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Introduction aux caractéristiques techniques d'un RNIS
Marc Orange, ICL Network Applications, Vetizy, France, p. 451

"La caractéristique principale d'un RNIS est d'assurer, au sein d'un même réseau, une large gamme de possibilités d'applications téléphoniques et non téléphoniques".

Cet article a pour objectif d'expliciter cette brève définition issue du C.C.I.T.T. Il commence par décrire les caractéristiques de base du RNIS, et donne ensuite une vue d'ensemble des protocoles RNIS mis en oeuvre au niveau de l'interface Accès de Base.

RNIS en France: Numéris et son Marché
L. Calot and A. Spiracopoulos, ICL Network Applications, IT Services, Velizy, France, p. 468

Cette article donne un aperçu du Réseau Numérique à Intégration de Services (RNIS) en France, appelé NUMERIS, et de son marché.

D'abord, il décrit l'évolution technique de NUMERIS, les différents réseaux de transmission de données pre-RNIS, et l'implémentation de NUMERIS. Ensuite, le RNIS correspondant à un changement important dans le monde des télécommunications, il convenait d'élaborer un marketing "subtil". Dans cet article nous présentons la stratégie mise en place par France Telecom, et conclurons par l'offre des terminaux et applications existantes sur le marché français.

L'Expansion du marché des Télécommunications en Espagne
J. Larraz, ICL Madrid, Spain, p. 493

L'Espagne doit être prête pour le challenge de 1992. Les usagers et les fournisseurs semblent envisager cette année l'augmentation de l'utilisation et du développement des produits de communication. Cependant, l'offre d'un réseau numérique à intégration de Services (RNIS) semble représenter le plus grand point d'interrogation.

Futures Applications du Réseau Numérique à Intégration de Services dans le Domaine des Technologies de l'Information
A. R. Fuller, ICL Network Systems, Windsor, UK, p. 501

Cet article examine les avantages offerts aux utilisateurs d'ordinateurs par les communications sur réseau numérique à intégration de services (RNIS).

Il démontre que le RNIS se prête particulièrement à de nouvelles applications qui sinon seraient difficilement réalisables ou trop coûteuses. Il décrit ensuite l'application de "Desk-Top Conferencing" qui a fait l'objet de démonstrations par STC/ICL. Cette application multi-médias permet à deux ou plusieurs personnes d'échanger des informations vocales ou visuelles pour, par exemple, travailler ensemble sur des données textuelles ou graphiques.

Il présente enfin les nouvelles possibilités offertes par le RNIS aux applications futures.

Un Système d'Informations Géographiques pour la Gestion de l'Actif d'une Compagnie des Eaux
C. E. H. Corbin, IT Southern Ltd, Brighton, UK, p. 515

Cet article décrit la manière dont la technologie de l'information traite les problèmes commerciaux liés à la gestion de l'actif immobilisé d'une compagnie des eaux. Cette compagnie possède des actifs de 2,469 millions de livres sterling (tarif 1989) et prévoit des investissements excédant 160 millions de livres sterling par an. L'actif est distribué en surface et en sous-sol sur une zone géographique couvrant 10,500 kilomètres carrés avec une population de 4 millions d'habitants.

La solution choisie par la société IT Southern consiste à exploiter une base de données d'informations géographiques (GIS, Geographical Information System). Le GIS a évolué depuis 1988 et son achèvement est dû pour 1995. Le GIS utilise des postes de travail SUN, des réseaux de transmission de données à large bande passante, des unités centrales ICL et une gamme de progiciels d'application. A terme, les bases de données associées au système GIS occuperont un volume de plus de 150 Giga-octets et seront reliées à l'unité centrale et aux serveurs SUN Microsystem.

Utilisation des Techniques de Programmation Logique en Fonction du Temps à la gestion des mouvements de containers dans un port
M. J. Perrett, ICL Strategic Systems, Bracknell, UK, p. 537

Cet article traite des problèmes de gestion de ressources au sein d'un terminal portuaire pour grands containers. Il décrit un système développé au terminal International de Hong-Kong (HIT), le plus important terminal privé pour containers au monde. Les techniques et outils utilisés dans le développement de ce système sont décrits ainsi que de l'utilisation d'un langage de programmation logique en fonction du temps, CHIP.

LOCATOR – Une base de connaissances au service de la clientèle d'ICL
G. W. Rouse, (formerly) ICL Customer Services, Stevenage, UK, p. 546

Ce texte décrit la conception et – après quelques faux départs –le développement d'un système de diagnostic rapide des causes vraisemblables de fautes dans les systèmes informatiques.

Le projet, désormais en exploitation, permet aux opérateurs en contact téléphonique avec les usagers de les interroger et de décider de la meilleure façon de traiter les appels, soit en conseillant immédiatement le client quant à l'action corrective à adopter, soit, si un ingénieur doit intervenir, en s'assurant qu'il est bien qualifié pour résoudre le problème en question et qu'il dispose de tout le matériel dont il aura vraisemblablement besoin. En conclusion figure un résumé des avantages pratiques du système.

Conception de l'Interface Homme-Machine d'un Editeur Graphique: Une Etude de Cas de Conception axée sur les Utilisateurs
K. Lewis, Standard Telecommunication Laboratories, Harlow, Essex, UK, p. 554

Cet article décrit le développement de l'interface homme-machine d'un éditeur pour base de connaissances hiérarchisées. Le système expert existant manquait d'un support adéquat pour l'élaboration et la maintenance de structures arborescentes. On nous a demandé de concevoir un outil permettant la cosntruction, l'édition et la maintenance d'une grande structure arborescente.

