

To appear in *Journal of Organizational Computing*

**Integrating Information From Global Systems:
Dealing with the “On- and Off-Ramps” of
the Information SuperHighway**

March 1995

WP# 3800
CISL WP# 95-02

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Acknowledgment: Work reported herein was supported by the MIT International Financial Services Research Center, the MIT Center for Coordination Science, the MIT Industrial Performance Center, and Advanced Research Projects Agency and USAF/Rome Laboratory under USAF Contract, F30602-93-C-0160.

**INTEGRATING INFORMATION FROM GLOBAL SYSTEMS:
DEALING WITH THE "ON- AND OFF-RAMPS" OF THE INFORMATION SUPERHIGHWAY**

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ABSTRACT

The notion of an "Information SuperHighway" has attracted considerable attention. It offers the possibility to access information from around the world in support of many important applications in areas such as finance, manufacturing, and transportation (e.g., global risk management, integrated supply chain management, global in-transit visibility.)

Unfortunately, there are significant challenges to be overcome. One particular problem is *context interchange*, which can be thought of as dealing with the "on- and off-ramps" of the Information SuperHighway. Each source of information and potential receiver of that information may operate with a different *context*. A context is the collection of implicit assumptions about the *context definition* (i.e., meaning) and *context characteristics* (i.e., quality) of the information. When the information moves from one context to another, it may be misinterpreted (e.g., sender expressed the price in French francs, receiver assumed that it meant US dollars.)

This paper describes various forms of context challenges and examples of potential *context mediation services*, such as data semantics acquisition, data quality attributes, and evolving semantics and quality, that can mitigate the problem.

1. INTRODUCTION

The "Information SuperHighway", and its current form as the Internet, has received considerable attention in government, business, academic, and media circles. Although a major point of interest has focused on the rapidly increasing number of users, sometimes estimated as 20 million and growing, an even more important issue is the millions of information resources that will be accessible.

Today, when people talk about "surfing the 'net," they usually refer to use of the World Wide Web (WWW) through some user friendly interface, such as Mosaic or Netscape. This type of activity can be effective for casual usage but requires significant human intervention for navigation (i.e., locating the appropriate sources) and interpretation (i.e., reading and understanding the information found.)

Consider the opportunities and challenges posed by exploiting these global information resources in an integrated manner. Let us assume that we have access to information from each of the various stock exchanges (possibly with a delayed transmission for regulatory purposes) and each of the weather services around the world. We might want to know the current value of our international investments, which might require access to multiple exchanges both in the USA (e.g., NYSE, NASDAQ) and overseas (London, Tokyo). As another example, you might want to know where are the best ski conditions at resorts around the world. To manually access and interpret the numerous information sources relevant to these examples would rapidly become impractical. Although some problems may be immediately obvious, there are subtle challenges. In this paper, we first illustrate these problems and then present new concepts and research approaches aimed at addressing these challenges.

1.1 Changes in the Information Technology Environment

The information technology industry has experienced tremendous improvement in the performance and capability of hardware and software, coupled with dramatic drops in costs over the past four decades. It is hard to think of any other industry that has seen such dramatic improvements while reducing costs, over such a sustained period of time.

These improvements are especially evident in three areas: (1) the increasing capabilities and comprehensiveness of *communication networks* (e.g., Internet), (2) the ability to store and provide access to tremendous amounts of *information* (e.g., very large data bases), and (3) the convenience of *user-friendly interfaces* (e.g., Mosaic), which make these capabilities available to a much wider variety of users than ever before.

1.2 Opportunities for and Difficulties of Increased Information Integration

Increased information integration is important to business in order to improve *inter-organizational relationships*, increase the effectiveness of *intra-*

organization coordination, and provide for much more *organizational adaptability*. Examples of these opportunities and their importance can be found in *The Corporation of the 1990s: Information Technology and Organizational Transformation* [10].

Many organizations are attempting to gain these advantages. For example, a recent headline from the *Financial Times* reads: "The growth in applications running on client server networks amounts to a second computer revolution." Clearly there is something fairly dramatic going on. On the technology side the article talks about the issue of communications while on the business side it talks about the need for more flexibility, more responsiveness, and more productivity.

