commercial developers have in common is a combination of penetrating insights, simple yet elegant design, consistency and coherence, and solid engineering.

This issue comprises eight papers, four from each camp. Dennis McLeod leads off the Research System section with a paper on the INTERBASE project at USC, covering the spectrum of heterogeneity, its accomodation in a federated system, and heuristic support for information sharing. Stuart Madnick, Michael Siegal, and Y. Richard Wang describe research on database instance matching, value interpretation and coercion, semantic reconciliation, and tagging of data sources, in the context of the CISL project at the Sloan School of MIT. The paper by Bipin Desai of UNC-Charlotte and Richard Pollock of Concordia University gives a general reference schema architecture, an associated mapping language, and approaches to database integration and query processing in their MDAS prototype. Finally, Alfonso Cardenas of UCLA covers pictorial database management, graph database modeling, and visual queries, for heterogeneous and multi-media databases.

The Commercial System section starts with an overview paper by Amar Gupta and Stuart Madnick of MIT's Sloan School comparing the data models, languages, and processing strategies used by eight commercial systems to integrate heterogeneous information systems. Wayne Duquaine of Sybase, Inc. describes the use of a general purpose client/server interface to provide mainframe database access (e.g., DB/2 under CICS) from workstations, via an extended RPC mechanism. Dave Simonson and Dave Benningfield of Ingres Corporation discuss the Ingres approach to Open SQL, network access, Gateways to diverse DBMSs, and distributed queries and transactions. Lastly, Peter Harris and I cover the DataLens specification, a capability-based interface that permits Lotus applications such as 1-2-3/3 to access and manipulate data sources ranging from relational servers to flat files and CD-ROM databases.

I would like to express my thanks to all of the authors who contributed to this special issue. They worked under time pressure to produce clear and concise descriptions of their systems and approaches.

David Reiner

David Reiner
June, 1990

INTERBASE: An Approach to Controlled Sharing among Autonomous, Heterogeneous Database Systems

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Abstract

The problem of accommodating the controlled sharing and exchange of information among a collection of distributed and/or heterogeneous data/knowledge bases has been examined over the years from a number of points of view, and is currently resurfacing as an emphasis in database research. This short paper describes several aspects of the INTERBASE project at USC, which focuses on an approach and experimental system for information sharing and coordination among autonomous, heterogeneous database systems.

1. Introduction

Consider an environment which consists of a collection of data/knowledge bases and their supporting systems, and in which it is desired to accommodate the controlled sharing and exchange of information among the collection. We shall refer to this as the (interconnected) autonomous heterogeneous database environment. Such environments are extremely common in various application domains, including office information systems, computer-integrated manufacturing systems (with computer-aided design as a subset), personal computing, business and financial computing, and scientific research information bases. The trend towards the decentralization of computing that has occurred over the past decade has accentuated the need for effective principles, techniques, and mechanisms to support the sharing and exchange among the component data/knowledge base systems in such an environment, while maximally retaining autonomy for the components.

Traditional research on "distributed databases" (see, e.g., [Ceri 84-1]), assumed a common, integrated database specification (conceptual database schema). While some of the research results obtained in this general area of endeavor are applicable in the autonomous heterogeneous database environment, such approaches generally assume a single conceptual database which is physically distributed. Work on "multi-databases", "superviews", and "virtual databases" has stressed the need to provide a unified, perhaps partial, global view of a collection of existing databases [Dayal 84-1, Litwin 86-1, Motro 81-1]. Techniques for database integration [Batini 86-1], which are often primarily considered for the design of a single database system based upon a number of application subsystems, have application to the problem of partially integrating existing heterogeneous databases as well. Notably, techniques for multi-databases and database integration all focus on conceptual schema level diversity. "Federated database" architectural issues and techniques for information sharing at the conceptual schema

level have also been specifically addressed in the interconnected, autonomous database environment [Heimbigner 85-1, Lyngbaek 84-1].

In this short paper, we briefly examine the INTERBASE project at USC. A major focus of this project is to devise and experimentally implement techniques and mechanisms to support the controlled sharing of information among a collection of autonomous, heterogeneous database systems. We shall not endeavor here to examine the thrusts of this research project in detail, but rather briefly examine two of its principal distinguishing aspects. First, the INTERBASE approach adopts a more general view of inter-operability among autonomous database systems than previously supported. In particular, we examine information sharing and coordination beyond the conceptual schema level; we note that sharing may be at a number of levels of abstraction and granularity, ranging from specific information units (data objects), to meta-data (structural schema specifications and semantic integrity constraints), to behavior (operations), to database model and supporting system (DBMS). Second, we propose a specific architecture (or, more precisely, a class of architectures) which directly address the need to support the dynamics of inter-database sharing patterns, and explore the notion of an "intelligent" advisor to assist non-expert database system users in establishing and refining sharing with external database systems.

2. The Spectrum of Heterogeneity

As a basis for our analysis of and approach to the various kinds of diversity which may exist in the interconnected autonomous database environment, consider a *federation* of *components*, which are individual data/knowledge base systems. A component includes both structural and behavioral information. Structural information involves the representation of information units (viz., objects) and their inter-relationships, at various levels of abstraction; included are both specific data facts and higher-level meta-data specifications. Behavioral information includes operations to manipulate information units and their inter-relationships, which can be either invoked by users or by the system itself; also included are services that a component may provide to itself or other components in the federation.

In this context, we can consider a spectrum of heterogeneity. That is, the heterogeneity in the federation may be at various levels of abstraction:

Meta-data language / Conceptual database model:
The components may use different collections of and techniques for combining the structures, constraints, and operations used to describe data.

Meta-data specification / Conceptual schema:
While the components share a common meta-data language (conceptual database model), they may have independent specifications of their data (varied conceptual schemas).

Object comparability / Database:
The components may agree upon a conceptual schema, or more generally, agree upon common subparts of their schemas; however, there may be differences in which information objects are represented, how they are identified, etc. This variety of heterogeneity relates to the interpretation of atomic data values as denotations of information modeled in a database (naming).

Low-level data form / Data format:
While the components agree at the model, schema, and object comparability levels, they may utilize different low-level representation techniques for atomic data values (e.g., "units of measure").

Tool / DBMS:
The components may utilize different tools to manage and provide an interface to their data. This kind of heterogeneity may exist with or without the varieties described immediately above.

3. Accommodating Heterogeneity in a Federation

One approach to accommodating heterogeneity in a federation is to deal with it on a component pairwise basis. This of course requires n^2 inter-component translators for a federation with n components. A second approach is to provide some common "language" which allows the components to communicate and share information and services. Both of these approaches have been explored to an extent, as noted above. In INTERBASE, we specifically attempt to provide a common inter-component communication and sharing model. This model, termed the *kernel object database model (KODM)* addresses the middle three levels of heterogeneity above (viz., meta-data, object, and low-level data form diversity).

Figure 1 illustrates the top level architecture of INTERBASE. Here, a number of component database systems (DBSs) share information via a sharing mechanism that supports KODM. Each DBS may be based upon KODM, or may support another model via a tailored translator. Note that this provides a means to handle database system heterogeneity (the fifth kind of semantic diversity above), but that this approach of course provides no specific support for it. An interesting special case is the one in which each DBS support KODM as a kernel, with some higher level model built on top of it. In this case, the heterogeneity supported involves the meta-data and object levels.

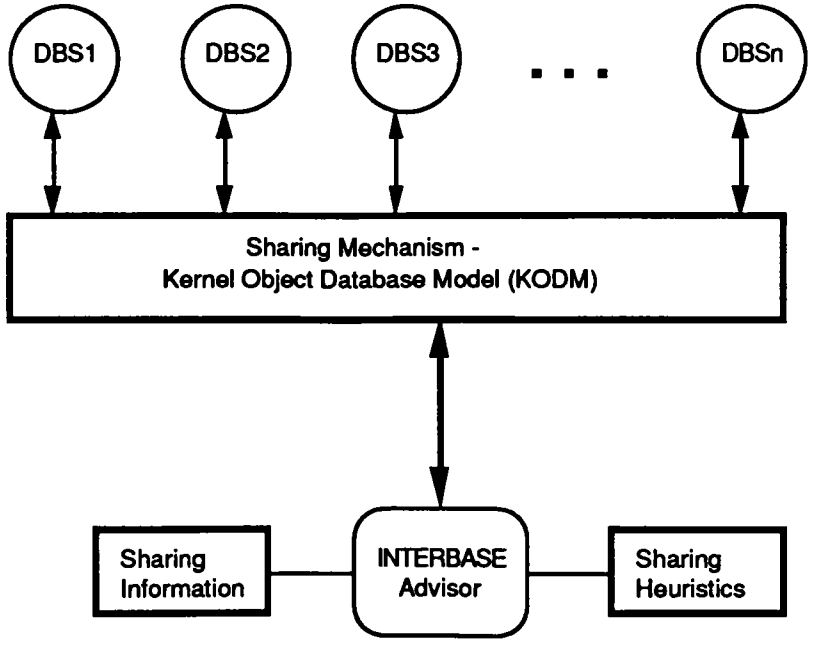

Figure 1. The Architecture of INTERBASE

The kernel object data model is a subset of the *3 dimensional information space (3DIS)* [Afsarmanesh 89-1], which includes prominent features from semantic and object-oriented database models. The principal features of KODM are as follows:

> Objects at various levels of abstraction and granularity are accommodated, including atomic data values, abstract objects, objects from various media, types (classifications of objects), etc.
>
> Inter-object relationships are supported, which represent associations among all varieties of objects, including meta-objects (such as object types).
>
> A pre-defined set of abstractions is provided, including subtyping (specialization) and inheritance of relationships. The set of abstractions is extensible, allowing new ones to be defined.
>
> Constraints (semantic integrity rules) are allowed. Again, a pre-defined set is provided, which is extensible.
>
> Operations which support the behavioral manipulation of objects and represent "services" can be defined.

4. The INTERBASE Sharing Mechanism and Advisor

We can observe that the top level architecture specified in figure 1 clearly offers the flexibility to accommodate a number of detailed architectural and implementation alternatives. In particular, each component DBS may see its local database plus **n-1** remote databases, or it may see a single unified remote database. Further, we may choose to make the remote database(s) to be transparent to the component or not. There are of course many other such architectural and implementation issues that must be considered here. In the INTERBASE project, we are examining this class of architectures, studying the appropriateness and utility of the alternatives experimentally.

There is conceptually a single *INTERBASE advisor* (see figure 1), which serves as an "intelligent" aid to the users of component DBSs (see, e.g., [Malone 87-1]). This advisor collects information on various components, and dynamically supports the establishment of new sharing patterns. Associated with the advisor is a collection of information which describes the sharing patterns that have been established among the component DBSs; this is a data/knowledge base in its own right, and is represented using an extension of KODM. Also associated with the advisor is a collection of heuristics which are used to attempt to "intelligently" assist users in locating and establishing access to remote data. An analogy can be made between the existence of related but not necessarily identical information in several databases, and the evolution of the content of a single database with time. In consequence, our initial attempt at representing the inter-component sharing data/knowledge base draws upon techniques we have developed to support database evolution using cooperation between user and system utilizing a collection of simple learning heuristics [McLeod 89-1]. To support sharing at the meta-data, object, and data form levels, we note that the notion of equivalence of information, at some level of abstraction, is central. In particular, the sharing heuristics employ the concepts of *object relative equivalence* and *behavioral relative equivalence*.

The sharing advisor and its associated data/knowledge base can be centralized, or can be logically decentralized. In the latter case, each component has an advisor with an associated data/knowledge base tailored to it. Our initial experimental environment employs a logically centralized advisor. The alternative of a decentralized advisor has the advantage of providing additional autonomy for the component DBSs, and avoiding a potential problem of over-integration; this of course comes at the possible price of more chaos. In the INTERBASE experimental environment, we plan to explore both the centralized and decentralized advisor approaches, and to analyze their relative merits and applicability.

5. Conclusions and Research Directions

This short paper has examined the problem of supporting dynamic patterns of sharing among a collection of autonomous, heterogeneous databases. We have explored the spectrum of heterogeneity that may exist in this environment, and have described a top level architecture and approach to sharing. The experimental INTERBASE system under development at USC explores a number of architectural and implementation issues, as well as providing as basis for the refinement of the sharing model and mechanism. The current prototype system is based on a network of SUN workstation and NeXT machines.

The principal current focus of research centers on the following issues:

Detailed design and implementation of the sharing mechanism;

Refinement of the kernel object database model, and experience with the use of the extensible features of the model;

The content of the sharing data/knowledge base;

The collection of heuristics that form the basis for the operation of the sharing advisor;

Studies of the tradeoffs involved in centralized vs. decentralized control and management of coordination information;

Access control (a related project is currently examining this); and

Utilization in specific application domains (viz., scientific information management, computer-integrated manufacturing).

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The Composite Information Systems Laboratory (CISL) Project at MIT

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ABSTRACT

The Composite Information Systems Laboratory (CISL) at MIT is involved in research on the strategic, organizational and technical aspects of the integration of multiple heterogeneous database systems. In this paper we examine the scope of the work being done at CISL. Certain research efforts in the technical areas of system integration are emphasized; in particular semantic aspects of the integration process and methods for tracking data sources in composite information systems.

INTRODUCTION

The increasingly complex and globalized economy has driven many corporations to expand business beyond their traditional organizational and geographic boundaries. It is widely recognized today that many important applications require access to and integration of multiple heterogeneous database systems. We have referred to these types of application systems as *Composite Information Systems* (CIS).

A fundamental CIS assumption is that organizations must deal with and connect pre-existing information systems which have been developed and administered independently. With this assumption, CIS follows two principles: (1) *system non-intrusiveness*, and (2) *data non-intrusiveness*. By *system non-intrusiveness* we mean that a pre-existing information system need not be changed. We have found that many of these systems are controlled by autonomous organizations or even separate corporations that are reluctant or unwilling to change their systems. By *data non-intrusiveness* we mean that changes are not required to the data in a pre-existing information system. Although we are in favor of data standardization, we have found that it is difficult to attain in a timely manner across organizational boundaries.

SCOPE OF CISL PROJECT

The CISL project is a broad-based research undertaking with nine component efforts as depicted in Figure 1. The remainder of this paper will focus on the technical aspects of prototype implementation and theory development as depicted in cell 8 and 9 of Figure 1.

Acknowledgements: Work reported herein has been supported, in part, by Citibank, IBM, Reuters, MIT's International Financial Service Research Center (IFSRC), MIT's Laboratory for Computer Science (LCS), and MIT's Leaders for Manufacturing (LFM) program.

Type of Connectivity	Methodologies: Field Studies	Prototype Implementation	Theory Development
Strategic	1) Medium	2) Low	3) Medium
Organizational	4) Medium	5) Low	6) Medium
Technical	7) High	8) High	9) High

Figure 1. Scope and Intensity of CISL Research Activities

A key objective of a CIS is to provide connectivity among disparate information systems that are both internal and external to an organization. Three types of connectivity have been researched:

1. Strategic Connectivity: The identification of the strategic requirements for easier, more efficient, integrated intra-organizational and inter-organizational access to information [MA88].

2. Organizational Connectivity: The ability to connect interdependent components of a loosely-coupled organization in the face of the opposing forces of centralization (e.g., in support of strategic connectivity) and decentralization (e.g., in response to the needs of local conditions, flexibility, distribution of risk, group empowerment) [OS89].

3. Technical Connectivity: The technologies that can help a loosely-coupled organization appear to be more tightly-coupled. This area is the primary focus of this paper and will be elaborated upon below.

The CISL research has employed three methodologies:

1. Field Studies: We have conducted detailed studies of several major corporations and government agencies to understand their current connectivity situation, future requirements and plans, and major problems encountered or anticipated [GA89, GO89, PA89, WA88].