Les exigences du client portaient sur un éditeur graphique sophistiqué, pouvant être utilisé par des utilisateurs inexpérimentés, mais il existait certaines opinions et aspirations divergentes. La complexité des exigences suggérait l'élaboration rapide et itérative d'un prototype d'interface et son évaluation. La conception de l'interface fut sélectionnée à partir d'un ensemble d'alternatives, en coopération avec les utilisateurs de système. La conception finale fut affinée à partir de l'option choisie.

Pour conclure, nous pensons que l'élaboration rapide et itérative d'alternatives d'interface, accompagnée de l'évaluation officieuse de l'utilisateur final, facilite l'acceptation du client et la construction d'un système utilisable. L'outil résultant est utilisé depuis plus d'un an et a reçu l'entière acceptation de ses utilisateurs sur plusieurs sites.

X/Open:Une Ascension Irrésistible
C. B. Taylor, Systems Integration Division, ICL, Bracknell, UK, p. 565

Un article dans le numéro de Novembre 1987 du "ICL Technical Journal" décrivait la création du X/Open Group en 1984 et son développement et ses réalisations au cours des trois premières années. Ce nouvel article s'attache aux trois années suivantes, au cours desquelles le label X/Open (tm) s'est développé pour impliquer la plupart des membres importants de l'industrie mondiale des technologies de l'information, et est devenu une grande force de progrès et d'unification pour le succès des Systèmes Ouverts.

Architectures de Processeurs dédiés à la Gestion de Bases de Données
K. F. Wong, European Computer Research Centre, Munich, Germany, p. 584

La recherche en matière de processeurs dédiés à la gestion de bases de données a toujours été très active depuis les années 70; cependant, peu de projets ont été convertis en produits commerciaux. Cet article présente les architectures de plusieurs processeurs – déjà commercialisés ou en cours d'étude – dédiés à la gestion de bases de données. Etant donné la rapidité des progrès réalisés en matière de technologie de logiciel et de matériel, certaines personnes pensaient que les machines à base de données n'étaient pas rentables. Cette opinion ne fait pas l'unanimité: au vu du succès de certaines machines à base de données déjà commercialisées, il est démontré que la machine à base de données est utile, surtout pour les utilisateurs de grandes bases de données qui travaillent sur de vastes bases contenant des gigabytes d'informations. De plus, à partir de l'étude réalisée sur les machines déjà commercialisées, les facteurs d'influence sur l'acceptation d'une machine à base de données sont identifiés. Ceux-ci peuvent influencer la conception des futures machines. A partir de la révision sur les prototypes de recherche, les tendances au sein de l'architecture des machines à base de données sont soulignées.

Simulation Informatique pour le Développement Efficace des Technologies à base de Silicium
P. Mole, Standard Telecommunication Laboratories, Harlow, Essex, UK, p. 614

Le coût très élevé de l'équipement nécessaire à la fabrication de circuits intégrés modernes nécessite que le temps de développement pour chaque génération de technologie soit le plus court possible. La simulation informatique est désormais utilisée pour assister ce développement et STL a été impliquée dans les programmes de collaboration Alvey et ESPRIT pour faire progresser de telles méthodes.

Le modelage est appliqué à deux classes de problème: les étapes de traitement qui mènent à la diffusion de l'élément dopant dans le silicium et à l'expansion des oxydes de surface, et les performances électriques du dispositif. Ces deux problèmes engendrent des ensembles conjugués d'équations différentielles partielles non linéaires qui peuvent être résolues par adaptation des techniques numériques souvent utilisées dans d'autres secteurs d'ingéniérie, telles que la méthode des éléments finis. La résolution du problème sur des sections bi-dimensionnelles à travers les dispositifs, conduit à de larges ensembles d'équations algébriques [4.000–12.000] qui ont nécessité le développement de techniques de matrices éparses efficaces pour leur résolution. Pour obtenir la précision requise, il est nécessaire de choisir le maillage avec le plus grand soin ainsi que la représentation des équations sur le maillage, afin d'obtenir une solution précise et stable.

Ces techniques de modelage ont été utilisées de manière extensive par STC pour assistance aux développements technologiques. Les applications actuelles incluent le développement de la technique bipolaire dans le cadre du répétiteur à fibre optique Gbit et le développement des technologies CMOS à 1 et 0,7 μm.

L'utilisation de la Méthodologie Structurée Ward et Mellor pour la conception d'un système temps réel complexe. 13/12/1990
R. Whetton, M. Jones and Don Murray, ICL Computer Products Division, West Gorton, Manchester, UK, p. 634

Le système temps réel décrit correspond au logiciel de gestion de l'Ordinateur de Support Nodal du Noeud SX qui a été décrit dans la précédente parution du Journal. L'objectif des concepteurs du projet –connu dans les mileux concernés comme ISA (Initialisation and Support Application) – fut de produire un système temps réel d'une meilleure qualité et, simultanément, d'augmenter leur propre productivité. Ces objectifs ont été atteints grâce à l'utilisation de la Méthodologie Structurée de Ward et Mellor, assistée par l'outil de saisie Excelerator de conception brevetée.

L'historique de ISA est rappelé et les raisons pour lesquelles la méthodologie a été choisie et la manière dont elle a été introduite dans le projet font l'objet d'une explication. Les phases d'analyse et de conception du projet sont ensuite décrites, en portant l'accent sur les caractéristiques Ward et Mellor employées et l'utilisation de l'Excelerator. Pour finir, quelques conclusions d'ordre général sont exprimées, suite au succès remporté grâce à l'utilisation de la méthodologie et de l'outil.