Similar articles can be found in newspapers and magazines, such as the *New York Times*, *Wall Street Journal*, and *London Financial Times*. At the same time, problems are also highlighted. For example, even the *Bangkok Post* talks about the great challenges of "managing heterogeneous, diverse computer environments" and the need to "access relevant and accurate information." This problem is referred to in that article as the "Tower of Babel" and will be explained in the next section.

2. THE ROLE OF CONTEXT

There is an important concept which we will refer to as *context*. In order for people to use information, whether electronic and other media, there is a need for context, which is the way in which we interpret the information. That is, what does it mean (which we call the *context definition*) and how good is it (which we call the *context characteristics*.)

The context is not explicit for at least two reasons. First, it provides efficiency of communication (e.g., if asked what is your grade point average by a fellow student, you can reply "3.8" without having to explain that it is a 4-point scale with 4 being best, etc.). Second, the context can be so fundamental in an environment that most are not even aware that there is another possible interpretation (e.g., we all know that "A" is a top grade.)

2.1 Context Differences

Context may vary in three major ways. First, context varies due to *geographical* differences, that is, the ways things are interpreted in the US is different from that in England, France, or China. Second, there are *functional* differences. Even within the same organization things going on in one part of the

organization are often very different from similar things that occur in other parts of the organization. Third, there are *organizational* differences. The information used in the same function, in the same industry, in the same country, can have different meanings between two companies. For example, the way in which CitiBank might define a credit rating could be different from the way Chase does the similar thing. Thus, context can differ from one organization to another.

Previously, people, information, and context were tightly coupled. For those in charge of cash management in a financial organization in New York City, the fact that they deal with the world in a particular way is not a problem because the information used and the people who use it are all together in one place and share the same context. In that same city a different function of the organization, loans for example, may operate differently but independently. Further, the same activity, such as cash management in New York City may or may not be identical to the same activity in London. The point is that although these contexts can differ, as long as the people, information, and context of a group are remain coupled together and separate from all other groups of people, information and their contexts, there is no problem.

The business needs to integrate information and the advances in technology have combined to produce both good news and bad news. The good news is that now we can communicate electronically in seconds or fractions of seconds, gathering information from all parts of our organization or from related organizations all over the world. The trouble is that we can gather the information, but the context gets left behind. We can ask for the price of an item and get an answer such as "23", but is that \$ or £? Is it single \$'s or thousands (as an aside, even if given a clue, such as 23M, there may be a problem because sometimes M means millions, sometimes it means thousands -- in which case MM is used to mean millions)? Is it for a single item or a group (e.g., block of shares)? Does it include or exclude taxes, commissions, etc.? The answers to these questions are usually well known to the traditional users of that source information and that share its context. In financial organizations, for example, this situation creates great problems in areas such as risk management, profitability analysis, and credit management where information must be gathered from many sources with differing contexts. In order to be effective all these applications require global information, but it must be integrated intelligently.

2.2 Examples of Context Differences

Let me share a personal example. At MIT periodically I serve on a review committee for our freshmen undergraduate admissions. There is a professional staff who review thousands of applications and select what we hope are the best students. Also there is a panel of faculty who review the staff decisions to see whether they are consistent and reflect what the faculty would like to see happen.

One day while going through a student folder, I was caught by the fact that this particular student had D's in almost every class. Normally, of course, we look for top students who make grades of A and sometimes B, maybe the occasional C. I phoned the Admissions Office and said, "Well I know that there are sometimes special factors, but this student unfortunately seems to be well below any standard I can imagine." The Admissions people answered, "Well Professor Madnick, you must understand that this student is from Australia." So I said, "Do we have a special program for Australians?" What was explained to me, and probably known to millions of Australians, is that in most of the Australian school systems "D" means "with distinction"! It is one of the highest grades given. The point is that context is all around us and we don't realize it.