2. Prototype Implementation: A prototype CIS, called the Composite Information Systems/Tool Kit (CIS/TK), has been developed to test solutions to many of the problems identified from the field studies [WO89].

3. Theory Development: In several areas problems have been found for which no directly relevant existing theories have been identified [SI89a, SI89b, WA89c, WA90]. Two particular technical connectivity theory development efforts described in this paper are *semantic reconciliation* which deals with the integration of data semantics among disparate information systems and *source tagging* which keeps track of originating and intermediate data sources used in processing a query.

CURRENT CIS PROTOTYPE STATUS

Our current CIS prototype, CIS/TK Version 3.0, has been demonstrated to provide access to as many as six disparate databases. The three MIT databases use different dialects of SQL and are run by different MIT organizations: **alumni** database (Informix-SQL on an AT&T 3B2 computer), **recruiting** database (oracle-SQL on an IBM RT), and **student** database (SQL/DS on an IBM 4381). Finsbury's **Dataline** service appears hierarchical to the end-user and has a menu-driven query interface. I.P. Sharp's **Disclosure** and **Currency** services provide both proprietary menu and query language interfaces. These databases provide breadth in data and provide examples of differences in style, accentuated somewhat by the different origins of each service (e.g., Finsbury is based in London, England and I.P. Sharp is based in Toronto, Canada).

CIS/TK Version 3.0 was completed in August 1989. It runs on an AT&T 3B2/500 computer under UNIX System V. Most of it is implemented in our object-oriented rule-based extension of Common Lisp, called the Knowledge-Oriented Representation Language (KOREL). Certain components are implemented in C and UNIX Shell. The current system provides direct access to, and integration of, information from all six databases.

We now present a simplified version of the actual heterogeneous CIS environments of CIS/TK. Suppose, as part of a major new marketing campaign, we wanted to know our top hundred customers in terms of total purchases from our two divisions over the past five years, expressed in dollars. Total purchases for a customer is calculated by summing purchases from each of the two divisions. In order to *reconcile the semantic heterogeneities*, two major tasks need to be addressed: (a) inter-database instance matching and (b) value interpretation and coercion [WA89a, WA89b].

Instance Matching

Each division may identify a customer differently. Thus, it will be necessary to match a customer in one database to the same customer in the other by means other than an exact string comparison. For example, "IBM Corp." in one should be matched to "IBM, Inc." in the other; also "MIT" should match "Mass. Inst. Tech."; and "Continental Airlines" should match "Texas Air Corp.". Each division may also use a customer number (or other unique identifier) for a customer, but it is unlikely that the same identifier would have been used by both for a given customer.

To match customers (or any entity) between two databases, we use a combination of three techniques: key semantic matching, attribute semantic matching, and organizational affinity.

- *Key Semantic Matching*: To match the two IBMs, we can use rules such as "Corp." and "Inc." suffixes are equivalent. These rules can be context sensitive.

- *Attribute Semantic Matching:* The two MIT's are harder cases because it is unlikely that we would have a rule that "M" and "Mass." were equivalent. Instead we identify the match based on the values of other attributes (such as both have CEO "Paul Grey" and HQ city "Cambridge").

- *Organizational Affinity*: In many cases there exists an affinity between two distinct organizations. For example, although "Continental Airlines" is a separate corporation from "Texas Air Corp", Texas Air Corp owns Continental. Thus, depending on the purpose of the query, it may be desirable to treat two distinct entities as being the same (e.g., from a marketing perspective Continental and Texas Air may be merged; from a legal liability perspective they should be kept separate).

Value Interpretation and Coercion

After instance matching is performed, we must compute the combined sales to each customer. This presents numerous challenges regarding value interpretation and value coercion.

- *Value Interpretation:* For example, in one division, the total purchase amount is expressed as a character string that combines the currency indicator and numeric value (e.g., ¥120,000). The other division does not explicitly identify the currency being used; it must be inferred from the country of customer information (USA = $, Japan = ¥).

- *Value Coercion:* In order to compute the total purchase in dollars (or to compare totals across customers), a currency exchange rate needs to be applied. Since the yen/dollar exchange rate varies considerably from year to year (if not moment to moment), it is also necessary to "know" what time period to use and where to find the currency exchange data for that time period.

Although many of the instance matching, value interpretation and coercion features described above are implemented in a rudimentary form in CIS/TK Version 3.0, it still provides an excellent tool for testing new algorithms and approaches. In the remainder of this paper we examine our present research efforts in the development of new algorithms and approaches for composite information systems.

SEMANTIC RECONCILIATION USING METADATA (Source-Receiver Problem)

It has become increasingly important that methods be developed that explicitly consider the meaning of data used in information systems. For example, it is important that an application requiring financial data in francs does not receive data from a source that reports in another currency. This problem is a serious concern for many corporations because the source meaning may change at any time; a source that once supplied financial data in francs might decide to change to reporting that data in European Currency Units (ECUs).

To deal with this problem, the system must be able to represent data semantics and detect and automatically resolve conflicts in data semantics. At best, present systems permit an application to examine the data type definitions in the database schema, thus allowing for type checking within the application. But this limited capability does not allow a system to represent and examine detailed data semantics nor handle changing semantics.

We have examined the specification and use of metadata in a simple *source-receiver* model [SI89a, SI89b]. The *source* (database) supplies data used by the *receiver* (application). Using metadata we described a method for determining semantic reconciliation between a source and a receiver (i.e., whether the semantics of the data provided by the source is meaningful to the receiver).

The need to represent and manipulate data semantics or metadata is particularly important in composite information systems where data is taken from multiple disparate sources. Typically, schema integration algorithms have been developed for component databases with static structure and semantics. However, to allow for greater local database autonomy, schema integration must be considered a dynamic problem. The global schema must be able to evolve to reflect changes in the structure and meaning of the underlying databases. If an application is affected by these changes, it must be alerted. As part of our research we are developing methods that use metadata to simplify schema integration while allowing for greater local database autonomy in an evolving heterogeneous database environment.

Methods for semantic reconciliation are described within a well-defined model for data semantics representation. This representation assumes that there are common primitive data types. From this base, for example, the currency of a trade price can be defined as the currency of the exchange where it was traded. Using this common language, sources can define the semantics of the data they supply and applications, using the same language, can define the semantic specification for required data.

The system architecture for semantic reconciliation is shown in Figure 2. Rather than a direct connection between the application and the database, the system includes a Database Metadata Dictionary component which contains knowledge about the semantics of the data and an Application Metadata Specification component which contains knowledge about the semantic requirements of the application. Semantic reconciliation is needed to determine if the data supplied by the database meets the semantic requirements of the application.

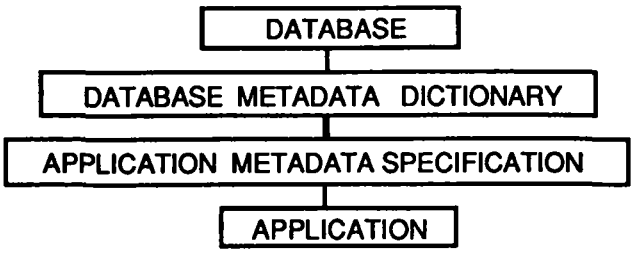

Figure 2. Semantic Reconciliation - System Architecture

We have developed an algorithm that compares the semantic requirements of the application with the meaning of the data supplied by the source to determine if the source will supply meaningful data [SI89b]. A similar algorithm can be used to determine if an application is receiving meaningful data from a set of component databases. In this case the data semantics of each database are examined to determine which sources might provide meaningful data. These methods can also be used to determine if an application can continue in the presence of changes in the component database semantics by making use of available conversion routines. Thus semantic reconciliation is a dynamic process which allows for component database semantic autonomy.

POLYGEN MODEL (Source Tagging Problem)

A typical objective of a distributed heterogeneous DBMS is that users must be able to access data without knowing where the data is located. In our field studies of actual needs, we have found that although the users want the simplicity of making a query as if it were a single large database, they also want the ability to know the source of each piece of data retrieved.

A polygen model has been developed to study heterogeneous database systems from this multiple (*poly*) source (*gen*) perspective [WA89c, WA90]. It aims at addressing issues such as "where is the data from," "which intermediate data sources were used to arrive at that data," and "how source tags can be used for information composition and access charge purposes." In a complex environment with hundreds of databases, all of these issues are critical to their effective use.

The polygen model developed presents a precise characterization of the source tagging problem and a solution including a polygen algebra, a data-driven query translation mechanism, and the necessary and sufficient condition for source tagging. The polygen model is a direct extension of the relational model to the multiple database setting with source tagging capabilities, thus it enjoys all of the strengths of the traditional relational model. Knowing the data source enables us to interpret the data semantics more accurately, knowing the data source credibility enables us to resolve potential conflicts amongst the data retrieved from different sources, and knowing the cost of accessing a local database enables us to develop an access charge system.

A polygen domain is defined as a set of ordered triplets. Each triplet consists of three elements: a datum drawn from a simple domain in a local database (LD), a set of LDs denoting the local databases from which the datum originates, and a set of LDs denoting the intermediate local databases whose data led to the selection of the datum. A polygen relation p of degree n is a finite set of time-varying n-tuples, each n-tuple having the same set of attributes drawing values from the corresponding polygen domains.

We have developed precise definitions of a polygen algebra based on six orthogonal operators: project, cartesian product, restrict, union, difference, and coalesce. The first five are extensions of the traditional relational algebra operators to operate on the data tags, whereas coalesce is a special operator needed to support the polygen algebra by merging the data tags from two columns into a single column. Other important operators needed to process a polygen query can be defined in terms of these six

operators, such as outer natural primary join, outer natural total join, and merge. A query processing algorithm to implement a polygen algebra has also been developed.

CONCLUDING REMARKS

This article has presented a brief overview of the CISL project objectives with specific focus on the prototype implementation and theory development regarding semantic reconciliation and source tagging. All of the research activities depicted in Figure 1 are currently underway and have been, or will be, reported in a series of CISL project reports and articles. From our interviews of major organizations, the problems being addressed are becoming increasingly critical to the development and deployment of modern information systems.

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MDAS: Multiple Schema Integration Approach[1]

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1. INTRODUCTION

A heteregeneous distributed database database management system (HDDBMS) supports an integrated view of multiple pre-existing databases. Such integration provides the advantages of database consolidation while avoiding local schema, software, and hardware changes, and the associated organizational upheaval. The major subproblems in HDDBMS design are physical and semantic integration. The goal of physical integration is to bridge differences in software and hardware at different sites, and is a problem in proportion to the degree to which existing hardware and software resources are to be incorporated into the HDDBMS.

Semantic integration is the process of discovering and representing the semantic relationships among multiple pre-existing databases. This is a more difficult problem than in conventional distributed DBMSs (DDBMSs) in which local schemata and data allocation are part of the design, therefore allowing database relationships to be controlled. Pre-existing databases may exhibit inconsistencies with respect to their contents as well as their schemes and an important goal of HDDBMS design is to provide means of resolving such inconsistencies without physically modifying or consolidating these databases. Also, in an HDDBMS restrictions on the degree of overlap between separate pre-existing databases that may simplify query processing cannot be assumed. In contrast, in a conventional DDBMS the requirement that relations in different local databases must either be disjoint or entirely replicated, for example, may be enforced.

The prototype HDDBMS described in this paper, called the multiple database access system (MDAS), allows an integrated view of distributed pre-existing databases managed by different local DBMSs to be specified with a global mapping language. The MDAS then services queries on such a view, as front-end to the local DBMSs which continue to perform all data management and processing. Updates are not supported through the integrated view. MDAS is designed for local DBMSs that implement essentially record-oriented data model.

2. REFERENCE SCHEMA ARCHITECTURE

Figure 2.1 shows the reference schema architecture of the MDAS design. This architecture is a generalization of other HDDBMS schema architectures encountered in the literature. The lines between the schema levels in Figure 2.1 symbolize mapping levels. Schemata of levels 2 to 5 are expressed in a global data model (we consider the query language to be part of a data model). This global data model is associated with a global mapping language which is used to specify the mapping between schema levels. In the MDAS a global data model based on the relational model and a global mapping language based on the relational algebra are used. This is discussed briefly in Section 3. The use of a global data model means that a facility must be provided for mapping schemas and operations between those of each local data model and the global data model. However, without a global data model, a facility must be provided for mapping between each pair of differing local data models, which implies a greater number of mapping facilities when there are more than 3 different local data models and more difficulty in adding a new site to the integrated system. The schema levels of the reference schema architecture are explained as follows:

Each site participating in the system has a local host schema that describes the database at that site using the data model of the local DBMS. From the local DBMS perspective the distributed system is simply another user with its own external view of the database.

The translated local host schema is a subset of the local host schema after translation into a global data model. The local participant schema is defined by any number of mapping operations on the translated lo-

[1] The research was supported in part by contracts from CWARC, Dept. of Communication, Government of Canada.

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cal host schema. The mapping may be performed in order to resolve a subset of the schema conflicts between databases. The mapping may also be performed in order to absorb changes to the translated local host schema made after the establishment of the HDDBMS. A local participant schema is similar to an "export schema" in that it defines the view of the local database available to other sites. As such, this is a critical schema level with regards to data independence since changes to a local participant schema would entail changes to information stored at one or more other sites.

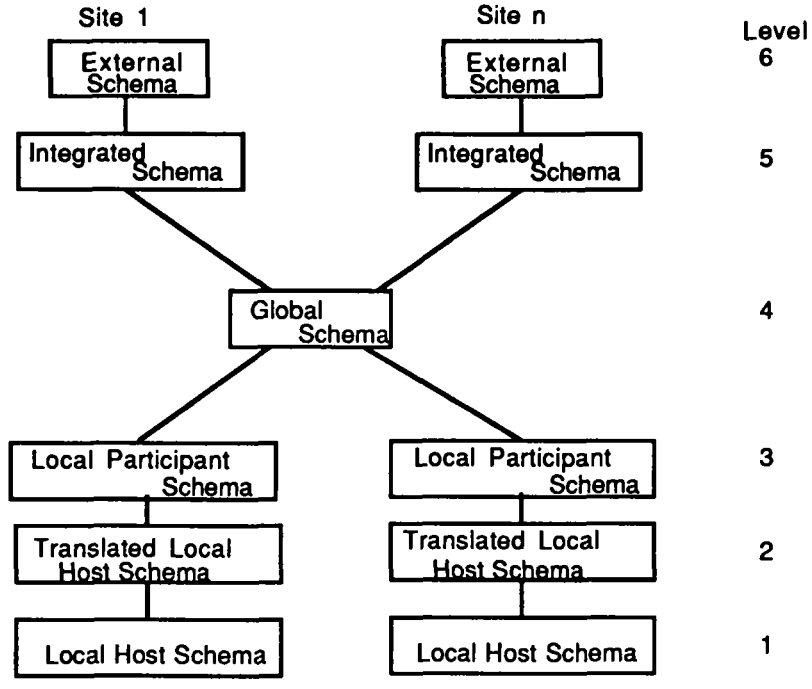

Figure 2.1 Reference HDDBMS schema architecture

A global schema is the collection of all local participant schemata from each site and represents the global database and the maximum amount of DDBMS data available to any one site [CARD87]. Each site has an integrated schema which is defined by any number of mapping operations on the subset of the global schema accessible by that site. These mapping operations resolve any remaining database conflicts and specify integrated objects, properties and relationships. It is possible for multiple sites to share the same integrated schema, or different sites to have different integrated schemata.

When it is necessary for the global database at a given site to be expressed in an external data model which differs from the global data model, an external schema may be derived from the integrated schema at that site [CARD87].