Zusammenfassungen

ISDN

Vorwort von *Mr R. D. Smith, Director Financial Services Business & Network Industry, ICL, London, UK*

Einführung in die technischen Merkmale von ISDN

M. Orange, ICL Networks Applications IT services, Velizy, France, p. 451

Die Haupteigenschaft eines "Integrated Services Digital Network" ist die Bereitstellung einer breiten Palette von Funktionen für Telephonie- und Nicht-Telephonie-Anwendungen innerhalb eines einzigen Netzwerkes.

Es ist das Ziel dieser Abhandlung, diese kurze vom C.C.I.T.T. gegebenen Definition zu erläutern. Es werden zuerst die Grundmerkmale von ISDN beschrieben und dann ein Überblick über die ISDN-Protokolle für die "Basic Rate" Schnittstelle gegeben.

ISDN in Frankreich: NUMÉRIS und sein Markt

L. Calot und A. Soiracopoulos, ICL Networks Applications IT services, Velizy, France, p. 468

Diese Abhandlung gibt einen Überblick über das französische ISDN, NUMÉRIS genannt, und seinen Markt. Zunächst wird der technische Hintergrund von NUMÉRIS, die verschiedenen Vorläufer von ISDN-Kommunikationsnetzen und die Implementierung von NUMÉRIS beschrieben.

Da ISDN eine grosse Veränderung der Telekommunikations-Vernetzung darstellt und ein sehr subtiles Marketing voraussetzt, wird dann die von France Telecom ausgearbeitete Strategie und abschliessend die angebotenen ISDN-Terminals und -Anwendungen erläutert.

Die Telecom-Szene in Spanien.

J. Larraz, ICL Madrid, Spain, p. 493

Spanien muss für die Herausforderung von 1992 bereit sein. Sowohl Anwender als auch Lieferanten scheinen zu erwarten, dass der Einsatz und die Entwicklung von Kommunikations-Produkten dieses Jahr erhöht werden. Der ISDN-Dienst ist jedoch das grösste Fragezeichen ....

Zukünftige ISDN-Anwendungen in der Informations Technologie

A. R. Fuller, ICL Networks Industry, Windsor, UK, p. 501

Diese Abhandlung untersucht zuerst die speziellen Vorteile der ISDN-Kommunikation für Computerbenützer. Sie deutet den Spielraum an, den ISDN für innovative Anwendungen bietet, insbesondere jene, deren Einsatz andernfalls schwierig oder zu teuer waren.

Sie beschreibt dann anhand von Beispielen eine Art von "DeskTop Conferencing", welches von STC/ICL demonstriert wurde. Dies ist ein Multimediensystem, das zwei oder mehreren Personen die Zusammenarbeit von entfernten Orten aus ermöglicht und sowohl Sprache als auch Bildübertragung benützt, um z.B. Texte zu überarbeiten oder eine technische Konstruktion zu entwickeln.

Die Abhandlung endet mit der Skizzierung einiger zukünftigen Anwendungen, die durch ISDN ermöglicht werden.

WEITERE ABHANDLUNGEN

Ein Geographisches Informationssystem für die Verwaltung der Vermögenswerte einer grossen Wasserversorgung.
C. E. H. Corbin, IT Southern Ltd., Brighton, Sussex, UK, p. 515

Die Anhandlung beschreibt, wie mit Hilfe von Informations-technologie die Probleme gelöst werden, die eine Wasserversorgungs AG. mit der Verwaltung ihrer Vermögenswerte hat, deren gegen-wärtiger Wert £2.649 Millionen betragen und die ein laufendes Kapital-Investitionsprogramm von über £160 Millionen pro Jahr hat. Die Vermögenswerte befinden sich über und unter der Erde, über eine geographische Fläche von 10.500 Quadratkilometern verteilt, auf der eine Wohnbevölkerung von 4 Millionen lebt.

Die gewählte IT-Losing benützt ein geographisches Informations-system (GIS). GIS wurde seit 1988 laufend weiterentwickelt, und seine Fertigstellung ist für circa 1995 geplant. GIS verwendet SUN-Workstations, Breitband-Datenübertragungsnetze, ICL Mainframes und eine Reihe von speziellen Anwendungspaketen. Bei Fertigstellung wird die GIS-Datenbank einen Umfang von über 150 Gigabyte haben und sowohl an den ICL-Mainframe als auch an die verteilten SUN Microsystem Server angebunden sein.

Verwendung von "Constraint Logic" – Programmiertechniken bei der Planung eines Containerhafens.
M. J. Perrett, ICL Strategic Systems, Bracknell, UK, p. 537

Diese Abhandlung beschäftigt sich mit dem Problem der Ressourcenverwaltung eines grossen Container-Umschlagplatzes. Sie Beschreibt ein System, das am Hong Kong International Terminal (HOT) entwickelt wurde, dem grössten im Privatbesitz befindlichen Container-Umschlagplatz der Welt.

Es werden die, bei der Entwicklung des Systems verwendeten Techniken und Werkzeuge erläutert, insbesondere die Verwendung von CHIP, eine "Constraint Logic" – Programmiersprache.

LOCATOR – Eine "Knowledge Engineering" – Anwendung für ICLs Kundendienst
G. W. Rouse, (ehemals) ICL (UK) Office Systems Services CS, Stevenage, p. 546

Die Abhandlung beschreibt, wei ein System zur schnellen Diagnose der möglichen Ursachen bei Fehlern in Computersystemen, erarbeitet und nach einigen Rückschlagen weiterentwickelt wurde.