As another example, on a recent flight to a conference in Vancouver, British Columbia, Canada, I was reading various magazines. In one there was an advertisement for IBM's OS/2 Warp operating system which had the comment "available for less than \$120." Another magazine had a similar ad that read "available for less than \$90." Was one of these ads wrong? Were the magazines for different dates and had the price dropped dramatically? What was going on? I noticed that both magazines were for the current month. One was *Forbes*, the other was the *Canadian Airlines In-Flight* magazine. As you may now have guessed, one was US dollars, the other was Canadian dollars. The only clue in the ad itself was the same print at the bottom which read "© IBM Corp" in one and "© IBM Canada" in the other. For the majority of passengers, Canadians, flying on that airline, the *Inflight* magazine would have been fine but the U.S. edition of *Forbes* would have been potentially misleading.

2.3 Challenges of Context in Global Systems

In global systems, the above examples represent serious problems. Information gathered from throughout the world in different organizations and different functions has many individual contexts, contexts that are lost when the information is transmitted.

Although some may think the solution is to come up with a single context for the whole world, or at least all of the parts of the same company, this is extremely difficult for any complex organization. There are often real reasons why different people, different societies, different countries, different functions, different organizations may look at the same picture and see something very different [16]. To assume that this can be prevented is a mistake. We must accept the fact that there is diversity in the world, yet we need global systems.

So what is the challenge that we face? We must realize that it is unlikely that there will be one single system. The challenge is to integrate global information from diverse organizations but to take the context differences into consideration. This paper focuses on how technology can help us to meet this challenge.

3. EXAMPLE APPLICATION

The issues and problems will be illustrated through a concrete example, which is fairly simple yet parallels many other examples. The Placement Assistant System (PAS) (See Figure 1) is being developed at MIT to help students get good jobs.