Our reference schema architecture represents a level of complexity that may be unnecessary in some cases, and the MDAS has been designed to allow the merging of adjacent schema levels in simplified situations. One such situation is where different sites may have the same integrated schema, the global data model may serve as the external data model, and the local participant schema may be identical to the translated local host schema. In this case, it would be possible to merge the local participant and translated local host schemas at each site, and to merge the external, integrated and global schema levels. The result would be similar to Multibase schema architecture described in [LAND82].

3. GLOBAL DATA MODEL AND MAPPING LANGUAGE

The relational model and relational algebra offer many advantages as a global data model and mapping language, respectively when the local databases all use a record-oriented data model. The relational algebra is easily extended with new operations to make it a mapping language with powerful conflict resolution capabilities [DEEN87]. An integrated schema would be defined as a set of relational views derived from the global schema using the extended relational algebra operations. Likewise, a local participant schema would be a

set of relational views derived from a translated local host schema. Considerable work has been done on defining relational views of hierarchical and network data model schemata, and in translating relational algebraic operations on those views into the DML of the underlying data model. Several commercial products have even been developed for this purpose, for example Cullinet's IDMS/R which provides a relational interface to a CODASYL IDMS database. Also, queries in common predicative query languages such as QUEL and SQL are easily translated into relational algebra expressions.

The global query and mapping language, referred to as GQML, implemented as part of the MDAS has the following operators (keywords in bold type). Only a brief, informal explanation of the operators will be given here. Further explanations on the operators are given in [POLL88]. The first six operators provide relational completeness in the sense of [CODD72]. Further capabilities that are provided by the remaining operators are required for the purposes of database integration (mapping) capability.

```
1   u : union                                    7  ren :  rename attributes
2 int : intersection                             8  onj :  outer natural join
3 dif : difference                               9  alt :  alteration
4 div : division                                 10 grp :  grouping
5 lim : limit(combined projection/selection)     11 trc :  transpose row to column
6 lnj : limited natural join                     12 tcr :  transpose column to row
```

The **ren** (attribute renaming) operator is used to rename one or more attributes of a relation. Renaming does not change the domain of an attribute or the values associated with it. The **onj**(outer natural join) operator differs from the outer natural join [CODD79] in two ways. First, the values used to 'pad' tuples in order to make them union compatible with the join result are not assumed to be 'null', or distinct from 'real world' values in a database. This allows local DBMSs that do not support null values to be included in the integrated system. The second difference is that the onj operation allows the specification of an additional 'origin' attribute in the result relation. For non-join tuples, this attribute is automatically evaluated to contain the name of the operand relation from which each tuple was taken. For the other tuples the single origin attribute gets a null value or a default value different from either relation name. The user specifies the name of the origin attribute and the system gives it a default domain related to the system's restriction on relation name length.

The **alt**(eration) operator is used to add new attributes to the operand relation and drop attributes from it. The drop clause functions as a complementary projection operation; the listed attributes are removed rather than retained. The add clause allows the name and domain of one or more new attributes to be specified, and allows the user to specify the value of each new attribute in each tuple either as a constant or as a function of the data in the operand. The **grp**(grouping) operator is similar to the "group_by" operator of the ASTRID language in that it behaves as a projection operator combined with extension. New attributes may be specified as in the alt operation and their values specified as 1) constants, 2) user defined or system defined non-aggregate functions of the projection list attribute values, or 3) system defined aggregate functions. In the result there is one tuple for each 'group' as defined by the projection attribute list, and new attributes are evaluated separately for each such tuple. If no projection attribute list is given then the result relation has only the new attributes and one tuple.

The operations **trc** (transpose row to column) and **tcr** (transpose column to row) are basically similar to the operators in the PRECI Algebraic Language[DEEN87] having the same name. A **trc** operation transforms a relation of the form R(a1, a2, ..., am, c1, c2, ..., cn) into a relation of the form R(a1, a2, ..., am, b, c) by changing values for 'c1' to 'cn' into values for 'c' in n different tuples and adding attribute 'b' to those tuples which has integer values to indicate sequencing. Attributes 'c1' to 'cn' must be defined on the same domain, which automatically becomes the domain for 'c'. A **tcr** operation performs the inverse transformation. It is permissible for there to be any number of 'a' attributes, including zero.

4. DATABASE INTEGRATION

Database integration with the relational model, for the purposes of read-only requests, may be regarded as consisting of two basic steps: (1) resolving schema inconsistencies among a collection of base relations, and

(2) merging multiple relations (which are free of schema inconsistencies) into single relations while resolving data inconsistencies in the process.

Data inconsistencies between two databases are caused by measurement error and blunders involved in the original procurement of the data, blunders involved in their input into the separate databases, and corruption of the electronically stored data. Schema inconsistencies arise when data representing the same object class conform to different schemata in different databases, or when data that must be present in the integrated database are missing from one or more of the original databases. A comprehensive survey and classification of schema inconsistencies, as reported in the literature, is presented in [POLL88], and is not reproduced here due to space limitations. Some examples of schema conflicts and their resolution are presented below. Relation merging is discussed first in order to provide a context for the discussion of schema inconsistencies resolution.

In the simplest case, two relations represent the same class of objects, and are disjoint. If not, there is a possibility of data conflict among intersecting tuples. In these cases, it is necessary to identify the intersecting tuples in order to resolve the data conflict. The onj operation provides a way of doing this in the process of merging the base relations. There are two basic alternatives for handling the data conflict. One alternative is to use the value corresponding to the most reliable database when there is a choice (if a most reliable database can be determined). The other basic alternative is to synthesize a single value from conflicting values in the join tuples. For data conflicts occurring due to measurement error, this might be done by computing the mean of the conflicting values using the alt operation. In cases where the above alternatives are not applicable, the best approach may simply be to keep the conflicting value attributes and let the user make the decision as to how to use the data.

In the cases described so far, mergeable base relations represented the same object classes. It is also possible for base relations to represent subclasses of a common generic object class. As with the previous cases, multiple base relations may represent either disjoint sets of objects or intersecting sets. For example, separate base relations representing managers, secretaries, and technicians, all of who are employees, would probably be disjoint while those representing employees who are students and employees who are politicians are easily imagined to be intersecting. However, unlike the previous cases, the separate base relations may have different attributes without implying unresolved missing data conflicts since they represent different object classes each of which is justified in having its own properties in addition to the common properties.

The subclass base relations could simply be used in the integrated schema without merging, or it may be desirable to create a relation representing the generic class. Only the properties common to all subclasses are applicable to the generic class. Therefore, for disjoint subclasses a generic class relation may be created by taking the union of the subclass base relations after they have been projected on the common attributes. For non-disjoint subclasses, the possibility of data conflicts on common attribute values exists, and a similar approach to that described earlier for merging non-disjoint relations representing the same object class is required to merge the subclass base relations, projected on common attributes, into a generic class relation.

Schema inconsistencies are obstacles to relation merging. The GQML provides means of defining conflict-free views of conflicting relations which may then be merged. A value scale inconsistency involving a given property can be resolved with the alt operator by replacing or augmenting the corresponding attribute in one or both of the conflicting relations with a new attribute whose values are the original attribute's values transformed to a new value scale. In general, values on a more precise scale can be directly transformed into values on a less precise scale, but the reverse is not true. An alternative to transforming one conflicting attribute's values to the value scale of the other would be to transform both attributes' values to a separate, common value scale.

Generalization inconsistency occurs when one relation represents objects at a higher level of generalization than similarly classed objects represented by one or more other relations. One approach to resolving this inconsistency would be to merge the multiple relations into one relation with **u** operations. This resulting relation could then be merged with the relation at the higher level of generalization to create an integrated relation. This may be satisfactory from the viewpoint of one database user but from the other database user's viewpoint there would appear to be a loss of specialization data. An alternative approach, which would yield a more satisfactory result from the second database user's viewpoint, would be to divide the generalized relation into multiple specialized relations. However, this would require auxiliary data

Row/Column inconsistencies occur when data represented by field values in one database are represented by field names in another database. A simple example of this is a 'Sales' relation which has 'Month' and 'Sales' attributes in one database and separate monthly-sales attributes ('Jan_Sales', 'Dec_Sales', etc.) in another database. Such inconsistencies may be resolved using the **trc** and **tcr** operations.

5. QUERY PROCESSING

In designing and implementing the MDAS query processor we assumed that the sites are connected by fast short-haul links, so intersite communication delay does not dominate data processing delay, each site is capable of supporting any GQML operation and that database statistics would not be available. In the MDAS, a join on relations residing at different sites is always be executed at the query site. However, schemes for optimizing these joins require database statistics.

Each site in the HDDBMS has its own unique site designator and its own process (qproc process) running the query processing algorithm. A GQML query submitted to the qproc process running at a particular site consists of a result relation name and a GQML expression (possibly nested) on terminal and/or non-terminal relations specified at that site with GQML virtual relation definitions and base relation declarations. The local site is the site where the qproc process is running, and the query site is the site where the query originates from, and where the results are required. If the query site designator is the same as the local site designator, then the query is local, otherwise it is remote. Local and remote queries are handled in exactly the same way, except that the result of a local query remains at the local site while the result of a remote query is sent to the query site. A detailed description of our query processing algorithm is presented in [POLL88]. A brief description is presented below.

The basic feature of our query processing algorithm is the decomposition of a query on virtual relations at a given site (the query site) into zero or more subqueries that are entirely satisfied by local data (local subqueries), zero or more subqueries on virtual relations which, according to the locally stored mapping specifications, are not derived from local data (remote subqueries), and a final subquery on the results of the local and remote subqueries and/or translated local host schema relations. The important thing to note is that local and remote subqueries can be further processed and executed in parallel. Local and final subqueries are translated into a form that can be executed by the local DBMS. When a translated subquery is submitted to the local DBMS the qproc process no longer has any involvement in it except to determine whether or not the execution was successful. The translated final subquery may be augmented with instructions to the local DBMS to present the user with options for activities such as viewing the final result, and erasing the result file. If data reformatting capabilities are an integral part of the local DBMS, it might make sense to also include, in the transformed final subquery, instructions to convert received global format remote data (the results of remote subqueries) to local format, rather than to perform the reformatting immediately on receipt of the data.

If there are no remote subqueries, then there will be no local subqueries, and the entire query will be executed as the final subquery. If there are no local subqueries and only one remote subquery then the result of that remote subquery would contain the query result data. In this case, the final subquery would be 'null' and would result in the activities that would be appended to any other final subquery upon translation, such as data reformatting and results display.

When a remote subquery is dispatched to a remote site, it is submitted as an ordinary query to the qproc process at that site (i.e., the receiving qproc process does not need to know that the query is actually a subquery from another site), which then processes it and returns the results to the dispatching qproc process site. When processing a remote query the qproc process may itself dispatch further remote subqueries if the local DBMS is a HDDBMS.

The query decomposition algorithm (decompose_query), described in [POLL88], is based on the decomposition of a directed acyclic graph (DAG) of operations representing the query into separate subgraphs representing the subqueries. The subqueries are described by an internal representation of a DAG of GQML operations.

6. SOME IMPLEMENTATION DETAILS AND CONCLUSIONS

The current MDAS prototype integrates two sites, represented by two PCs connected by a null modem. One site has dBase III as its host DBMS, and the other site has KnowledgeMan (KMan). All data processing, including data file reformatting, is performed by these DBMSs under the direction of the MDAS. The MDAS provides each site with a relational integrated schema of the local host databases. Users can submit ad hoc global queries the result of which is a file in the local file format. All MDAS modules were written in the 'C' programming language.

The user executes a terminal monitor process which requests the result relation name and the GQML query text. It is assumed that the remote request server process is executing on the remote systems when a query is submitted. The global query processor transmits all remote subqueries in a single communication session with the remote request server process.

The result of a user's query is assembled at the query site. The global query processor instructs the local host DBMS to offer to display the results at the terminal when the data processing is complete. In contrast, the result to a remote request is ultimately assembled in a global format ASCII text file (by the local host DBMS under the instruction of the global query processor) and is then sent back to the query site by the remote request server.

Since the MDAS processes a remotely submitted query on a local participant schema with much of the same software that it uses to process a locally submitted query on an integrated schema, a local participant schema is readily supported as a view of the local host schema, defined by GQML operations on the local host schema relations.

The current design emphasizes practicality over optimization. In particular, the global query processing algorithm does not attempt to optimize the degree of parallelism in local query processing and execution. In fact, a query that can be executed at a single site (entirely as a 'final subquery') will be executed this way, with no parallel processing at all. Parallelism and optimization would require estimates and comparisons of the delay involved in individual operations and global knowledge of the additional mapping operations required to materialize remote global schema relations. This in turn would increase the complexity and size of the system considerably. Furthermore, simple local DBMSs of the type that we assumed in our design and incorporated in our implementation do not maintain the database statistics required for the estimation of the relative execution times of operations.

Extensions to the MDAS prototype are planned. Incorporating additional sites (assuming communications support from network software and hardware) into a MDAS integrated system involves building a new low-level module to support the mapping level between the local host schema and the translated local host schema for each additional local DBMS with a previously unsupported data model and query language. The global schema would also have to be expanded and the integrated schemata for those sites that wish to incorporate the additional data would have to be modified. Few requirements are imposed on local DBMSs and host schemata, so the MDAS approach is widely applicable in the context of record-oriented data and read-only requests. Integrating the MDAS with a natural language interface is underway. Longer term planned extensions include the implementation of global and local query optimization techniques proposed in [POLL88] which do not require database statistics or global knowledge of local low-level mappings. Also, the feasibility and desirability of accommodating update at different schema levels, and the impact and possible control of update performed directly through local DBMSs will be investigated.

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PICTORIAL/VISUAL ACCESS TO MULTIMEDIA/HETEROGENEOUS DATABASES

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Abstract

The need is stressed for (1) future-generation generalized pictorial and graph database management; and (2) (a) an effective and integrated view and (b) high-level pictorial/visual accessing of data residing in a network of different pictorial and non-pictorial databases. Some highlights and illustrations of our R&D goals, progress and direction are briefly introduced herein.

1. INTRODUCTION

As we enter the 1990's, there is a growing number of heterogeneous of databases under a variety of both conventional database management systems (DBMSs) and recently emerging pictorial data management systems. The major thrusts of our research and development effort are to develop the architectural framework, detailed specification and proof of concepts of advanced system software:

1. To provide future-generation generalized pictorial and graph database management

2. To provide (a) an effective and integrated view and (b) high-level pictorial-oriented or visual-oriented accessing of data residing in a network of different pictorial and non-pictorial databases.

2. PICTORIAL DATA MANAGEMENT

For many years special image data handling systems have been developed to store and retrieve specific types of pictorial data. More recently, however, it has been realized that instead of a one-of-a-kind approach, a generalized pictorial database management system is better (much in the same way that today's DBMSs for record-type data are preferred in most cases over tailor-made systems to manage a particular type of record).

For pictorial data consisting of clearly delineated objects (such as road maps and physical-wire layouts) that can be reduced to points and lines, conventional DBMSs can represent the data, and frequently needed pictorial operations can be rather well supported, although not always directly, by conventional DBMS operations (join, project). Unfortunately, other pictorial data (vegetation photographs, X-rays) cannot be easily reduced to points and lines because there is rarely a clear boundary between objects, e.g., between desert and non-desert areas. Thus, conventional DBMS cannot be used practically to define the data objects. Furthermore, typical operations required by users of such pictorial data are rarely well supported by the operations of a conventional DBMS [CHOC81]. It is this type of data that is perhaps the most voluminous and the one being collected at the fastest rates. For example, the rates at which imaging sensors on satellites collect data is astonishing: dozens of megabits per second operating around the clock for days, months and years.