Der Plan ist nun in Betrieb und erlaubt es im telefonischen Kontakt mit den Anwendern, diese zu befragen und sofort zu entscheiden, wie der Kundendienstanruf am besten zu erledigen ist: entweder durch eine sofortige Beratung des Kunden über die zu ergreifenden Abhilfemassnahmen, oder wenn ein Technikerbesuch notwendig ist, zu gewährleisten, dass dieser zur Lösung des Problems auch qualifiziert ist und, dass er die wahrscheinlich benötigten Ersatzteile mit sich nimmt. Abschliessend werden die praktischen Vorteile dieses Systems zusammengefasst.

Konstruktion des HCI für einen grafischen "Knowledge Tree" Editor: Eine Fallstudie für anwenderorientierte Entwicklung
K. Lewis, STC Technology Ltd., Harlow, Essex, UK, p. 554

Die Abhandlung beschreibt die Entwicklung eines HCI (Human Computer Interface) für einen "Knowledge Tree" Editor. Dem bestehenden Expertensystem fehlte die ausreichende Unterstützung zum Aufbau von "Knowledge Trees", deren Erweiterung und Pflege. Wir wurden aufgefördert ein Werkzeug zu entwickeln, das die Konstruktion, Änderung und Pflege eines grossen "Knowledge Trees" ermöglicht.

Die Kundenanforderung nach einem leistungsfähigen Grafik-Editor, geeignet zum Gebrauch durch unerfahrene Anwender, war durch unterschiedliche Meinungen und Erwartungen gepragt. Die Komplexität der Anforderung verlangte die schnelle, iterative Entwicklung und Auswertung eines HCI-Prototyps. Der HCI-Entwurf wurde, durch Diskussionen mit potentiellen Anwendern, aus einer Anzahl von Alternativen ausgewählt. Die endgultige Entwicklung wurde aus der gewählten Option vervollständigt.

Wir schliessen daraus, da die schnelle, wiederholende Prototypen-Entwicklung von HCI-Alternativen, zusammen mit einer informellen Auswertung durch Endbenützer, die Konstruktion eines brauchbaren Systems und die Akzeptanz durch den Kunden erleichtert. Das resultierende Werkzeug ist seit über einem Jahr in Gebrauch und hat vollständige Akzeptanz durch seine Benutzer in mehreren Anwendungsorten gewonnen.

X/OPEN – Ein Erfolg nach dem Anderen
C. B. Taylor, ICL Systems Integration Division, Bracknell, UK, p. 565

Ein Artikel in der Ausgabe vom November 1987 des Technical Journal beschrieb die Entstehung der X/OPEN-Gruppe im Jahre 1984 und ihr Wachstum und ihre Errungenschaften in den ersten drei Jahren. Dieser Artikel führt die Geschichte durch die folgenden drei Jahre weiter. In dieser

Zeit wuchs die X/OPEN-Gruppe, an der heute die meisten der weltweit grössten IT-Firmen teilnehmen und wurde zu einer sehr bedeutenden, treibeden und vereinigenden Kraft des Erfoltes von offenen Systemen.

Architektur von Datenbanksystemen
K. F. Wong, European Computer Research Centre, D8000 Munchen, Deutschland, p. 584

Die Forschung hat sich schon seit den 70er jahren sehr aktiv mit Datenbanksystemen beschäftigt; jedoch wurde nur eine geringe Anzahl der Forschungs-Prototypen zum kommerziellen Erfolg. In dieser Abhandlung wird die Architektur einer Anzahl von Forschungs- und kommerziell genützter Datenbanken beschrieben. Aufgrund der Entwicklungsfortschritte bei den Software- und Hardware-Technologien, glaubten einige, da Datenbanksysteme nicht kosteneffektiv seien.

Diese Ansicht wird angezweifelt: der Erfolg einiger kommerziellen Datenbanksysteme beweist den Nützen von Datenbanken, besonders für Benützer, die mit sehr grossen Datenmengen von mehreren Gigabytes an Informationen arbeiten. Des weiteren werden, aus der Studie über kommerzielle Datenbanken, die Faktoren identifizierte, die die Akzeptanz eines Datenbanksystems beeinflussen. Architekturen von Forschungs-Datenbanken sind ebenfalls wichtig. Sie können die Entwicklung zukünftiger Systeme beeinflussen. Ausgehend von der Technologie einiger Forschungs-Prototypen werden Trends in der Datenbank-Architektur erläutert.

Computer-Simulation für die rationelle Entwicklung von Silizium-Technologien
P. Mole, STC Technology Ltd., Harlow, Essex, UK, p. 614

Die sehr hohen Investitionskosten, die für die Herstellung moderner integrierter Schaltungen benötigt werden, machen es notwendig, da die Entwicklungszeiten für die einzelnen Technologie-Generationen soweit wie möglich reduziert werden. Computer-Simulation wird heute dazu benützt, um diese Entwicklungen zu unterstützen, und STC war an den kooperativen Alvey- und ESPRIT-Programmen zur Weiterentwicklung dieser Methoden beteiligt.