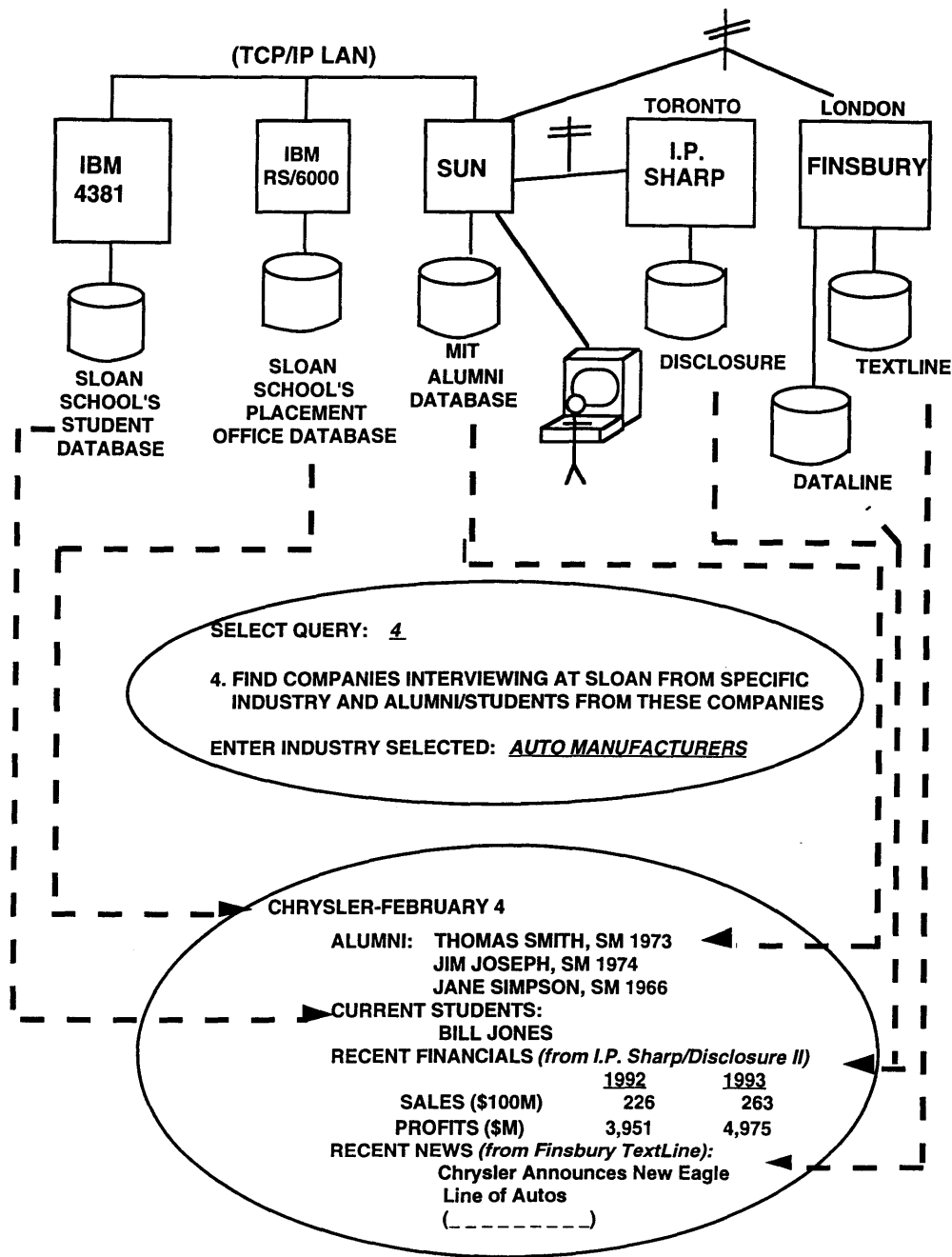


Figure 1: Prototype Placement Assistance System

This example illustrates the need to integrate information from multiple sources. Although the term "global information" has been used, similar challenges exist for "geographically local information." For example, in one insurance company in their headquarters building alone, there are over a dozen different definitions of what "net written premium" (their primary measure of sales) means

in different organizational groups. Context difference can occur in such "geographically local" but "contextually global" systems, this also occurs at MIT.

3.1 Component Systems

There are three internal systems in the PAS example. They are managed by different parts of MIT, where like most universities different parts of the bureaucracy may be continents apart philosophically. The Sloan School Student Database keeps track of its students, their grades, prior job experience and such. Another database run by the Placement Office helps the students by keeping track of companies who interview at Sloan, the positions offered, interview dates and such. Yet another system run by the MIT Central Alumni Office keeps track of alumni, where they work, how much they have donated, and such.

In addition, there are two external systems illustrated here. One is a service of I.P. Sharp, called Disclosure, from Toronto, Canada. This service provides financial information on companies such as their profits, sales, number of employees, etc. This system focuses mainly on North American companies. The other service, operated by Finsbury Data Services out of London, called Dataline, has information primarily on European companies, their sales, profits, and number of employees, etc.

3.2 Example Usage

Consider a simple example of an application that might need to use all of these information sources in unison (see Figure 1). A student is about to go for a job interview prior to graduation and has selected a particular industry of interest, such as the automobile industry. In this case, he may want to know which automobile companies are going to be interviewing at MIT (e.g., Chrysler on February 4). This is found in the Placement System. He may want to know whether there are any alumni from MIT who are already working for that company that might be called to find out what is going on in that organization. This is found in the Alumni system. He may want to know if there are any students currently at the university who have previously worked for the company. This is in the Students database. He also may want to know how that company is doing financially. This information comes from the Disclosure or Dataline services.

This example illustrates how one particular activity, that is applying for a job, might require information from five or more autonomous systems. The same

thing is found in many applications, such as market research, financial risk management, production planning.

3.3 Context Challenges in the Example

Some of the problems encountered in the PAS example are illustrated in Figure 2. The information on the left-hand side emanates from the Disclosure system, and the information on the right from the Dataline system. These have information on the HONDA automotive company, which by coincidence happens to have data in both computer systems. So, whereas one system is primarily for North American companies and the other is primarily for European companies, they both have information on certain Japanese companies.

DISCLOSURE		DATALINE	
ATTRIBUTE	VALUE	VALUES	ATTRIBUTE
COMPNO	3842	HOND	CODE
CF	19,860,228	28-02-86	PERIOD ENDING
NI	146,502	146,502	EARNED FOR ORDINARY
NS	2,909,574	2,909,574	TOTAL SALES
NRCEX (ROE)	0.11	19.57	RETURN ON SHAREHOLDERS EQUITY

Figure 2: Context Differences in Information from Two Sources
(Information on HONDA from Disclosure and Dataline)

Identification differences. First, for rapid access to the information in Disclosure you would need to know the company's COMPNO, which is 3842, whereas in Dataline you would need to know its CODE, which is HOND. Assuming that you were able to get the above information, let us see how the rest of the information shown in Figure 2 can be interpreted.