The Pictorial Database Management System (PICDMS) has been designed at UCLA since the mid 1980's [CHOC85, JOSE88]. It supports data object definition, storage, accessing, and interpretation. The data model proposed is the stacked-images database model, illustrated in Figure 1. It shows several types of pictorial data, some of which is data directly measured by instruments (such as elevation), and other of which is derived, or entered directly by humans (such as census tracks or any free form sketches). No conventional DBMS is used internally. PICDMS was built from the ground up with pictorial data management facilities as the major requirement. A procedure oriented language was initially defined and partially implemented for PICDMS [CHOC85]; a QBE-flavored PICDMS language, PICQUERY [JOSE88], has been subsequently also designed to operate at an even higher level. Joseph outlines the major pictorial data management operations on an entire picture(s) or object(s) within the picture(s) to be supported by PICQUERY or any other powerful pictorial data accessing language [JOSE88]: (1) Image manipulation (rotation, various types of zooming, masking, etc.); (2) pattern recognition (edge detection, similarity retrieval on the basis of shape or size or any other criteria, etc.); (3) spatial (distance, length, intersection of objects, union or difference of region objects, etc.); (4) input/output (read, write, update picture or object(s) within the picture).

Example 1

English: Identify the points in picture PIC1 where missiles with range greater than 5000 miles and speed greater than 25,000 mph are deployed

PICQUERY:

Picture 1	Object Name	Picture 2	Selection Condition				
			Variable	Relation Operator	Value	Logical Operator	Group
PIC1	MISSILES	PIC2	Range Speed	.gt. .gt.	5000 25000	.and.	1 1

The underlying databases actually involve: (a) picture PIC1 with objects that look like missiles and (b) other pictures (PIC2) of known missiles with their non-pictorial information (range, speed, etc.). The non-pictorial information would actually be in a conventional DBMS, in which all other related non-pictorial information would be held. Internally, powerful pattern matching facilities would search automatically PIC1 to find any objects that match the pictures in PIC2 of missiles with the indicated non-pictorial characteristics. This pictorial object recognition and matching capability plus the integration of pictorial and non-pictorial data is not available in commercial DBMS.

Example 2

English: Retrieve objects in picture P2 similar to objects identified in picture P1. Similarity retrieval operations can be done on the basis of size, shape, texture, or any other user-defined application dependent basis.

PICQUERY:

Picture 1	Object Name	Basis	Picture 2	Object Name	Object Type
PIC1	C1	Shape	PIC2	P.	P.

Visual Oriented Model and Query Language

It is our belief that visual query languages will be very attractive and in many cases highly preferred over text-oriented conventional database query languages and programming languages. [CHAN88] outlines visual languages. Visual languages also avoid one difficulty of text oriented languages: understanding by those who do not read/write in the particular text language. [PIZA89] presents the highly visual data model features and the language that we propose for querying and specifying spatial integrity constraints in pictorial data bases.

Figure 2 shows a sample of the data model serving as the background. Pictorial and non-pictorial entities or objects and their attributes are involved. Pictorial or spatial relationships (associations between pictorial objects because of their relative positions in the picture) and conventional DBMS relationships (e.g. city x 'receives-money-from' county y) between objects are involved. The data model visualized by the user conceptually is an extended Entity-Relationship data model developed to support pictorial and multi-media data management. Underneath the conceptual layer, multiple pictorial and non-pictorial databases are involved. All this and the stacked-images data model features illustrated in Figure 1 constitute major features of our logical data model.

Figure 3 provides an entirely visual constraint specification for "automobiles and people (denoted as * in the picture) can not be in a crosswalk simultaneously". Entities and spatial relationships addressed in the integrity constraint are highlighted. Note that in this example we have avoided entirely the use of any text language.

3. GRAPH DATA BASE MODEL AND QUERY LANGUAGE

New database support is proposed for an important class of data objects: those that may be defined as graphs (made up of nodes and edges). Examples include instances of network layouts, from office procedures diagrams to computer networks to telephone networks to road networks. Figure 4 contains some specific examples of graph-type data objects from the information systems design and development (software engineering) area: E-R diagram in the E-R database model, process and data flow diagrams, and SADT diagrams of the structured analysis and design technique. These examples constitute a collection of seemingly heterogeneous databases which need to be managed and accessed as "one" database. There are many applications where the data objects can be more adequately managed as graphs; most importantly, from the logical user view point and the required operations on such data objects, they are graphs. A "graph data model" (GDM) and a data manipulation language for the data represented in the GDM has been designed and proposed [CARD90, WANG90].

Graph data objects are not well handled by existing database management systems, nor pictorial DBMS (including PICDMS). This inadequacy of DBMS is due primarily to the lack of fixed structure in graph-type data objects even among instances of the same data class. The GDM provides a natural representation for graph-type data objects. This natural representation in turn makes query and manipulation of graph-type data objects simple and natural to the average end user. For a user, it is undoubtedly more convenient, for example, to add or delete (a) an entity and/or relationship in an E-R model or (b) a function (shown as a box and its connecting flows in an SADT diagram), directly on the graph model rather than on the indirect representation of such graphs expressed in relational tables and using a relational language. In particular, the GDM eliminates the need for recursive queries which are inherently associated with representing graph-type data objects in a conventional data model such as the relational model.

5. CONCLUSION

Our R&D and actual experiences in data management lead to envisioning the following needs and directions:

- New pictorial DBMS for generalized pictorial/image data management
- New graph DBMS for generalized graph data management
- Conventional DBMS possibly extended for pictorial data but only with well delineated

geographical boundaries (e.g., street maps)

- More intelligent data dictionary/directory systems capable of dealing with pictorial, graph and conventional record-type data
- A "multi-media DBMS" consisting of conventional DBMS, pictorial DBMS and graph DBMS, with a new software layer on top (including a very intelligent data dictionary/directory) providing a single integrated DBMS environment and language for users
- More intelligent visual oriented languages for pictorial and multi-media database management

These are the overall needs and challenges addressed by our R&D effort. In short: integration of a variety of databases of the above types, such that from the user point they appear as one integrated database, and such that they may be accessed via a common integrated language capable of referring to any combination of heterogeneous databases. The architecture, specification, prototype implementation of key elements, and proof of concept of such an integration capability have been our goals. We have progressed a great deal and shown the feasibility of achieving these goals in various references.

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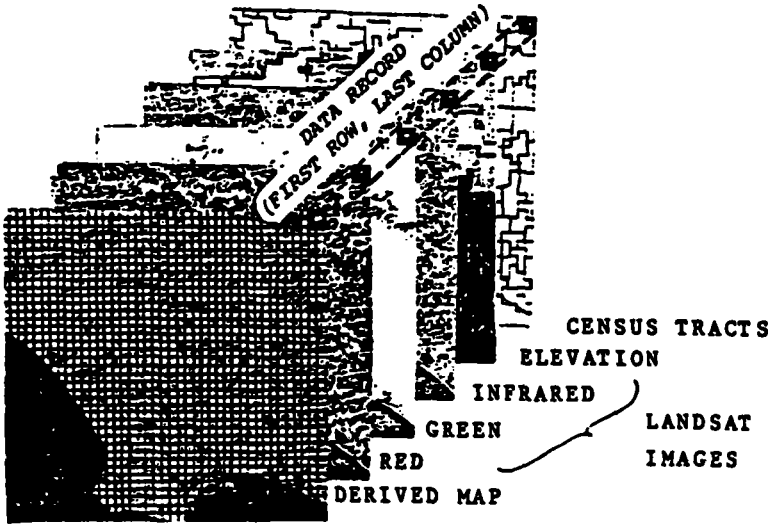
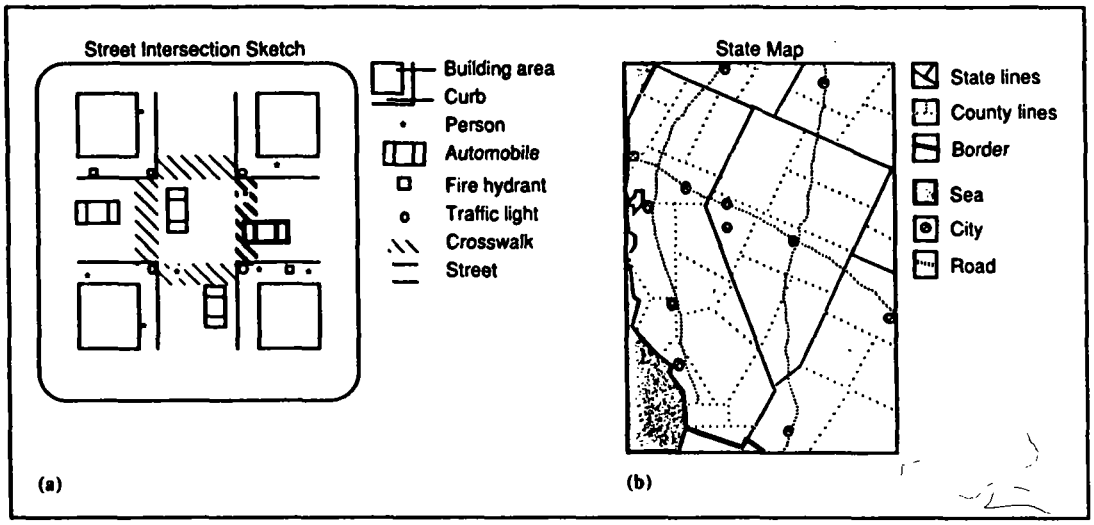


Each (row, column) record contains one data item per image: an intensity for Landsat spectral band 4, 5, 6; an elevation; a census tract; and a derived map.

A Stack Image Data Base

Figure 1

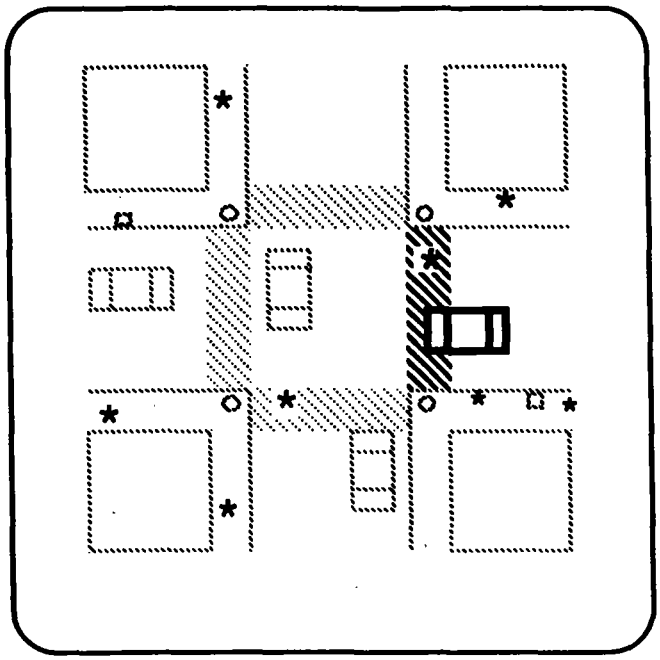


Sample database pictures showing (a) the traffic database and (b) the geographic database.

Geographic database conceptual model: entities and attributes. (NP: nonpictorial, PP: primitive pictorial, PD: pictorial derived)

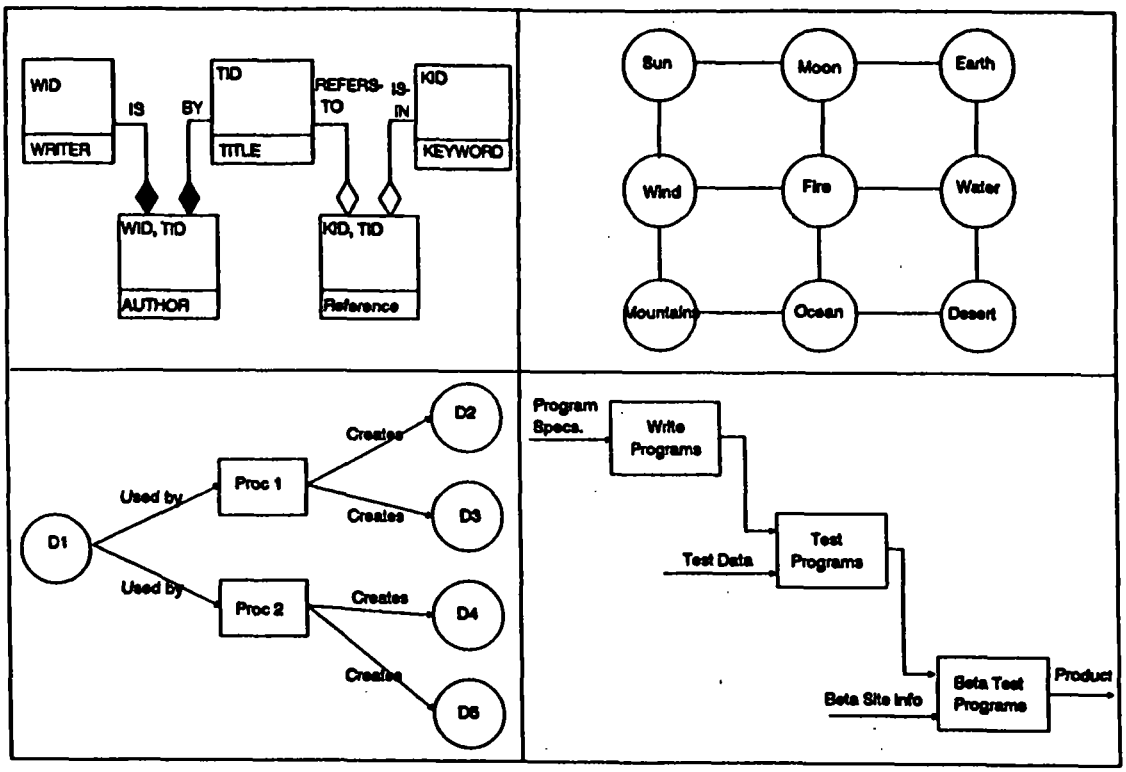
States	Cities	Landmarks	Counties	Roads
name(NP,string)	name(NP,string)	name(PD,string)	name(NP,string)	number(NP,string)
population(NP,integer)	population(NP,integer)	year-built(NP,integer)	population(NP,integer)	built(NP,date)
governor (NP, string)	mayor (NP,string)	location(PP,point)	boundaries(PP,polygon)	type(PP,constant)
incorporation-date(NP,string)	date-founded(NP,date)		area(PD,float)	path(PP,line-set)
boundaries(PP,polygon)	state-capital(NP,string)			length(PD,float)
area(PD,float)	state-revenue(NP,integer)			
border-length(PD,float)	annual-visitors(NP,integer)			
	boundaries(PP,polygon)			
	area(PD,float)			

Figure 2



Constraint description using entity highlighting: Automobiles and people cannot be in a croswalk simultaneously.

Figure 3



Example graph data objects

Figure 4

A Taxonomy for Classifying Commercial Approaches to Information Integration in Heterogeneous Environments

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ABSTRACT

Commercial systems and research prototypes for integration of heterogeneous information systems can be broadly classified into four major categories depending on the level of changes required to existing systems and the type of capabilities provided. Eight current systems representing the four categories are compared with respect to data models, global schemas, query processing, and transaction management.

INTRODUCTION

Ongoing efforts at MIT's Sloan School of Management in the field of connectivity in heterogeneous environments are described in a companion paper in this special issue. As a part of these efforts, many commercial systems and research prototypes were studied, both to determine areas characterized by gaps in technology, as well as to avoid "reinventing the wheel" in areas where other researchers and designers have achieved success.