Modellierung wird auf zwei Problemklassen angewendet: die Verarbeitungsschritte, die zur Diffusion von Dotierungsstoffen innerhalb des Siliziums und zum Wachstum von Oberflachenoxiden führen, und die elektrische Leistung der Schaltung. Beide verursachen gekoppelte Mengen nicht linearer partieller Differentialgleichungen, die durch die Anwendung numerischer Techniken gelöst werden konnen, wie etwa die "Finite Element" Methode, die auch auf anderen technischen Gebieten weit verbreitet ist. Die Problemlösung von zweidimensionalen Schniten durch die Geräte resultiert in grosse Mengen von algebraischen Gleichungen (4.000–12.000), die die Entwicklung wirksamer Sparse Matrix-Techniken für ihre Lösung erförderten. Um die erförderliche Genauigkeit zu erhalten und eine stabile Lösung zu erreichen, muss man vorsichtig sein, bei der Auswahl der Maschen und bei der Darstellung der Gleichungen auf den Maschen.

Diese Modelliertechniken wurden von STC umfassend zur Unterstützung von Technologie-Entwicklungen verwendet. Aktuelle Anwendungen umfassen die Entwicklung bipolarer Technologie für Anwendung in Gbit-Glasfaser-Repeatern oder die Entwicklung von CMOS-Technologien von 1 und 0,7 μm.

Der Gebrauch der strukturierten Methodologie nach Ward und Mellor für den Entwurf eines komplexen Echtzeitsystems.
R. Whetton, M. Jones und Don Murray, ICL Computer Products Division, West Gorton, Manchester, UK, p. 634

Das beschriebene Echtzeitsystem liefert die Software-Funktionalität für den "Node Support Computer" des SX-Netzknotens, der in der vorigen Ausgabe des Journals beschrieben wurde. Das Projektziel der Entwickler -intern als ISA (Initialisation and Support Application) bekannt - war es, ein Echtzeitsystem mit verbesserter Qualität zu produzieren und gleichzeitig ihre eigene Produktivität zu erhöhen. Diese Ziele wurden erreicht, indem die strukturierte Methodologie nach Ward und Mellor benützt wurde, unterstützt durch das eigene Entwicklungswerkzeug EXCELERATOR.

Der Hintergrund von ISA wird dargestellt, und die Gründe für die Auswahl der Methodologie, und wie sie in das Projekt eingeführt wurde, werden erläutert, wobei die verwendeten "Ward und Mellor" - Merkmale und der Gebrauch von EXCELERATOR betont werden. Abschliessend werden umfassende Rückschlüsse aus dem Erfolg gezogen, der sowohl durch den Gebrauch der Methodologie als auch des Entwicklungs-Werkzeuges erzielt wurde.

ISDN

Foreword

The topic of the following four papers the new Integrated Services Digital public Networks (ISDN), is a very interesting one for me because I've been involved in it for several years, trying to understand how information systems and the world's networks will work together to change the computer and communication industries.

I've come to believe the changes will be dramatic, and sooner than most people think. If I'm right, the 1990s will see a major market discontinuity. From 1995 at the latest, a large share of the *new* information systems business will be sold as *services* through the networks, instead of as customer premises computers. I don't know how large a share, but it will be enough to change the computer business dramatically.

A return to time sharing? Why would anybody do that? There is in fact a reason, a system theoretic one.

The Personal Computer has shown us the beginning of what people really want a desktop device to do. And it's been so different from the old DP systems that we've called it a *revolution.*

But what's really different about a PC? Isn't it just a desktop version of a terminal connected to a mainframe? Is the computer itself different? No, it's not even a very sophisticated processor. The operating system? No, DOS is rather primitive compared to VME. Its languages? Nothing new. What, then?

One simple thing about a PC makes all the difference. *The screen is close to the computer.* And that proximity matters only because it means the link between them can be fast. All the amazing graphics that make PCs so useful are made possible by that bandwidth. Nothing else is fundamentally different.

But with such bandwidth across the Public Switched Network, things will change. The computer can be remote from the user again, without losing any of the sophisticated presentation or user interface possibilities. This will open enormous scope for network-based services.

Basic rate ISDN is just the beginning, but an important beginning, because it's an order of magnitude step, and because it's here today. I'm very pleased the ICL Technical Journal is featuring it, and I hope you'll be stimulated to see it's impact on your field of interest.

Robert D. Smith
Director, ICL Networks Industry and Financial Services Business

Introduction to the technical characteristics of ISDN

Marc Orange
ICL Network Applications IT Services, Velizy, France

Abstract

"The main characteristic of an Integrated Services Digital Network is to provide, within a unique network, a wide range of possibilities in telephony and non-telephony applications".

The goal of this paper is to explain this short definition given by the C.C.I.T.T. It first describes the basic characteristics of ISDN, and then gives an overview of the ISDN protocols for the Basic Rate Interface.

1 Introduction

About the end of the 60's, the arrival of the first electronic switches and then the time-division systems opened up a wide range of new applications in communications and computing.

This offered new services to send and process voice, data, text and image according to differing needs of the customer.

These services are usually offered through different interfaces with different characteristics and different bearer networks. For the handler of the network this implies some complications, such as compatibility and security between the networks, cost, etc.

ISDN (Integrated Services Digital Network) offers integration of these different bearers and services, using digital techniques through a powerful set of international standards, and seems to be the solution for success and progress in telecommunications.

The international aspect of the ISDN standards gives these services a universal characteristic. This integration will give more support to the user: only one interface, whatever service used, one number, one order, one installation with the different terminals connected to a universal socket.

The configuration of Fig. 1 will become that of Fig. 2. ISDN was born about 10 years ago in research labs and is now being implemented in many countries, as specified by the CCITT (International Telegraph and Telephone Consultative Committee).