Format differences. Note the "period ending" information for the Dataline system, it is 28-02-86. Notice the order in which this date is indicated, with the day first. If you are American you would say that the day and month are backwards because it is our custom first to represent the month, then the day. This problem can be recognized because there is no month 28. In only seven or eight years there

will be dates like 01/02/03! What is this? Is it January 2, 2003? Is it February 1, 2003? Is it February 3, 2001? If this is the shipping date, it can make a big difference.

On the left-hand side of the same row you see the variable CF with the value: nineteen million, eight hundred, sixty thousand, two hundred and twenty eight. What is this? Some might guess that it is some kind of measure of time. (One of my students guessed that it is the number of elapsed seconds since Elvis Presley died. But of course that would not be very good because there seems to be a question of whether he actually died or not.) It is really 1986-02-28 that is February 28, 1986. In this system all data, including the date, are displayed as financial data, with commas and a dollar sign in front. (In fact, it actually appeared as \$19,860,228, leading one student to remark, "this proves that time really is money!") For those who use this system every day, there is no problem -- it is obvious to them. But for those who do not use it every day, clearly it is confusing.

Attribute naming differences. As some of the above examples also illustrate, the attribute names, such as CF, are not necessarily obvious since abbreviations are often used. Thus, NI for Net Income and NS for Net Sales are typical and may be decipherable whereas NRCEX for Return on Shareholder Equity may not be quite so obvious. The attribute named "Earned for Ordinary" requires a bit of context background to understand. What are called "common shares" in the USA, are called "ordinary shares" in the UK. In typical UK accounting reports, the profits or earnings of the corporation are referred to as "Earnings attributable to the Ordinary Shareholders" or "Earned for Ordinary" for short. A reasonable abbreviation for a UK accountant but likely to be a puzzlement to a USA analyst.

Scale differences. At the bottom of this table there are two numbers. These are return on equity. These numbers illustrate a scale difference. On the left-hand side, the number is expressed as a decimal fraction -- 0.11. On the right-hand side, it is expressed as a percentage -- 19.5%. That is a difference that could have a significant impact if not realized.

Definitional differences. What is more fundamental, and more puzzling, about this return on equity example is that one number is approximately 11% and the other is approximately 20%. How can the same company in the same year have two different "return on equity" values that vary by a factor of two? And yet there is no mistake, it is not a typographical error.

Anyone with accounting experience would know that return on equity is return divided by equity. However, this opens the question of what is meant by "return" and "equity"? Within generally accepted accounting principles there are

many variations of interpretation (e.g., how are extraordinary expenses handled, what depreciation rules are used, how are certain types of stock options handled?). Starting with the exact same raw data, the Disclosure people came up with one number, and the Dataline people came up with a different number. Both are correct -- for their own context.

What is quite intriguing is an assignment given to a doctoral student (it was referred to as "the trail of intrigue."). He was to telephone these two companies and ask a simple question: "What does 'return on equity' mean in your database?" It took about two weeks to track down an answer to the question. Multiple steps were required: the local customer support people normally deal with simple questions, such as "what does this command do" or "what is the charge for your service?", so we were referred to their local data expert -- who did not know the answer. Then the search moved to their headquarters support staff and likewise went from the first-line staff to the data experts. One unexpected problem that increased the difficulty and time effort is that one of the companies got some of the data from another company and resold it, so they did not even know what it meant, they just got it and passed it on. The key point is that as information goes from organization to organization, flowing around the world, we have more and more information but we know less and less what it means.

Inter-database Instance Identification. There is one further problem in the PAS example not shown in Figure 2, which we refer to as "inter-database instance identification." In the Alumni database you would find a company called "Ford Motor Co." In the Placement database there is something called "The Ford Motor Company." In Disclosure there is something called "Ford Motor Co", and in the Textline database there is something called "Ford Motor USA."