Based on information collected from various sources, over 100 potential candidate systems were identified. Initial scrutiny reduced this number to 24 that actually provided significant capabilities. For each of these 24 systems, the respective companies completed a questionnaire composed of 21 items. Presently, the accuracy of these responses is being verified, and the answers are being normalized to use common terminology.

Page limitations make it impossible to reproduce all the information gathered in this paper. We cover only the most important issues using a representative set of eight commercial approaches. Additional comparative information is available in [BHAL87], [REDD88], [GUPT89a], and [GUPT90b].

TAXONOMY

There are many potential schemes for categorizing approaches to integrating heterogeneous systems. We have developed a taxonomy focusing on the business and organizational impacts. This taxonomy classifies approaches into four categories: (i) Unintrusive Integration; (ii) Intrusive Integration; (iii) Interfacing with Controlled Redundancy; and (iv) Interfacing with Transaction Transfer.

Unintrusive Integration techniques do not demand that specific modules be resident in or added to each participating database system. This is based on the premise that existing information systems cannot, and should not, be tampered with.

Intrusive Integration requires either some modification of existing information systems or the placement of specific modules

within these systems. These modules are typically utilized to perform network services, to store information on the location of specific files, or to initiate secondary processes in case some resources are inoperational or too slow in responding to requests.

Interfacing with Controlled Redundancy focuses on strategies for getting the necessary pieces of information on a "just-in-time" basis, by making assumptions about the perceived needs of the user. No effort is made to create a global conceptual schema. Instead, pieces of data are prestaged and systematically assembled together over time to provide the final unified answer. As part of this process, data are selectively replicated.

Interfacing with Transaction Transfer constitutes the simplest technique for managing transactions in a heterogeneous environment. Instead of creating a global schema or prestaging data to meet anticipated needs, information is accessed from a relatively small number of systems in response to the user query. Queries and updates are replicated and transmitted to individual systems for processing by them.

Of the 24 systems analyzed, more than half of them belonged to the category of Intrusive Integration. Although many systems do not fall exclusively into one category, the table shows the closest category for eight systems.

CONCLUSION

Information in the table shows the diversity in the strategies adopted by various design teams for developing commercial products and approaches. Not surprisingly, in virtually all cases, the global query processing capabilities are more sophisticated than the global update processing capabilities. In fact, the latter capabilities are unavailable in several cases.

Although not shown in the table (because of space constraints), a number of commercially available approaches can be hosted on systems of dissimilar architectures. Features which were considered advanced on research prototypes just two years ago are now available on commercial systems.

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Category	BBN SYSTEMS & TECHNOLOGIES: CRONUS	CONTROL DATA CORP: CDM*PLUS	DATA INTEGRATION INC: MERMAID	CINCOM: SUPRA
	Unintrusive Integration (UI)	Unintrusive Integration (UI)	Unintrusive Integration (UI)	Intrusive Integration (II)
Local Data Models Supported	Object-oriented and Relational.	Relational, Network/Codasyl, and Hierarchical.	Relational and Network. Also, supports objects in files. Qualification to locate files is done on an structured relation that contains the file name. Retrieve process and display process are specific to object type.	Relational and Network.
Global Data Manipulation Language	A subset of SQL.	Neutral Data Manipulation Language (NDML), a SQL based query language. NDML can be embedded in Cobol, Fortran, and C.	SQL.	SQL.
Global Data Model	Object oriented.	A 3-schema architecture with conceptual schema stored in IDEF1X, and ER based modeling method.	Relational.	Relational.

	GUPTA TECHNOLOGIES INC: SQL SYSTEM (II)	ORACLE CORP: ORACLE	TRW: TRW DATA INTEGRATION ENGINE	METAPHOR: DATA INTERPRETATION SYSTEM
Category	Intrusive Integration (II)	Intrusive Integration (II)	Interfacing with Controlled Redundancy (ICR)	Interfacing with Transaction Transfer (ITT)
Local Data Models Supported	Relational (extended).	Relational.	Hierarchial, Relational, and Network.	Relational and relational interface. Interface to other non-relational DBMS facilitated through TTY, 3270, and 3780 emulators that are invoked through simple mouse point-and-click actions by the user.
Global Data Manipulation Language	SQL with enhancements (SQL-Talk), pre-compiler for ANSI COBOL, and application program interfaces for C.	SQL.	None required.	User points-and-clicks at same iconic interface across all supported relational DBMS. SQL automatically produced. Metaphor gateway servers convert SQL as required for platform.
Global Data Model	Relational (extended).	Relational.	ECR. Also allows multiple global schemata.	Relational.

	BBN SYSTEMS & TECHNOLOGIES: CRONUS (UI)	CONTROL DATA CORP: CDM*PLUS (UI)	DATA INTEGRATION INC: MERMAID (UI)	CINCOM: SUPRA (II)
Global Schema Construction	Global Schema definition is supported for object-oriented data storage and retrieval. Schema defined when specifying the interface definition for an object type.	CDM*plus dictionary directory uses the ANSI/SPARC 3 schema architecture to provide global data schema mappings. This allows full access to all enterprise data descriptions and accommodates mappings between schemata.	Many global schemata may exist for different applications defined across various local databases. Definition done with an off-line tool.	Defines entities to Global Directory. These are validated at definition time against the local schema of the target DBMS.
Query Processing (Retrieval)	Query processing (QP) across distributed object-oriented data storage is supported; QP over object-oriented replicated data is under development.	CDM*plus relational operations are based on relational views as created in the external schema described above. The query is embeded in current applications replacing multiple queries and processing or it is created as part of new application development.	Query in SQL is parsed and validated against Global Schema. An optimizer selects local databases needed to process a query and chooses the lowest cost strategy based on processing and network costs.	A global task running in the global layer spawns local tasks running in the local layers of each Supra involved in the query. Local tasks are subdivided to local database management systems by the Heterogeneous Data Management Processor (HDMP).
Global Update and Transaction Management	Updates may be performed on an object by object basis.	CDM*plus was designed to allow and support distributed global updates.	Transactions that can be passed to one database are permitted. Read concurrency is not guaranteed.	Secure only when Supra database management systems are involved.

	GUPTA TECHNOLOGIES INC: SQL SYSTEM (II)	ORACLE CORP: ORACLE (II)	TRW: TRW DATA INTEGRATION ENGINE (ICR)	METAPHOR: DATA INTERPRETATION SYSTEM (ITT)
Global Schema Construction	Supports full Relational catalog. Several tools for definition of database design are available. (SQL Base, SQL Windows, SQL Talk, and SQL Network).	Imported database schemata converted into relational format may be further analyzed to ensure proper naming conventions, dependencies and data definitions. No global schema exists or is considered necessary by the vendor.	A front end tool called the Integration Advisor allows the interactive construction of global integrating schema.	Local schemata of one or more databases are graphically depicted for the user. If a particular application needs to aggregate data across two or more physical databases, Metaphor's object oriented development environment can be used.
Query Processing (Retrieval)	Full SQL support for queries from various query tools (SQL-Talk, Windows-Talk, Express Windows, APIs, SQL-Windows, etc.).	Once data are imported from the non-Oracle based databases, queries may be performed via the SQL language. Direct querying of non-Oracle based systems, besides those running DB2 or DBase III, is not permitted at this time.	A local database SQL query can be processed against a remote IMS database (retrieval only).	A query is performed by point-and-clicking at objects presented as a logical view tailored for the specific end user. End user menus, browse lists, and computed fields are presented in a similar manner. SQL queries are automatically generated by the DIS tool set
Global Update and Transaction Management	Currently supports multiple databases and multiple cursors per transaction. SQL Host must reside on host computer and SQL Router on each PC.	Offers data and referential integrity for data concurrency.	Automatic updates are permitted and a cooperative access framework based on "ownership" is utilized.	Not supported directly.

Mainframe DBMS Connectivity via a General Client/Server Interface

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Abstract - This paper reports on the integration of a general purpose Client/Server Interface (CSI) into a mainframe online transaction processing (OLTP) environment. The client/server paradigm provides a powerful means to effectively create distributed, heterogenous database and transaction processing environments. The CSI implementation described in this paper allows access to both relational and non-relational databases, as well as access to other data sources and/or applications present in high-end mainframe OLTP environments.

Index Terms - Database, client/server model, transaction processing, remote procedure call, distributed processing, cooperative processing.

I. Introduction

With the confluence of local area networks providing cheap high bandwidth interconnection, microprocessor and RISC technologies providing high-end personal computers and workstations, and sophisticated operating systems such as UNIX, MACH, or OS/2 running on such computers, decentralized systems have become an organizational fact of life. The rapidly falling price of such systems has resulted in wide deployment of them. High-end microprocessors (such as the Intel 80386 and 80486) and their associated high-speed backplanes (such as Microchannel and EISA) have resulted in systems performance that rival the mainframes of the previous decade (e.g. the IBM 370/168 and 3033 mainframes). However, the methods of exchanging data between such powerful workstations and their mainframe counterparts have seriously lagged the gains in hardware. High-end workstation-based server systems with 3033-like mainframe power are typically reduced to interacting with larger mainframes using either dumb terminal emulation (e.g. 3270 or tn3270) or simplistic file transfer schemes (e.g. RJE or FTP). This seriously restricts the range of functions and the timeliness of the information that is exchanged between these systems.

This paper discusses a significant method to overcome these restrictions, by utilizing a general client/server model between workstations and mainframes. This method extends the Client/Server model into the IBM mainframe environment. It marries the strengths of the client/server paradigm with the strengths of IBM's mainframe OLTP monitors and databases. The solution models the concepts described by Gray[1] and Spector[2], as well as concepts embodied in the SUN/UNIX RPC model [3]. The architecture not only allows general client/server interoperability between workstations and mainframes, but also allows mainframe to mainframe, as well as mainframe to workstation interoperability. This architecture has been implemented in the Sybase Open Gateway/CICS and Open Gateway/DB 2 products.

The client/server model consists of a set of clients and servers, interconnected by a network, which cooperate for the purpose of processing work in the form of database accesses, file access, transaction scheduling, and so forth. In the client/server model, each server provides a service to the clients of the system. A client requests a service by sending a request message to the corresponding server. The server performs the requested service

and then returns one or more reply messages to the requesting client. In the Sybase server environment, a set of functions called DB-Library, provides the standard interface for passing a client's SQL requests or RPC procedure calls to a server. SQL pre-compilers may also be used, that allow "embedded SQL" statements to be converted into DB-Library calls. DB-Library provides the underlying message/datastream processing and networking needed to communicate with a server.

A client/server model provides the following primary advantages:

• distribution of work across multiple platforms in an enterprise: applications can be decomposed, allowing the client end to focus on analysis and presentation of results, while the server end can focus on providing high-speed servicing of results and management of large amounts of data.

• decentralization: because no single mainframe can meet all the computing needs of a large organization, mainframe workloads have by necessity been split up among multiple systems. The CSI model provides an ordered, structured way to decentralize and distribute work among homogeneous and hetergenous systems.

• improved cost/performance benefits: CPU intensive work can be shifted to the clients where the MIPs are often cheaper. In addition, specialized databases or departmental specific data can be moved down to powerful workstation-based data servers, where both the MIPs and disk storage costs are cheaper. Conversely, if a database grows to the point that it overwhelms the capability of a workstation-based server, the data can be uploaded to a more powerful mainframe. Because of the transparency provided by the CSI model, the client applications and users are not affected by such a move.

• integration of pre-existing systems: an RPC-based client/server model allows data from existing systems to be accessed, by using RPCs to invoke transactions that operate against the existing data.

• access to non-database resources: the client/server model is not just limited to database servers. Production CSI applications have been built that access real-time data feeds such as Dow Jones stock quotes, or real-time in-memory data structures for manufacturing process-control, or even interactive data exchange with spreadsheets. Each of these resources is operating as a "server", with the relevant data arguments being supplied on the RPC call from the client.

A robust client/server environment requires the following underpinnings:

(1) a peer-to-peer architecture, so that work can be easily moved around the network as new nodes are added, or as new data servers are added. Master-slave architectures inhibit the ability to easily access and/or re-deploy resources as needed.

(2) a well defined set of messages with which to exchange requests and replies between clients and servers.

(3) remote procedure call (RPC) support, so that clients (or other servers) can invoke transactions running on other nodes, without having to know the names of (database) tables or fields on the remote system. This allows integration of pre-existing (non-relational) data sources, and provides an efficient means to invoke pre-compiled, pre-bound SQL programs (e.g. "static SQL" support for DB 2). By encapsulating data requests into RPC calls, the client applications are decoupled from the contents of the remote node's data structures. This allows the remote server to have better site autonomy and control over its data, e.g. an MIS department can enforce integrity and authority constraints over its mainframe data by assuring that only its transaction programs (invoked as RPCs) alter the data.

II. Mainframe OLTP Environment

In the IBM mainframe environment, the most popular relational database system is IBM's DB 2. DB 2 is a high-end, ANSI SQL compliant database system, capable of processing hundreds of database transactions per second. DB 2 by itself does not normally have any built-in communications support. Instead, it relies upon a communications/transaction monitor, such as IBM's Customer Information Control System (CICS) or the Information Management System-Data Communications product (IMS-DC) to perform communications management and other OLTP functions. Of the two IBM communications/transaction monitors, CICS is the more popular.

CICS provides OLTP monitor and access functions not only for DB 2 relational databases, but for a number of other databases that operate in the mainframe world, including IDMS (a CODASYL style database system) and IMS-DL/1 (a hierarchial database system), as well as providing transaction-based access to other data sources such as VSAM ("flat files") and FIFO based message queues. CICS, with a base of almost 30,000 licenses, is installed in nearly 90% of all large IBM mainframe shops, with over 55% of all mainframe attached terminals connected into CICS. CICS provides several rudimentary client/server-like functions between homogenous CICS systems (called "function-shipping") and has been a leader in distributed applications in the IBM mainframe world. It was for these reasons that CICS was chosen as the initial mainframe OLTP environment into which a heterogenous client/server environment was targeted.

Providing heterogenous client/server capability for such a mainframe OLTP environment encompassed solving the following technical issues:

(1) Open applications programming interface (API) supporting both client and server functions
(2) RPC support
(3) Common datastream, including data translation
(4) Gateway support between IBM's SNA and and the workstation world's TCP/IP protocols.

III. Technical Aspects of the Solution

All CICS transaction programs access CSI services through an open high level call interface. The interface provides facilities for Server transaction programs to accept requests from clients, setup and describe the reply columns, and to send the reply data (rows and/or return parameters). Client transaction programs have facilities to call RPCs on other mainframes or SQL servers to perform operations on remote objects (databases, queues, flat files), and receive the reply results (rows and/or return parameters) from the server system. The detailed communications I/O (e.g. LU 6.2 send/receive calls, etc) are automatically performed by the "CSI library", relieving the application programmer from such details. In addition, because it is a high-level call interface, the details of the underlying datastream are hidden from the programmer, allowing the programmer to concentrate on the business application, rather than datastream or communication aspects.

The call-level interface follows standard (OS/370) calling conventions, and hence fits into the CALL structure of conventional 3GL and 4GL languages used on the mainframe. The call interface consists of a stub that is link-edited to the CICS transaction program. This stub logic calls the common "CSI library" that is shared by all CICS transaction programs running in the CICS address (process) space. An overall diagram depicting the main components of the mainframe CSI implementation is shown Figure 1.