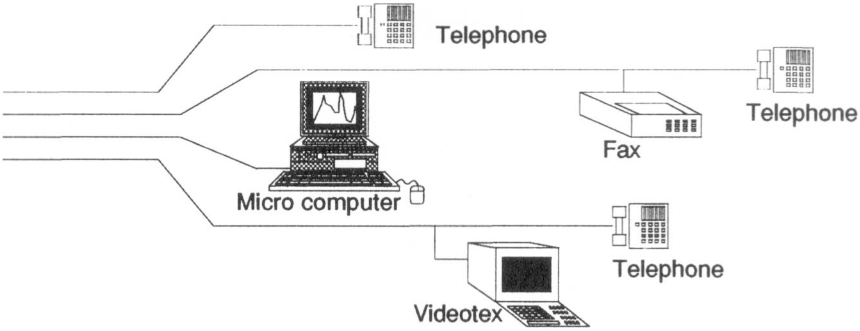


Fig. 1 The classical configuration: one interface for one service

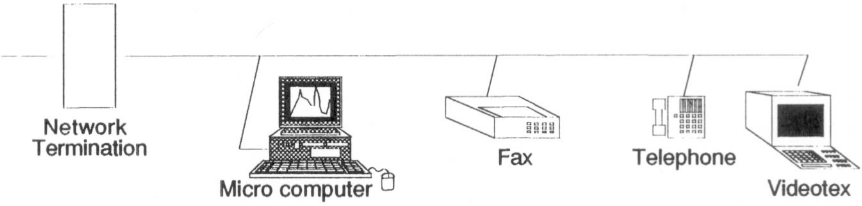


Fig. 2 The ISDN configuration: one interface for several services

2 Basic characteristics of ISDN

2.1 The OSI reference model

The ISO (International Standardization Organisation) divided the set of functions concerning the communication services into 7 "functional layers" on the basis of the following main criteria:

- homogeneity of the functions within one layer,
- definition of layers between which interactions are as limited as possible,
- restriction of the number of functional layers.

Fig. 3 represents the 7 layers of the OSI model (Open System Interconnection). The 3 lower layers refer to the functions necessary for ensuring the transfer of information between two terminals across a network.

The 4 upper layers concern more closely the applications available to users. They describe the rules for information transfer, dialog, presentation etc... allowing applications to run between distant users.

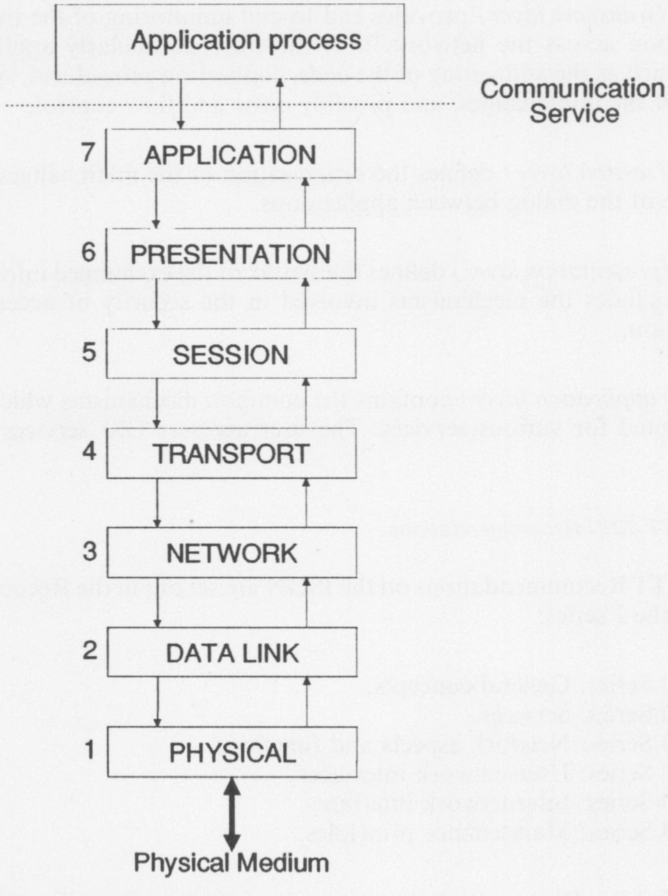


Fig. 3 The OSI model with its 7 layers

These layers are defined as follows:

Layer 1 (physical layer) handles the physical aspects of the connection of the terminals to the communication lines: mechanical and electrical interfaces and binary element exchange protocols.

Layer 2 (data link layer) corresponds to the transfer of information over the communication lines; it usually contains detection and recovery mechanisms against transmission and overflow errors.

Layer 3 (network layer) ensures the establishment and release of communication as well as the routing of user information across the network. It is the first layer to include the network (and routing) notion.

Layer 4 (transport layer) provides end-to-end monitoring of the transfer of information across the network. It is therefore particularly applicable to aspects such as the addressing of the ends, connection procedures, synchronization of the interchanges, and possibly error and flow control.

Layer 5 (session layer) defines the organization of the interchanges and the structure of the dialog between applications.

Layer 6 (presentation layer) defines the syntax of the exchanged information. It also includes the mechanisms involved in the security of access to the information.

Layer 7 (application layer) contains the common mechanisms which can be implemented for various services. The user accesses OSI services via this layer.

2.2 CCITT ISND Recommendations

The CCITT Recommendations on the ISDN are set out in the Recommendations of the I series:

- I.100 Series: General concepts,
- I.200 Series: Services,
- I.300 Series: Network aspects and functions,
- I.400 Series: User-network interfaces,
- I.500 Series: Internetwork interfaces,
- I.600 Series: Maintenance principles.