In short, for the same company there are four different ways that the name was recorded. At first it might look like at least two are the same, but there is a subtle difference. The first has a period at the end of "Co." for Company whereas the third does not have the period. We might not have noticed this, but computers would have viewed them as different names. If the Alumni computer system were asked for "Ford Motor Co" without the period it would say "I do not have that company." Dealing with this type of situation is a very difficult task for computers.

4. CRITICALITY AND CHALLENGES IN GAINING A GLOBAL VIEW

Although the detailed example of the previous section was a university application, similar needs and problems occur throughout all businesses. The following short example is quite typical.

A newly-appointed Vice-Chairman of the Board for a major company, asked his marketing and IT people, "who are our top one-hundred customers?" It must be noted that this company operates through 157 different subsidiaries in over fifty countries, and their customers are in turn large companies with many divisions. When the executive asked for an answer there was a pause, and they asked "How soon would you like that?" He said "Late this afternoon would be fine." They said, "How would three months be?" Eventually the report was pulled together in about three weeks. The major technology that they used was Faxes sent from all over the world, using college students hired to go through them in the evenings, sorting, matching, and reconciling them. Most large organizations would have similar difficulty performing similar chores. Other examples of actual situations can be found in [2, 9].

There has been tremendous successes within local systems -- the systems that do sales; the systems that do inventory; the systems that do forecasting within the autonomous parts of our organization. The challenge is how to tie these systems in with other functions in the organization, with other geographical parts of the organization, and with partners: suppliers, customers, and other forms of allies.

5. EXAMPLES OF CONTEXT MEDIATION SERVICES

Effectively integrating information from multiple sources both within and across organizations represents an important solution to many critical business needs [3], but a key challenge for integration technology research [6, 7, 11]. Organizations can be simultaneously "data rich" and "information poor" if they do not know how to identify, categorize, summarize, and organize the data. Although there are many important integration technology research directions in this area, three particular examples will be highlighted: data semantics acquisition, data quality, and data semantics and quality evolution. We refer to these types of efforts as *context mediation services*.

5.1 Data semantics acquisition

As business operations become increasingly dispersed geographically and functionally, differences in work processes at each site performed by people trained

for each site will become more critical, leading to data incompatibilities and inconsistencies when these differing sites must interact. Before these differences could be reconciled, we would need to be able to represent the semantics of the data as used in each environment, what we have called the *context* of the data [14].

Research on using metadata to represent *context definitions* provides the basis for capturing and disseminating knowledge about data meanings and can facilitate the data reconciliation and integration process [12, 13]. In this particular approach, the context of both sources and receivers is captured (A receiver may be a human, an application, or another database). A *context mediator* is thus able to compare the contexts and determine if they are same; if they are not, it attempts to translate the source information into the receiver's context if it has sufficient general-purpose *context conversion knowledge* (e.g., knows how to convert from feet to yards, \$ to £, without-tax to with-tax).

5.2 Data quality

Organizations have become very concerned about quality in areas ranging from manufacturing quality to software program quality. Data quality, in comparison, has received relatively little attention. Issues relating to data quality are becoming increasingly important as information is moved through multiple organizations. To a large extent, data quality considerations in the past were handled through personal familiarity; the user knew the characteristics of the data used in his or her organization and informally took this into account when using the data. This approach is not feasible as increasing numbers of information sources are used, many not well known to the user. They are increasingly exposed to data with various levels of quality for which they do not have first-hand familiarity. Furthermore, many currently automated processes for converting, merging, and manipulating the data renders inaccessible information about the original data that might have conveyed information about its quality. For example, the originating source of a given piece of information is often a key element in judgements about its credibility and quality [8, 18].

There are many data quality attributes that may be important, such as accuracy, completeness, timeliness, source, and stability [15, 17]. Defining and measuring the important data quality attributes, which we refer to as *context characteristics*, is an important step. Then, properly maintaining this quality-related information as data moves through and between systems, as part of the context mediation services. Both the defining/measuring and propagation of context

characteristics represent significant challenges and important research areas. But, with this quality information, decision makers would be better able to make effective use of the data.