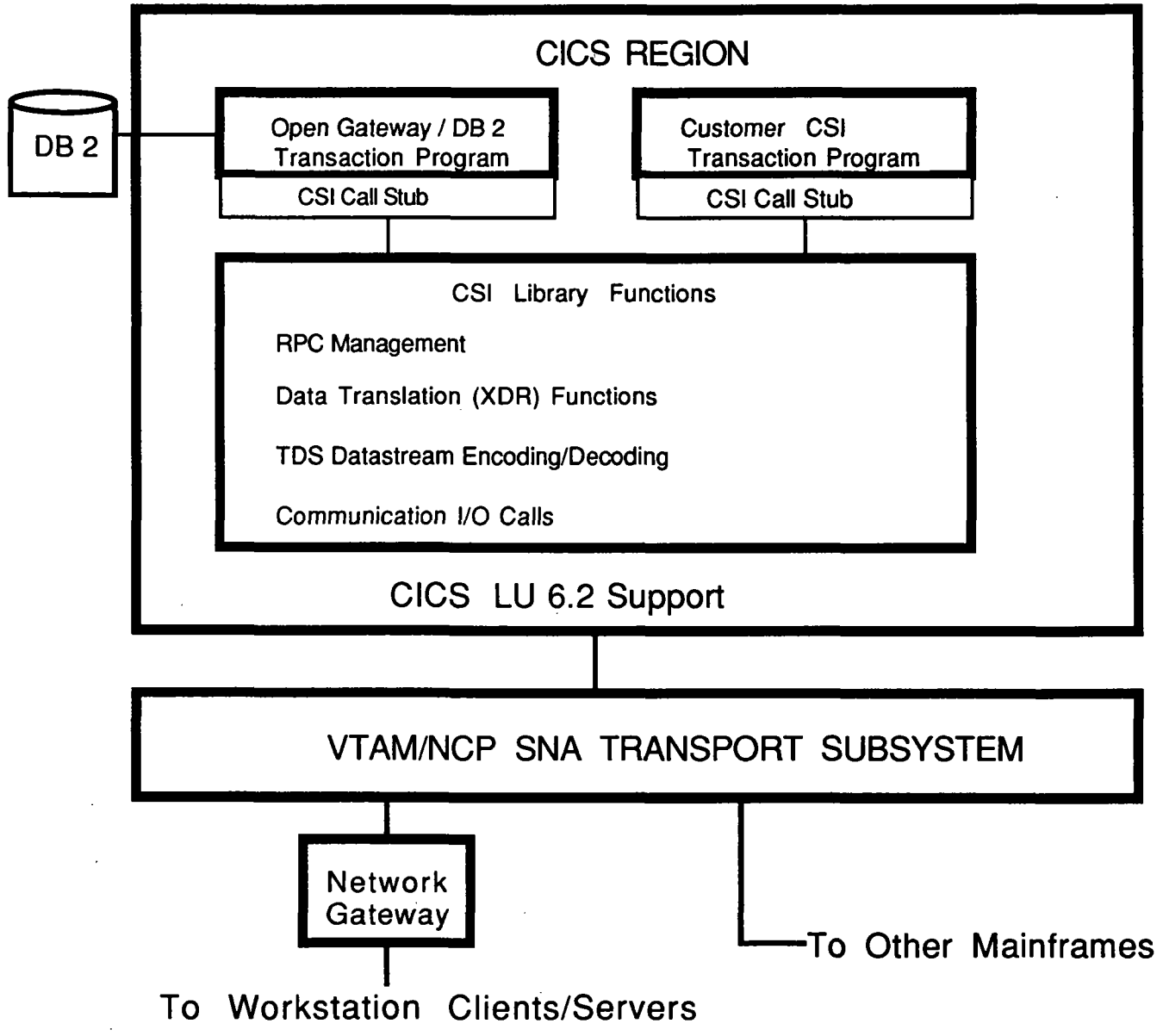
Both Sybase and customer-written Server applications utilize the CSI library. For example, the Sybase Open Gateway DB 2 product provides general purpose gateway capability

between Sybase clients and servers, and DB 2 databases. It is a Sybase provided Server application that uses the mainframe CSI library to provide "plug in and go" access to DB 2 databases.

The mainframe CSI support utilizes a message-based, extended Remote Procedure Call (RPC) mechanism. It is an "extended" RPC mechanism in the following ways:

(a) Most current RPC implementations only allow a single set of parameters to be sent up and a single set of return parameters/values to be returned. The extended model used by Sybase allows multiple rows of data to be sent back, as well as any return parameters in response to a single client request. This significantly reduces network traffic, obviating the need for the client to request each individual row as a separate reply.

(b) RPC calls from client programs are mapped into invocations of corresponding mainframe transaction programs. This allows host CICS programmers to design and code RPCs in the same way that they code any other CICS transaction program. RPC calls from workstation-based clients are converted (by the network gateway) into LU 6.2 "ALLOCATE" calls, to invoke the associated host transactions.



The messages exchanged between the clients and server are encoded in a common application layer datastream called the Tabular Datastream (TDS). TDS is a self-describing datastream, and is used in existing Sybase client/server systems, including the mainframe CSI component. For client requests, it delineates SQL text for "dynamic SQL" operations, and it describes RPC parameters (length, data type, value) for RPC operations. For Server replies, TDS supplies column descriptions (length, type, name, etc), row data values, return parameters, and error and status messages. The encoding of TDS is similar to the proposed ISO-RDA datastream, consisting of a data type token, length, and data value.

Data translation support (sometimes referred to as XDR support) is built into the TDS layer. At the beginning of the client request, XDR information is sent, describing the type of client (little endian or big endian, ASCII or EBCDIC based, etc). This XDR information is subsequently used by the Server's TDS component to process the incoming SQL text or RPC parameters, performing any needed data translations. Similarly, the XDR information is used when results are sent back to the requesting client.

Connection of (non-SNA based) workstation clients to CICS is through a network gateway, that converts from TCP/IP transport protocols into SNA LU 6.2 protocols. The network gateway appears to the workstation-based clients to be another (SQL) Server. The network gateway exists as a software process that runs on one (or more) of the customer's workstations. Attachment from a gateway workstation to the mainframe can be either SDLC, Token-Ring, or X.25. LU 6.2 was chosen as the protocol of choice for mainframe attachment for the following reasons:

(a) LU 6.2 is a robust peer-to-peer protocol [4], allowing bi-directional invocation and data transfer from either workstation-based applications or host-based applications. It does not suffer from the performance and functional deficiencies found in master/slave terminal oriented protocols (such as 3270 protocols).

(b) LU 6.2 has been designated by IBM to be the backbone of its SAA and cooperative processing strategies [5]. By adhering to such a significant standard, customer investments are preserved.

(c) LU 6.2 and its derivative "Intersystems Coupling" (ISC) facilities are frequently used for workload sharing between mainframes. By using LU 6.2, mainframe CSI applications can utilize existing communications facilities when CSI servers are located on other mainframes in the enterprise.

IV. Unique Aspects of the Solution

There are three unique aspects to the described CSI implementation that distinguish it from other heterogenous database access solutions: an open API with RPC support, client facilities at the host, and concurrent access to multiple, different data sources within the same server application.

Current database gateways tend to be closed, fixed function systems. Virtually all of them provide support for only "dynamic SQL" command requests (i.e. the shipment of ANSI SQL command strings between different vendor's DBMSes). Dynamic SQL requests tend to be quite expensive to support, requiring the request to be parsed, bound, and finally executed each time a new client SQL request is sent to the mainframe's DB 2 database. By providing a callable CSI API, frequently executed DB 2 requests can be turned into "static SQL" pre-compiled and pre-bound transaction programs, invoked as RPCs with parameters. Static SQL requests typically can be executed in 1/3 to 1/2 the path length of Dynamic SQL requests. This savings is achieved through the use of pre-compilers that parse the SQL request and bind it to the application plan through offline processing. Static SQL support has a dramatic impact on DB 2 throughput, and the number of client invoked DB 2 transactions that can be executed per second. And, as previously mentioned, it provides MIS groups with better site

autonomy and control over DB 2 resources. It can also avoid malicious or accidental destruction of DB 2 data, that could be caused by an authorized end-user issuing an ill-formed dynamic SQL update or delete.

The mainframe CSI implementation allows Client side access from the Host, i.e. CICS transactions can operate as clients, requesting data from other servers. Those other servers can reside on another mainframe system, or they can reside on SQL Servers running on high-end workstations or mini-computers. This allows data to be dispersed around the enterprise in a transparent fashion, based on system workloads and cost/performance tradeoffs.

Because mainframe CSI server applications can be customer (or ISV) written transaction programs, they can access any of the various data resources (DB 2, IDMS, DL/1, VSAM, Queues) that exist in the CICS environment. This allows mainframe server applications to concurrently access multiple, different data resources in the same transaction, operate upon them, and return the synthesized results to the requesting client.

V. Future Directions

The current mainframe CSI implementation does not provide cross-environment two-phase commit. The IBM mainframe environment's OLTP monitors (CICS and IMS-DC) provide 2-phase commit support [6] utilizing "Presumed Nothing" algorithms, an outgrowth of the original two-phase commit algorithms pioneered by IBM during the mid-1970s. The Sybase SQL Server environment provides two-phase commit capabilities utilizing "Presumed Abort" algorithms, that were invented during the late 1970s. "Presumed Abort" protocols are slightly more efficient, and are the most popular form of two-phase commit protocols in use today. "Presumed Abort" protocols have also been adopted by leading standards such as OSI's transaction processing standard (ISO-TP) and X/Open's transaction processing standard (XTP). The next phase of CSI development will provide two-phase commit capability across the two environments, thereby providing guaranteed, transaction-based update capability across heterogenous workstation and mainframe server based systems.

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INGRES Gateways: Transparent Heterogeneous SQL Access

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Abstract: The Ingres connectivity products, INGRES/Net, INGRES/Gateways and INGRES/Star, provide the functionality necessary to access almost any data source, at any location, in any grouping, transparently using SQL. This article describes the concepts and some of the design considerations of these products.

Organizations today have multiple data managers. Studies have shown an average of about 4 DBMS systems alone in an organization. Few, if any, of these systems are able to share data today other than by exchanging data extracts. This is rapidly becoming unacceptable to these companies, as their data is an important competitive resource that must be available as a whole.
Accessing this data through one interface is important. A program should not have to be rewritten because it is moved in the network, because the database manager has changed, because a distributed database is being used, or because a new release of a data base manager has been installed. Indeed, it should not even be necessary to relink. To provide this single image of an organization's data, it is necessary to hide from the programmer any indications that the data is in other than a local relational data manager. This requires making a least the following transparent at the application level:

- Local or remote location of the data
- Processor architecture and character set
- Network protocol
- SQL dialect differences
- Presence of any SQL capability at all
- Release of the DBMS system(s)
- Geographic distribution or lack of it

The INGRES connectivity product line, consisting of INGRES/Net, INGRES/Gateways and INGRES/Star, provides the organization with this seamless, transparent access to all of its data. We'll look at each of the three INGRES product line offerings, and see what each contributes to achieving this goal.

INGRES Open SQL

To provide transparent access among data sources using SQL, it is necessary to specify, completely, four items:

- The SQL dialect (including data types and transaction behavior)
- Error handling and return codes
- Catalog definitions
- Communications

A complete specification of all of these items is required; if any one is missing, the systems can not be fully transparent to the programmer or the user.

There are numerous standards designed to help in these areas, such as the ISO and ANSI SQL standards, the X/Open SQL definition, the work done by the SQL Access Group and IBM's SAA. Unfortunately, for one reason or another, all of these fall short of a complete, practical implementation specification. By studying the available SQL implementations, Ingres has developed the Open SQL definition. Open SQL completely specifies the programmer interface, so the programmer no longer has a dependency on the source of the data.

The Open SQL dialect was derived from a study of approximately a dozen SQL DBMS systems. It consists of the set of SQL that these systems can support, or can be made to support (more about this later). It is not simple dialect; it contains more functionality than some systems provide through their native interface. The entire INGRES toolset, some 700,000 lines of code, consisting of a 4GL system, screen painter, X/Windows system, business graphics, etc. is written using Open SQL. (Incidentally, this makes the whole tool set able to run on all of the gateways.) Beyond the native SQL capabilities of the particular RDBMS, there are some proprietary INGRES functionality and performance extensions universally supported as well.

The system handles all of the different error codes generated by the various systems through the Generic Error codes. The Generic Error set provides for a large granularity mapping of the errors from the DBMS system into one of a set of about 45 codes. These codes describe the class of the error, but usually don't describe the exact error. This granularity was chosen to allow the program to easily make run-time decisions using the codes, but not to replace the local DBMS error code and message. The local code and message are supplied in the SQLCA, the standard query status return structure, along with the Generic code so that the programmer has enough information to debug with, and the program can look at them if it knows the system it is running against. This philosophy differs from that of the SQL2 SQLSTATE values, in that those are intended to be the only code returned, with no provision for specific local error information returned in any portable or transparent manner.

The Standard Catalog definitions provide a similar transparency for the DBMS catalogs. Many applications look at the system catalogs, if only to determine what data are available for processing. The Standard Catalogs provide all of the information required by the INGRES toolset (representative of a complex application system) and INGRES/Star (representative of a distributed database manager). This is a superset of the information provided in the SQL2 Schema Information Tables. The Standard Catalogs are implemented as views on top of the native DBMS systems catalogs, allowing them to be active. (Note that the issue of their updatability does not arise; system catalogs are not updated by the end-user.) They provide the same release independence that the Generic Errors do - the views are merely reinstalled on the new level of the system and continue to provide the same information.

Through the Open SQL dialect, the Generic Errors and the Standard Catalogs, the programmer is given independence from the characteristics of the underlying data source.

INGRES Networking

The INGRES networking system is built around GCA, the Global Communications Architecture, which specifies the set of services and protocols used by the system components to communicate with each other. It is designed to let the various components transfer SQL commands and data, regardless of the inter-connection mechanism and circumstances. GCA consists of the upper four layers of the OSI basic reference model: Application, Presentation, Session, and Transport. The Application Layer is part of all processes, and provides the mechanism for local interprocess communication. The Presentation, Session, and Transport Layers, along with the network protocol specific code, are contained in the Communication Server process. GCA is implemented in three parts.

The first part is the application program interface, also known as GCA. This is the interface used to access the communication services provided by the system. GCA allows the system components to communicate in terms of "native" SQL data entities such as rows, descriptors, queries and commands. It also enforces a clearly defined inter-component application layer protocol that has a fixed set of messages which carry data objects of well-known structure. Supported operations include association initiation and termination, query processing, interruption, and transaction management (with one and two-phase commit).

The second GCA component is the Name Server. The Name Server resolves a database name and returns to the client GCA interface the name and returns to the client GCA interface the necessary information, including authentication information, to establish the database connection, whether local or remote. The Name Server is always present.

The third part, the Communication Server, provides and manages the facilities required to establish and maintain a connection between two processes (a client and a server) on two different nodes. The Communication Server is responsible for recognizing a cross-architecture communication session and performing the necessary application data transformations to support it. This function is contained within the transport layer and is transparent to the application layer users of the facility.

GCF uses standard proprietary network protocol implementations for data transport, such as DECNet, TCP/IP and SNA. The use of these protocols as a tranport mechanism is hidden in the lower layers of the GCF system and cannot be seen by the programmer.

Thus the INGRES Networking architecture handles the issues of machine architecture, network protocol and location transperancy. The next section covers how the gateways transform Open SQL into the appropriate processing at the host data source.

INGRES Gateways

The Ingres Gateways provide the interface between the INGRES Open SQL and GCA interfaces and the native interfaces of a particular data source. There are currently two different architectures used for gateway implementations. Which one is used depends on the capabilities of the underlying data source. For convenience, the two structures are called Type 2 and Type 3. The Type 1 gateway architecture is obsolete; it will be briefly mentioned at the end of this section.