Some of these Recommendations may be found under other references (X, Q, ...).

For the User-network interfaces,

- I.410, 411, 412 are general descriptions, reference configurations and structures,
- I.420 concerns the Basic Rate Interface, pointing to I.430, I.440/441 and I.450/451,
- I.421 concerns the Primary Rate Interface, pointing to I.431, I.440/441 and I.450/451,
- I.430 defines the B.R.I. physical layer protocol,
- I.431 defines the P.R.I. physical layer protocol,
- I.440/441 defines the link layer protocol (called LAPD),
- I.450/451 defines the network layer protocol (called D protocol),
- I.460, 461, 462, 463, 464 define multiplexing, rate adaptation, interface conversion,...

2.3 *ISDN Services*

The operator of an ISDN can offer two types of service (I.200 Series):

- bearer services, offered by layer 3, which concern the rates and the transmission quality levels,...There is no guarantee of compatibility between the terminals in communication.
- teleservices, which imply that the terminals use the same protocols in order to guarantee compatibility between them. Each of these types is divided into "basic services" and "supplementary services".
  The CCITT has defined "attibutes" characterizing these services.

Bearer services:

- information transfer attributes:
  – information transfer mode: circuit or packet;
  – information transfer rate: 64 kb/s, 384 kb/s, 1536 kb/s, 1920 kb/s, or other;
  – information transfer capability: unrestricted digital, speech, audio 3.1 kHz, audio 7 kHz, audio 15 kHz, video, or other;
  – structure: 8 kHz integrity, service data unit integrity, none;
  – communication set up: on demand, permanent, or reserved;
  – communication configuration: point-to-point, multipoint or broadcast;
  – symmetry: unidirectional, symmetrical bidirectional, or assymetrical bidirectional.
- access attributes:
  – channel and rate: D (16 kb/s), D (64 kb/s), E (same as D), B (64 kb/s), H0 (384 kb/s), H11 (1536 kb/s), H12 (1920 kb/s), or other (these high rates concern the Primary Rate Interface);
  – signalling access protocol: I.451, CCITT 7, I.462 or other;
  – information access protocol: G.711, I.460, I.451, X.25 or other.
- general attributes:
  – supplementary services (see further);
  – service quality;
  – interworking possibilities;
  – operational and commercial aspects.

Teleservices:

- low layer attributes
  – information transfer attributes (see bearer services);
  – access attributes (see bearer services).
- high layer attributes
  – user information type: speech, sound, text, fax, videotex, video or other;
  – layer 4 protocol: X.224, T.70 or other;
  – layer 5 protocol: X.225, T.62 or other;

- layer 6 protocol: T.73, T.61, T.6, T.100 or other;
- resolution (if applicable): 200, 240, 300, 400 or other;
- graphic mode (if applicable): alpha-mosaic, geometric, photographic or other.

- general attributes
  - supplementary low and high layer attributes;
  - user-oriented quality of service;
  - interworking capabilities;
  - operational and commercial aspects.

Supplementary services:

- *sub-addressing*: enables a caller to select a particular terminal within an installation, adding 1 to 4 extra digits to the public installation number. On receiving a call, a terminal compares its own programmed S.A. (sub-address) to the incoming one, and accepts the call if there is matching. This service doesn't require a network action, except for carrying through the S.A.
- Direct Dialling In with designation numbers: this service is very much used in PABX (Private Automatic Branch eXchange) installations, where different suscriber numbers are grouped to the PABX, and the designation numbers (extracted from the called number) are used (by the PABX or the terminals) to select a particular terminal.
- *systematic call presentation*: as the D channel is always available, it can report every incoming call to the user, even when the B channel resources are saturated.
- *user-to-user information*: allows users to exchange small information blocks using signalling messages (via D channel).
- *to-and-fro facility*: allows a user to switch between 2 communications by holding one or the other.
- *temporary call diversion*: when a terminal receives a call, it can reroute it to another number in its response. This is different from the "call forwarding" because it is a call-by-call feature and it is handled by the terminal itself (no registration in the exchange).
- *call forwarding*: allows the rerouting of all the incoming calls to another number (registered in the local exchange).
- *terminal portability*: allows a user to suspend an active call and retrieve it on another compatible terminal within the same installation.
- *caller identification*: allows a user to know the number of his caller.
- *charging indication*: during a call, the user can know in real-time, the cost of its communication. The charging indication can be sent at the end of the call only.
- *restricted connection*: enables outgoing calls to be restricted according the charge for the communication requested, or the number dialled.
- *one-way connection*: enables the reservation of a certain number of B channels for outgoing calls or incoming calls.
- *priority connection*: allows a user to initiate a call, even when the exchange is overloaded.

- *concealement of the caller's identity*: when a user does not wish to be identified by his correspondant.
- *malicious call identification*: when a user wishes the network to keep track of the caller's identity (for legal proceedings).
- *itemized billing*: allows a user to have a detailled bill for all or part of his communications.

2.4 Functional groups and reference points

The CCITT has defined certain functional groups and reference points designating the boundaries between these groups. Fig. 4 gives the usual representation of them.