5.3 Evolving semantics and quality

It must be realized that autonomous databases are independently evolving in semantics and quality as well as in content (i.e., values). For example, consider the situation of stock exchanges around the world. Not only are the stock prices changing continuously, but the definition of the stock price also can change. At some time in the future, the Paris stock exchange will probably change from being measured in French francs to ECUs (European Currency Units). The normal "ticker tape" data feeds do not explicitly report the currency, it is implicit in the context of the source.

Although the example of changing francs to ECUs is currently hypothetical, a recent actual example was the change by NASDAQ (the USA over-the-counter stock exchange) to reporting prices in units of 64ths (code #) in addition to reporting in 16ths (code *) and 32ths (code /). This change caused enough problems to have received front page coverage in the *Wall Street Journal*.

More subtle examples include changes from reporting "latest nominal price" to "latest closing price" or from a percentage based pricing to actual prices, as happened at the Madrid stock exchange. Furthermore, in a historical database of stock prices, it must be recognized that the meanings had changed over time especially when doing a longitudinal analysis.

Of course, the quality of the sources and the quality requirements of the receivers also change over time. In many cases, new data capture technologies and procedures can improve the quality. Alternatively, cost-cutting measures or organizational and procedural changes may decrease the quality. Likewise, the receiver may need higher quality information due to its more critical role in decision-making or may be able to settle for lower quality due to its less critical role or the available of additional comparison sources.

By capturing the context of the sources and receivers, the *semantic context mediator* can formally and automatically compare the contexts to determine if they are compatible, partially compatible, convertible, or incomparable. Similarly, by representing the quality characteristics of the source data and the quality needs and tradeoffs of the receiver, the *data quality context mediator* can determine if they are compatible. These mediator services can be performed on a dynamic basis. Thus, as

source or receiver contexts change, the necessary adjustments are made automatically allowing the autonomous evolution of the individual systems. This is a critical requirement in most environments and an important premise for the growth of the Information SuperHighway. Such research efforts [13] represents a direction towards solving the more general problem, which we call *context interchange* [1, 14].

6. CONCLUDING COMMENTS

A key challenge in effectively integrating global information and exploiting the capabilities of the Information SuperHighway is our ability to tie the contexts together. There are systems now being developed to deal with this challenge, which over the next few years will rise in importance.

One dramatic example of the importance of these efforts can be found in a US government study of lessons learned during the Gulf War. There was a tremendous transportation coordination issue involved since over 70% of all materials shipped to the Gulf used commercial carriers: commercial trucks, trains, ships, planes, with material coming from a wide range of commercial companies -- food companies, clothing companies and so on.

According to this study, there were about thirty-thousand huge containers of material shipped from around the world -- much from the US but also from elsewhere -- to the Gulf theater of operation. An occasional container would arrive at the Gulf with no information to explain what was inside. These containers then had to be opened and all the materials unloaded and inventoried at a port in Kuwait or Saudi Arabia, repacked once its contents were identified, and then shipped on to an appropriate destination. Of the forty-thousand containers shipped to the Gulf, how many would you guess had to be hand-inspected this way? Ten, twenty, a hundred, a thousand? It was over 27,000 containers.

The point here is that *we can move containers weighing tons around the world faster than we can move the information to tell us what is in these containers*. This is not an issue of "stupidity" or human error. It results because there are hundreds of different computer systems in the airlines, the shipping companies, the port facilities, railroads, trucking companies, and manufacturing companies. These systems were never designed to directly operate with each other. Although each system itself may be quite efficient, the interfaces between these systems, effectively the "on and off-ramps" of the information highway, introduce

tremendous disruptions and delay, usually necessitating significant human intervention or specialized handling.

To address this particular problem, a new project, called Transportation Information Access Dual-Use (TRIAD), is being proposed to set up a global transportation information infrastructure that allows information to be shared and exchanged among these autonomous companies around the world. This need is not limited to the US government and its military since the same requirements exist for all large organizations.

In conclusion, there is a tremendous need to be truly effective in integrating global systems. The technology is becoming more advanced and more readily available. The challenge to management is twofold: to use the existing technology effectively and creatively; and, in preparing for the future, to look to new technologies emerging out of research groups [4, 5] to address currently unsolved problems, such as context. Exciting opportunities and challenges lie ahead for all of us.