The INGRES Type 2, or Non-Relational, Gateway is the interface to those data sources that either do not support SQL or do not support enough SQL functionally to put them into the Type 3, or Relational, category. Examples of these systems are IBM's IMS, the VMS RMS file system and real-time network data feeds.

Looking at the requirements for a Type 2 gateway shows a lot of processing may be required. The gateway must take an arbitrary SQL command and execute it against, in the worst case, a flat file system. The gateway is thus required to syntax check, parse, optimize (you DO want to use the secondary indexes, don't you?) and then execute the query. It must access the data out of the datasource, perform any aggregate processing, joins, sorts, etc. and then return the result. Note that this is what a relational database does with the data in its files or tables.

Having a relational database system to hand, INGRES uses the INGRES DBMS as the gateway for these Type 2 systems; the Gateway runs as part of the INGRES DBMS server. The interface it presents to the user is that of Ingres, so that when the user accesses the gateway, the user is actually interfacing with INGRES itself.

The interface with the DBMS is quite straight-forward. The INGRES system supports 4 file structures for its own tables: hash, heap, ISAM and BTrees. The gateway is added as a fifth, so that it looks just like another access method to Ingres. The source of the data now becomes transparent to the rest of the DBMS. This means that the data operated on has no special restrictions, so it can use all the functionality that is in INGRES itself. It supports SQL and Quel. It uses the Ingres optimizer to build query plans, and it uses all the information in the INGRES catalogs to describe the data. The statistical distribution information, used by the cost-based optimizer, is gathered by the standard INGRES OptimizeDB utility, regardless of the source of the data.

All of these Gateways support update access as well as read. The INGRES permissions system, integrities, rules, data base procedures, all control accesses to the data just as if it were in an INGRES table, with the same constraints that would be encountered, in that case. Any additional constraints applied by the data source itself would also, of course, apply (and are beyond the scope of Open SQL).

The interface to the data source is the standard application interface: e.g. DL/1 for IMS and RPLs for VSAM. No bypassing of the native security system is performed.

The gateway itself is implemented as about 18 different exit routines from mainline data management processing, performing normal file system operations such as position, update, delete, replace, get, put - the standard operations performed in an access method. Keys and read-ahead requests are processed as determined by the optimizer.

Defining the data to INGRES for the Gateway is about the same as creating a table. Descriptive information is needed in the INGRES catalogs so that it can be accessed by the optimizer and user applications. The REGISTER command is used to define the data to the system, populating the proper catalogs as if a new table were being created. The REGISTER TABLE command defines tables and REGISTER INDEX defines any secondary indices.

Ingres currently has IMS, VSAM and RMS gateways running at customer sites. The Type 3 Gateway is the interface to a fully relational DBMS. The implementation is much simpler that the Type 2 gateway, because the system being interfaced with already is capable of processing SQL. The Type 3 Gateway runs stand-alone: there isn't an Ingres DBMS required anywhere in the enviroment.

Since the interface provided is that of INGRES, as far as the end user programmer is concerned, this is INGRES. An INGRES application written to the Open SQL specification runs without change (including recompilation or relinking) across any of the gateways.

The majority of the work performed by the gateway involves scanning the input text of the SQL statement types (e.g., CREATE TABLE) that may need syntax changes to execute properly at the underlying DBMS, and substituting the appropriate 'local' syntax. On occasion, datatype coercions will also be done. On output, the returned error code(s) are mapped to the appropriate Generic Error code(s).

The gateway always runs on the machine that the host DBMS runs on. This makes it easier to use the native operating system interfaces, and avoids the necessity of porting the gateway, and any enhancements or maintenance, to multiple platforms. It also avoids the difficulties of trying to provide network support for the internal, undocumented application-to-DBMS protocols of these data base systems. If the underlying DBMS provides a transparent networking facility, the gateway can take advantage of that to provide further remote access.

As long as the underlying DBMS provides an external interface to drive a two- phase commit process, the gateway may participate in distributed update transactions. If no interface is available, the gateway is restricted to a single site update.

The Type 3 gateway always uses the standard application interface to the local DBMS. It does not bypass operating system or DBMS security, does not run in a privileged mode, and does not access the native DBMS files directly.

The Type 1 gateway was a first generation gateway, basically an implementation of the Type 3 gateway done as a Type 2. This means that a relational DBMS was acting as a gateway for a second RDBMS.The query was parsed and optimized by the first RDBMS, and the second was treated only as a file system. All catalog information had to be duplicated by hand in the higher-level system, causing many problems for the DBA. The approach was quickly discarded after an analysis of the overhead involved, as well as the requirement for special interfaces for each RDBMS system.

INGRES/Star

Ingres/Star provides, in a single session with an application, simultaneous access to tables residing in multiple databases, and extends transaction semantics across those databases. This is done through the concept of a distributed database.

To define some terms used in this section: "LDB" denotes a local database, accessible through an Ingres DBMS or gateway, and "DDB" denotes a distributed database, accessible through the INGRES/Star server.

An LDB is a collection of tables managed by a single DBMS or gateway instance. An application connected to an LDB can do joins, unions, nested queries, etc. which access only the tables and views resident in that LDB.

A DDB, in contrast, is a collection of tables, indices, and views selected from multiple LDBs which may be in any installation, local or remote. A DDB may also contain views which themselves map to tables and views from a combination of LDBs. A DDB is assembled by selecting objects from any number of INGRES DBMS or gateway instances. A DDB is not made up of whole LDBs - only the selected objects from the LDBs are visible.

Any table in the DDB is available to take part in the processing of an SQL statement: that is, joins, unions, and other relational operations can be performed across tables which would otherwise have to be in the same LDB.

An application can connect to a DDB just as it does to an LDB and has access to all of the tables in that DDB, subject to the access controls of both the DDB and the underlying LDB. As long as the application uses Open SQL and the Generic Error codes, the nature and location of the underlying DBMS is transparent to the application. By making the DDB catalogs appear to be Standard Catalogs, INGRES/Star also provides the common catalog appearance.

INGRES/Star is also able to make use of the products in the INGRES family. Any of the LDBs, and the DDB itself, may be accessed through INGRES/Net. The DDB definition itself may also reside in a gateway, as well as in an INGRES database. This means that it is possible to have a configuration including INGRES toolset, INGRES/Star, INGRES/Net, and INGRES/Gateways without an INGRES DBMS installed.

The INGRES/Star server can be described by using the natural division of DBMS into a relational query manager and storage manager. INGRES/Star can be seen as a relational data manager that uses other data managers, both local and remote, as its storage managers.

A distribution strategy is chosen for each SQL statement, even though connections from INGRES/Star to the data managers, once established, will be kept for the duration of a transaction and may be held for the duration of the session. The distribution strategy for a given SQL statement will vary according to how many LDBs are required to provide the data used in the processing of the query.

If the tables accessed by the SQL statement all belong to the same LDB, and are therefore managed by the same data manager, the application query is sent to that local data manager without distributed optimization.

It is possible to have a session in which every SQL statement is sent to a different data manager, without any distributed optimization being performed. In this case, the distributed transaction would span multiple local transactions, but no single statement would affect more than one LDB.

In the following cases, a different strategy for each different SQL statement is necessary:

- A join of tables in different LDBs
- A union of tables in different LDBs
- A subselect in a different LDB from its parent select

All of these situations are referred to as multi-site queries. In this case, INGRES/Star must play a more intelligent role in the access planning of the statement. The distributed optimizer must reduce the query into independently computable subqueries, each of which is sent to an LDB for processing. The intermediate and final results are assembled by INGRES/Star, which then returns the final result to the application

Multi-site joins require extracting and moving the data for one of the sides of the join from the LDB where it resides into the LDB containing the other side. This transfer is managed by INGRES/Star, and is done as efficiently as possible: the transferred stream has had all possible restrictions and projections applied at the source LDB. A join of three or more LDBs requires creating a series of query fragments which will effect a convergence of derived relations ending at the LDB where the final result will be computed. Intermediate relations are stored in temporary tables at the sites where later query fragments will use them.

A simple illustration of this convergence is explained by describing some of the convergence graphs of a three-way join which the distributed optimizer would consider.

Given a join of tables A, B, and C, in three different LDBs, where A is connected to B, and B to C, by a join predicate.

One possible strategy is to apply restrictions and projections to C and then move the derived relation to the LDB containing B. Then join B to the derived relation from C in B's LDB (while applying restrictions and projections to B), moving the resulting derived relation to the LDB containing A. Finally join A to the previously derived relation resulting from the join of B and C.

Another possible strategy is to apply restrictions and projections to A and move that derived relation to the LDB containing B. Then apply the restrictionsand projections to C and move this derived relation to the LDB containing A. Finally join A to the previously derived relation resulting from the join of B and C.

Another possible strategy is to apply restrictions and projections to A and move that derived relation to the LDB containing B. Then apply the restrictions and projections to C and move this derived relation to the LDB containing B. Finally join B with the two derived relations in its LDB.

Other strategies, involving semi-joins or cartesian products, may also sometimes be considered depending on the original query. The number of possible convergence graphs grows as the number of tables and LDBs grows.

The distributed optimizer is a component of the INGRES DBMS query optimizer, using much of the same technology. The lowest cost strategy of all possible strategies is found, taking advantage of statistics on each object's pertinent data value distributions, which can be maintained both in the INGRES DBMS and all INGRES gateways.
Additional factors evaluated by the optimizer include network cost estimates over various routings, comparitive capabilities of gateways, availability of useful storage structures and indices on pertinent attributes, table cardinality, and repetition factors of pertinent attributes.

SUMMARY

By providing a uniform SQL application interface to the programmer, (including the use of Open SQL and its Standard Catalogs and Generic Error codes), and by implementing that interface through the INGRES Gateways, we remove the application's dependency on the particular DBMS containing the data that it needs to access. By providing location, network and architecture transparancy through the INGRES networking system (GCA, the Name Server and INGRES/Net), we make transparent the location and architectural representation of the data to be used. Using INGRES/Star, the logical and physical distribution of the data is made unimportant as well. The independance of these interfaces from the components that they are connected to is shown in Figure 1, below.
By providing a uniform interface to a data manager, we leave the programmer to concentrate on the program, not the data. This allows applications to be developed more quickly, and to be easily reused, regardless of the source of the data. It also allows advanced capabilities, such as distributed database managers, to be implemented using a single interface, without the need to develop a special interface for each individual data source to be accessed.

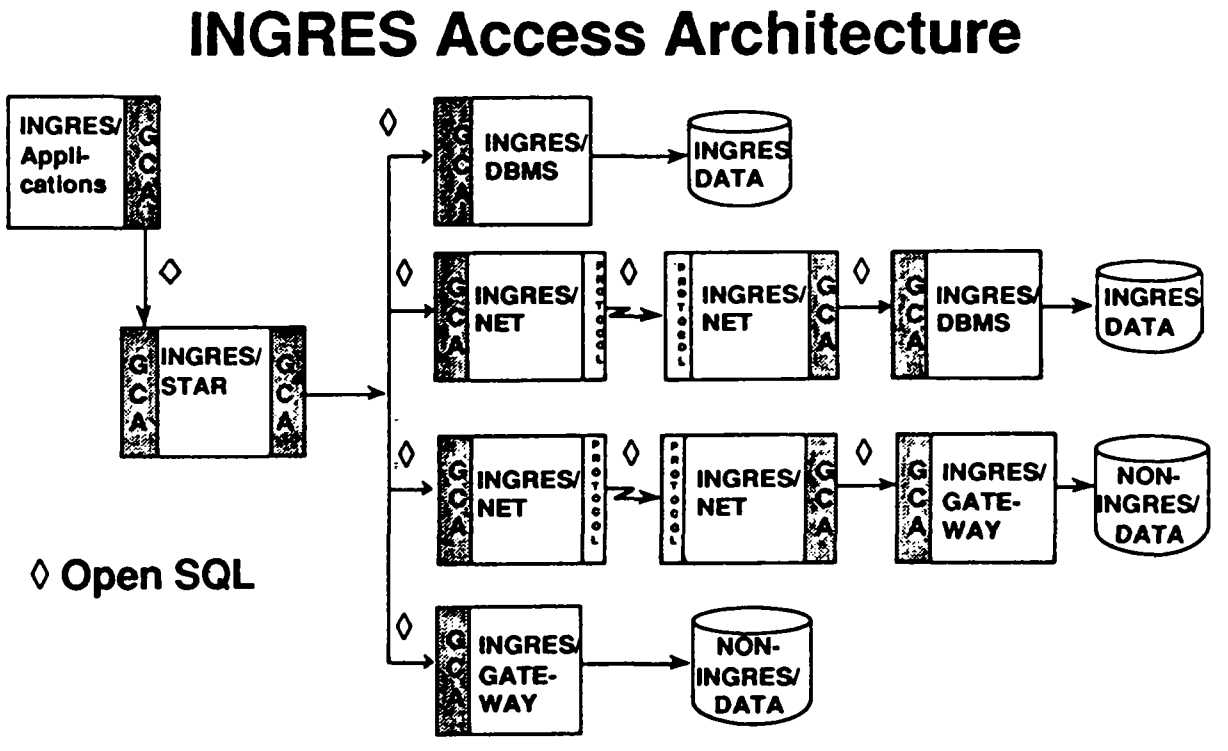

FIGURE 1

The Lotus DataLens[1] Approach to Heterogeneous Database Connectivity

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Abstract

DataLens is a specification for a programming interface that enables applications such as 1-2-3 to access external data sources through the client-server model. Developed at Lotus, DataLens was designed to support access from both decision support and transaction-oriented applications to a broad spectrum of backend servers and data sources. Differences in access protocols are transparent to both the application and its end user. The specification permits DataLens applications to leverage advanced database server features if desired, without requiring that all data sources supply these features. This paper covers the DataLens architecture, how it copes with differences in server capabilities, and how it compares with other approaches to heterogeneous data access.

1 Introduction

Our primary goal in developing DataLens was to allow Lotus applications -- and hence their users -- to gain access to data wherever it might reside. Potential data sources include commercial and proprietary database systems located on corporate mainframes, departmental minicomputers, workstations, and PCs. They also include less traditional databases such as flat files, VSAM files, and CD-ROM databases.

We sought to improve data connectivity regardless of data location, format, and communications protocol. The major barrier to accessing such a wide variety of data sources from an application is the number of interfaces that must be supported. Therefore, we hid the differences in access protocols at all levels -- Application Programming Interface (API) calls, the syntax of the query language, data type representations, and character string encodings.

Incorporating the DataLens interface into applications created a consistent and transparent means for Lotus users to move data into their applications for analysis, manipulation, and storage. Initially, the driving-force application was the 1-2-3/3.0 spreadsheet; the technology has now been incorporated into a number of other Lotus applications (see Section 6 for details).

DataLens drivers are currently available for the Sybase SQL Server under OS/2, Ashton-Tate's dBASE III and Novell's Netware SQL under DOS and OS/2, DEC's RDB under VMS and ALL-IN-1, and IBM's DB/2 on MVS and SQL/DS on VM. Driver development efforts have been announced by Gupta (SQLBase), Oracle, Microrim (Vanguard and rbase), CCA (Model 204), Teradata (DCB/1012), Ingres (Ingres DBMS), and Unify (Accell SQL). Also announced as under development are drivers for Borland's Paradox, IBM's OS/2 Extended Edition Data Manager, and a driver to manipulate simple ASCII files.

The rest of this paper is divided as follows. Section 2 gives an overview of the DataLens architecture, and Section 3 addresses the important question of coping with differences in server capabilities. Section 4 describes the benefits of the DataLens approach, while Section 5 compares it to other approaches. Finally, Section 6 discusses some of the design decisions and issues involved in commercializing DataLens.