Acknowledgements

Advice and feedback from Yang Lee, Diane Strong, Veda Storey, and Richard Wang are gratefully acknowledged.

Work reported herein has been supported, in part, by the Advanced Research Projects Agency (ARPA) and the USAF/Rome Laboratory under contract F30602-93-C-0160, the MIT International Financial Services Research Center (IFSRC), the MIT Leaders For Manufacturing (LFM) Program, the MIT PROductivity From Information Technology (PROFIT) Program, and the MIT Total Data Quality Management (TDQM) Program.

REFERENCES

- [1] "C. Goh, S. Madnick, and M. Siegel, "Context Interchange: Overcoming the Challenges of Large-Scale Interoperable Database Systems in a Dynamic Environment", *Proceedings of the Third International Conference on Information and Knowledge Management (CIKM 94)*, November 1994.
- [2] R. L. Kay, "What's the Meaning of This?", *Computerworld*, October 17, 1994, pp. 89-93.
- [3] S. Madnick, "Chapter 2: The Information Technology Platform", in *The Corporation of the 1990s: Information Technology and Organizational Transformation*, M. S. Scott-Morton (Editor), Oxford University Press, 1991.

- [4] S. Madnick "The Challenge: To Be Part of the Solution Instead of Being the Problem", *Proceedings of the Workshop on Information Technology and Systems* (WITS'92), December 1992, Dallas, Texas.
- [5] S. Madnick "Chapter 16: Putting IT All Together Before it Falls Apart", in *Information Technology in Action: Trends and Perspectives*, Richard Y. Wang (Editor), Prentice-Hall, 1993.
- [6] S. Madnick, M. Siegel, and R. Wang, "The Composite Information Systems Laboratory (CISL) Project at MIT, *IEEE Data Engineering*, June 1990, pp. 10-15.
- [7] S. Madnick, and R. Wang, "Logical Connectivity: Applications, Requirements, and an Architecture", *Proceedings of the 1991 Hawaii International Conference on Systems Sciences*.
- [8] S. Madnick and R. Wang, "Introduction to the TDQM Research Program", TDQM Report TDQM-92-01, MIT Sloan School of Management, Cambridge, MA, May 1992.
- [9] P. Quiddington, "Cruising Along the Information Highway", *MIT Management Magazine*, Fall 1991.
- [10] M.S. Scott-Morton, (Editor), *The Corporation of the 1990s: Information Technology and Organizational Transformation*, Oxford University Press, 1991.
- [11] M. Siegel, S. Madnick et al, "CISL: Composing Answers from Disparate Information Systems, *Proceedings of the 1989 NSF Workshop on Heterogeneous Databases*, December 1989, Evanston, IL.
- [12] M. Siegel and S. Madnick, "Schema Integration Using Metadata", *Proceedings of the 1989 NSF Workshop on Heterogeneous Databases*, December 1989, Evanston, IL.
- [13] M. Siegel and S. Madnick, "A Metadata Approach to Resolving Semantic Conflicts", *Proceedings of the VLDB Conference* (Barcelona, Spain), September 1991.
- [14] M. Siegel and S. Madnick, "Context Interchange: Sharing the Meaning of Data", *SIGMOD Record*, December 1991, pp. 77-79.
- [15] D. Strong, Y. Lee, and R. Wang, "Beyond Accuracy: How Organizations are Redefining Data Quality", TDQM Report TDQM-94-07, MIT Sloan School of Management, Cambridge, MA, September 1994.
- [16] M. Van Alstyne, E. Brynjolfsson and S. Madnick, "Why Not One Big Database? Principles for Data Ownership", to appear in *Decision Support Systems*.
- [17] R. Wang, V. Storey, and C. Firth, "A Framework for Analysis of Data Quality Research", to appear in *IEEE Transactions on Knowledge and Data Engineering*.
- [18] R. Wang and S. Madnick, "A Polygen Model for Heterogeneous Database Systems: The Source Tagging Perspective", *Proceedings of the VLDB Conference* (Brisbane, Australia), August 1990, pp. 519-538.