2 DataLens Architecture

The DataLens technology is implemented via code built into the application software that communicates through a DataLens driver to the data source. A **DataLens driver** is a module that connects the application with an external data source. It receives requests for information from the application, translates them into DBMS commands, and sends the results back to the application. The application and the driver communicate through the DataLens Application Program Interface (API), which consists of function calls whose arguments include data structures. The end user does not see these calls directly.

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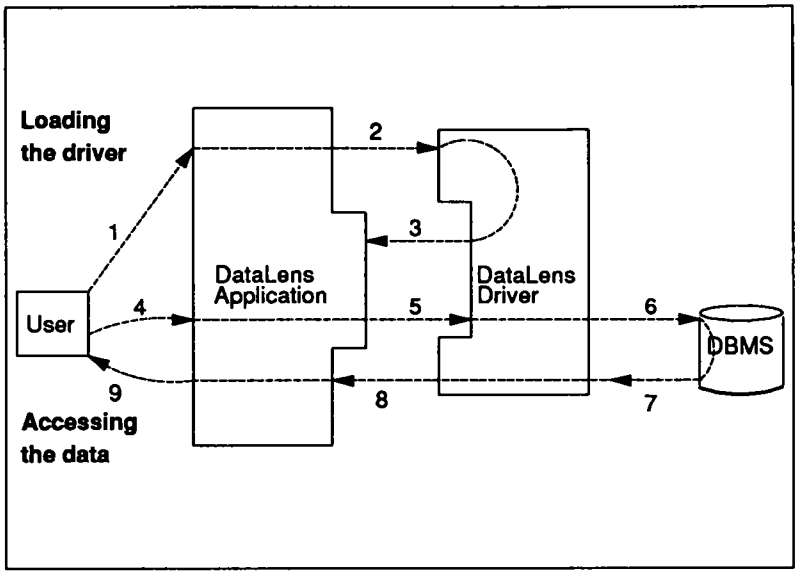
1 Patent applied for.

Unlike many other database APIs, DataLens has no string sub-language that is passed into the server.[2] Queries are formulated by building what amounts to a parse tree, and passing that form over the interface. This removes most of the syntactic oddities of different dialects of query languages (i.e., "!=" vs "<>" for "not equal"), resolves the interpretation of nested algebraic expressions, and allows simple drivers to avoid implementing the equivalent of an SQL parser.

The DataLens driver and the DBMS communicate using the native DBMS interface. To the DBMS, the driver is just another client application making calls to the DBMS kernel.

The figure below shows the sequence of events, and the interplay between DataLens application and driver. Once the driver is loaded, the user can make any number of requests for data. The driver and the application do the rest of the work[3], making access to that particular external database appear as a natural extension of the functionality of the application.



1. Using the commands or user interface of the application, the user makes a request to access a database (for example, using /Data External in 1-2-3).

2. The application loads the appropriate DataLens driver, establishes connections, allocates control blocks, and passes the control block pointers to the driver.

3. The driver supplies driver and database connection information by filling in the control blocks, and passes a function vector of entry points to the application.

4. Using the commands or user interface of the application, the user makes a request to access data (for example, using /Data Query in 1-2-3).

5. The application uses the function vector to call specific DataLens functions within the driver.

6. The driver translates the request into the DBMS-specific API and the associated language used by the database (such as a particular dialect of SQL) and transmits it to the DBMS.

7. The DBMS processes the request and returns the results to the driver.

8. The driver converts the results to DataLens standard format and passes them to the application.

9. The application displays the data and returns control to the user.

There are a few system services needed to support dynamic driver connection by applications. These services -- catalog services and dynamic loading services -- are provided on most platforms by a small piece of code called GAB.

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2 There is an "execute string" trap door, however, for passing arbitrary strings to the server.

3 Due to restrictions arising from the patent application process, we will not give the specifics of DataLens function calls or their sequencing in this paper.

GAB provides a rudimentary naming service for browsing DataLens drivers. This can be a stand-alone implementation, or implemented over a real naming service if the operating environment provides one. GAB also manages the loading and sharing of multiple DataLens drivers. By centralizing this activity on a machine, multiple applications can share drivers simultaneously. Another benefit of implementing loading and catalog services as a separate module is that they can be updated independently of applications and drivers when the underlying services change.

3 Coping with Differences in Servers

Interfaces from application development tools to heterogeneous data sources have traditionally taken one of two roads. The "low road" assumes that only the functionality common to all sources can be relied upon. This is workable, but fails to take advantage of any advanced features possessed by a particular backend server. The "high road" assumes that all sources provide a rich set of functionality, including, for example, selections, relational joins, and a queryable system catalog. While this eases the task of the application, it sets the bar too high for implementing a DataLens driver to a simple, non-relational data source. Effectively, the driver-writer must write a DBMS.

3.1 Description and Use of Server Capabilities

With DataLens, Lotus defined and followed a "middle road." The DataLens interface is divided into Basic (required) and Optional parts. A DataLens application can rely on the presence of all Basic function calls and capabilities, which are the minimum needed to bring external data into the application. The application can choose to use those Optional calls and capabilities reported by the driver. This allows an application to read data from all data sources, and to selectively demand more of those data sources capable of handling advanced requests. The power of full-function relational database servers such as Sybase SQL Server can be tapped, while simple, non-relational systems -- which may be little more than file access methods -- can participate as data sources at low implementation cost.

Specifically, Basic capabilities allow the application to:

- Connect to a driver, a server, and a database managed by the server
- Determine the database's characteristics, such as supported capabilities, data types, and character sets
- Determine the tables and fields in the database
- Open and close database tables
- Browse through a given table
- Execute a simple query (involving projection but not selection)
- Fetch data
- Provide information about a function call that failed
- Execute a command in the native language of the database and return information about that command

The driver uses a capability bit mask to tell applications which Optional capabilities, if any, it supports. Optional capabilities include:

- Data definition
- Non-sequential fetching
- Long data handling
- Record selection
- Transactions and concurrency control
- Breaking out from an executing query
- Privilege handling
- Updating
- Querying and subquerying
- Prepared statement handling
- System catalog querying
- Operators and functions (logical, arithmetic, mathematical, string, date, aggregation, financial, and set)

When a given Optional capability is present, the driver must support it through standardized DataLens function calls. It is also possible to define Extended capabilities, corresponding to server-specific functions not covered by Basic or Optional capability bits. However, there is no standard protocol for manipulating Extended facilities.

3.2 Location of Functionality

The capability mechanism of DataLens allows flexibility with respect to the location and extent of functionality. A particular function, such as sorting, might be implemented in the DBMS server kernel or in the DataLens driver above it. This

distinction is transparent to the application (except for performance implications, if any). Alternatively, the application itself may either provide the function, or prevent the user from invoking it. This last choice leads to two major modes of DataLens usage.

The value-added approach: If a particular backend (i.e., the driver/server combination) does not support a function invocable in an application, the application supplies that function. For example, a backend might support selection via equality comparisons only (COMPONENT-LENGTH = 6), and not support relative comparisons (COMPONENT-LENGTH > 6). The application could then request all of the data and perform the selection. As another example, a particular backend may not be able to perform a relational join. In this case, the application could ask for the appropriately projected and restricted intermediate tables, and then perform the join itself (similarly to the Global Data Manager of Multibase [SMIT81]).

The passive approach: The application allows the user to invoke only those operations that are supported by the currently connected driver. Loosely speaking, this can be thought of as "greying out" menu choices in a user interface, or restricting the complexity of queries that can be constructed. If a backend cannot do a left outerjoin, for example, the application user is not permitted to request one.

3.3 Fundamental Differences

Putting aside questions of exact functionality, there are a number of thorny areas to address in connecting to heterogeneous data sources. Below is a brief list, together with the DataLens approach to each.

Data types: DataLens uses standard platform-independent data types (e.g., integer, packed decimal, date, floating point) to transfer data between the application and the driver. These are standard C types; their implementations on particular hardware may vary. Non-standard data can be converted to one of the standard data types, or the driver can define extended types (e.g., stock market quote fractions).

Character sets: Characters inside the driver and its data source can be in any character set. However, drivers and Lotus applications communicate data across the DataLens API via the Lotus Multibyte Character Set (LMBCS). LMBCS is a portable and expandable character set, similar to DEC's Multilingual Character Set, that can represent every character in any character set (including Chinese and Arabic), regardless of country and computing platform. Files created in other countries can be read and written without being corrupted, even if there are conflicting definitions among the characters in the IBM code pages of the respective countries.

System catalogs: Drivers translate meta-data queries and updates, expressed as DataLens functions, down to the implementation of the underlying system. The capability mask mechanism is used to specify whether the server supports views, user authorization, synonyms, rowids usable for update, etc. At a minimum, all drivers must support a set of simple catalog browser functions that allow applications to obtain basic information about tables and columns in the database. An Optional capability is to allow direct queries against system catalog tables (e.g., to find all columns in a table).

Exception handling: DataLens defines 102 standard error conditions, plus a mechanism for drivers to deliver detailed event- and backend-specific error descriptions to an application. This allows DataLens applications to gracefully handle a very wide range of error conditions without having to be aware of the precise behavior of many database servers.

Isolation models and transactions: The capability definition mechanism allows description of the different treatments of isolation (level of interference with other server users) to be found across servers (e.g., read repeatability versus read only connections). Some servers have a transaction capability, so that the application can commit and abort transactions; others do not. The capability to break out of a currently executing query is often tied to the server's transaction model.

Distributed database capabilities: DataLens itself does not directly define any distributed database manipulation support. However, DataLens does allow an application to simultaneously connect to multiple drivers, servers, and databases in heterogeneous systems. Lotus 1-2-3 uses this functionality to support queries across distributed data. For example, a table residing in one database system may be joined with two tables from a different DBMS. 1-2-3 distributes the parts of the query which can be handled independently at each site, and assembles the answer. For all other distributed and cross-database support, 1-2-3 depends on servers which themselves handle distributed databases, including issues of two-phase commit, distributed catalogs, fragmentation, replication, and distributed query optimization.

4 Benefits of the DataLens Approach

DataLens gives end users access to external data through their applications. It allows applications to use both basic and advanced server features. Finally, it is an efficient approach to developing connectivity from multiple applications to multiple data sources.

4.1 Direct Access from within Applications

The DataLens technology allows users to access external data directly from within their familiar applications, using commands and menu choices that already exist in the applications. In 1-2-3, for example, users can continue to use the */Data Query* command and its associated input, criteria, and output ranges. Users do not need to learn new installation procedures, applications, commands, translate utilities, or data extract tools. Users no longer need to re-key data, and are able to receive current, uncorrupted data for timely analysis. Training costs are also kept low, since users do not need additional training for each data source.

4.2 Leveraging the DBMS

DataLens drivers use the existing DBMS interface to communicate with the DBMS. DataLens is thus non-intrusive to the host server, while still exposing substantially all of the power available from that server.

DataLens drivers can be written initially to support a minimum of functionality (Basic capabilities) so that access to data can be provided very quickly. Later, a new driver which exposes the power inherent in the backend (Optional capabilities) can be substituted. It is significant that the driver developer is not limited to offering a common subset of features supported by all DBMSs.

The flexibility built into the DataLens technology makes it easy for driver developers to add support for new DBMS features. Escape mechanisms to access server-specific features include an execute-string trap door, an execute-function trap door, and Extended capabilities. Periodically, it will pay to incorporate evolving DBMS features more formally into the DataLens model, via new capability bits and functions.

4.3 Universality

DataLens allows a driver to be written once for a particular data source that will support all DataLens applications. Similarly, once an application understands DataLens, it needs to do no other work to gain access to many sources of data. As the number of applications and drivers grows, connectivity increases geometrically, but the amount of work any one party needs to do stays constant. Specifically:

- The development cycle is reduced since developers are not constantly modifying their database extract and reporting programs.
- The DBMS product gains enhanced product positioning and increased product use by providing access from many applications.
- Because DataLens drivers can be easily ported, the driver developer can provide access to the DBMS from applications on different platforms.

5 Comparison to Other Approaches

5.1 Simple Approaches

The most common method of transferring data from a database into an analytic application is to re-type the data by hand. This is not only annoying and error-prone, but depends on a report being printed which can be analyzed to extract the needed data.

Both generic and custom data translation programs exist to aid in the transfer of data. This method is generally cumbersome and time-consuming. If the data happens to reside on a corporate mainframe and is needed on a PC, the turn-around time for a data request is measured in days and weeks. If a custom extract program must be written, the wait can be measured in months and years.

Cut-and-paste is a step up from these methods, but it suffers from two drawbacks. The user must learn a second program to request the data (and a third, fourth, fifth for each new data source), and data type information is lost in most cut-and-paste systems, where data is commonly rendered as character strings.

Against these ad hoc methods, DataLens provides a real-time connection to the data, preserves type information, and saves the user from having to learn a second application.

5.2 Complex Approaches

Server gateways to third-party backends generally take either the low road (least common denominator) approach or the high road approach (often SQL strings) to expose functionality. As we have noted above, DataLens permits either extreme,

but allows a more flexible third choice with the middle road. The cost of this flexibility is that a DataLens application wishing to take advantage of advanced features must first determine if they are present. If not, the application must either work around them or deny them to the user.

In addition, since DataLens allows applications to communicate directly (via drivers) to a variety of servers, no "middle-man" DBMS is required by the architecture. This is an advantage over many "gateway" DBMSs (e.g., Ingres), which must themselves be present to facilitate access to diverse backends. The CL/1 connectivity language for the Macintosh also needs no intermediary between application and driver, but lacks the concept of server capabilities.

More ambitious approaches to heterogeneous connectivity have attempted to construct global (or federated) schemas (e.g., [TEMP87]), or "interoperable" heterogeneous DBMSs ([LITW86]). While DataLens resolves architectural dilemmas related to datatypes, character sets, system catalogs, and different capability sets, it stops short of addressing schema integration issues and inter-schema conflicts. Of course, once the data has arrived, there are often powerful facilities for transforming it within applications such as 1-2-3.

6 Commercialization Issues

Recall that our primary goal for DataLens was to be able to access data wherever it might be stored. It is our belief that most data is now stored in non-relational systems. In fact, much data is stored in extremely simple systems, exemplified by a VSAM file created and managed by one COBOL program. Realistically speaking, this will be true for some time into the future, until the new wave of relational servers takes over. While DataLens is a very good match for SQL servers, we did shape the approach to provide an optimal interface to simpler, less intelligent backends. This is manifested in two main areas. The first is the very simple requirements placed on a DataLens "Basic" driver, the simplest legal version of supporting the specification. The second area is in the choice of the call interface over a string language. Under this approach, simple drivers do not need any sort of parsing facility.

The DataLens specification itself was about half of the work Lotus had to do. Driver developers -- both external and internal to Lotus -- needed tools to help them. Lotus therefore created a *DataLens Developer Toolkit* to provide a comprehensive development environment for building DataLens drivers [LOTU89]. The Toolkit includes code samples, a sample driver, testing and diagnostic tools, LMBCS character-handling routines, and documentation (including the DataLens specification). Driver developers are encouraged to develop their drivers following the samples and to document the drivers using a standard documentation template. There is currently support for creating drivers for PC DOS, OS/2, DEC VMS and ALL-IN-1, and Sun Unix.

On the application side, DataLens technology has now been incorporated into 1-2-3/3.0 for DOS and OS/2, 1-2-3/M for IBM mainframe environments, 1-2-3/G for OS/2 Presentation Manager, 1-2-3 for Sun workstations, and 1-2-3 for DEC VMS and DEC ALL-IN-1 on the VAX. Thus, 1-2-3/M users can now access DB/2 directly, 1-2-3/G and 1-2-3/3.0 users can access Sybase SQL Server, and so on. In the future, DataLens technology will be used for Lotus database tools.

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