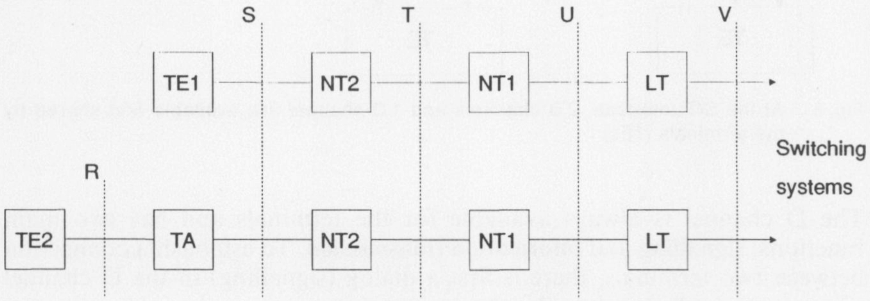


Fig. 4 The functional groups and reference points defined by the CCITT

- The *Terminal Equipment* (TE) whose access to the network is at the reference point S if it is a native ISDN terminal (TE1), or at the reference point R if it is a terminal (TE2) conforming to existing interfaces (V or X Series) using a Terminal Adapter R→S (TA).
- The *Network Termination 2* (NT2) which handles user internal functions (a PABX is a NT2). The access to the network is at reference point T. This group may be omitted; in this case, S and T reference points coincide.
- The *Network Termination 1* (NT1) which controls layer 1 functions (power supply, frame multiplexing,...). This group is linked to the Line Termination (LT), which is part of the network, through the reference point U. The output of the LT (towards the switching) is at point V.

3 The protocols at the S or T reference points for the Basic Rate Interface

At the S and T reference points, two types of interface are defined: the Basic Rate Interface, and the Primary Rate Intreface. This paper describes only the B.R.I. which is the smallest and the most commonly used for terminals. The P.R.I. is more used for PABX (Private Automatic Branch eXchange).

The main difference between these two interfaces is at layer 1; layers 2 and 3 described below are common to both interfaces.

3.1 General aspects

At the S/T interface, the total bit rate is 192 Kbits/s full duplex. This rate is demultiplexed, into two 64 Kbits/s B channels and one 16 Kbits/s D channel (see Fig. 5).

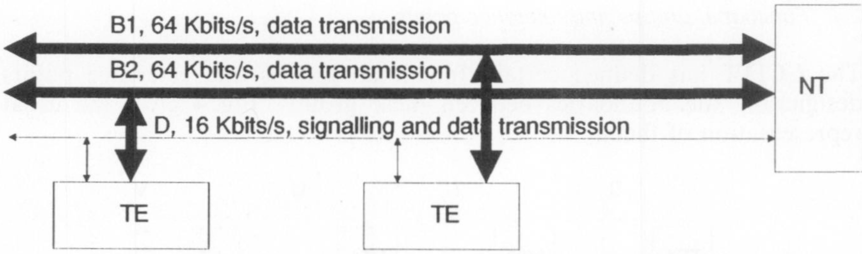


Fig. 5 At the S/T interface, 2 B channels and 1 D channel are available and shared by the terminals (TEs)

The D channel is always available for the terminals and has two main functions: **signalling** and **information transmission**. To establish a connection between two terminals, there is first a dialog (signalling) in the D channel to set up the call and describe the nature of it.

After that, the two terminals can exchange information through one of the B channels or through the D channel itself (information transmission). To release the transmission, the D channel is used again (signalling).

The protocol architecture in the D channel conforms to the OSI model (introduced above).

A B channel could be considered as a pair of wires (dynamically connected and disconnected with D signalling), in which the network does not intervene except for the full duplex bit-by-bit transmission. It is the terminals' choice to use a particular protocol to understand one another.

In fact, layer 1 is common for the B and D channels. Fig. 6 gives a protocol implementation example in a data terminal.

3.2 The physical layer (I.430)

Layer 1 offers the following services:

- transmission capability (in D and B channels),
- activation and deactivation,
- access to the D channel for signalling,
- terminal power supply.

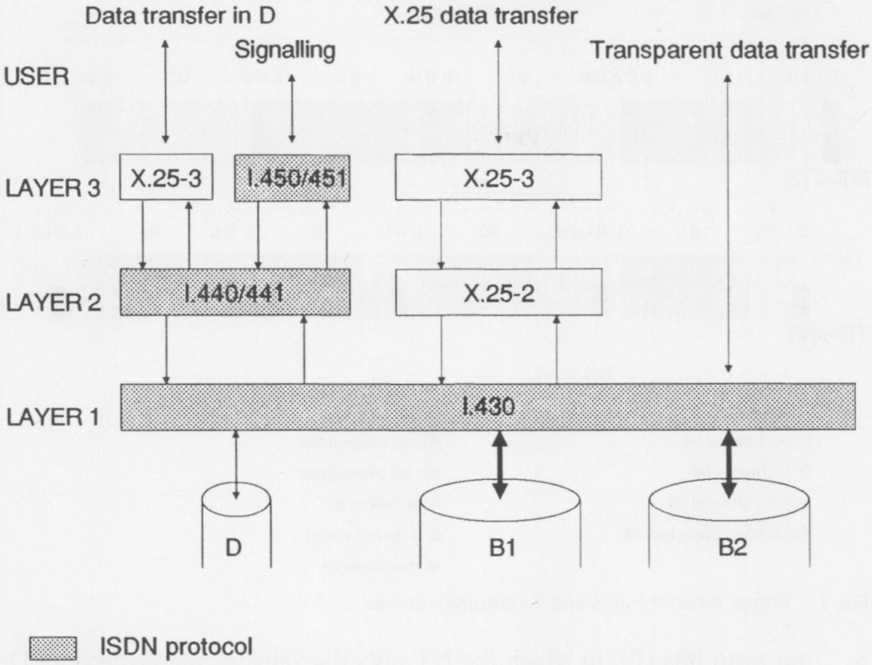


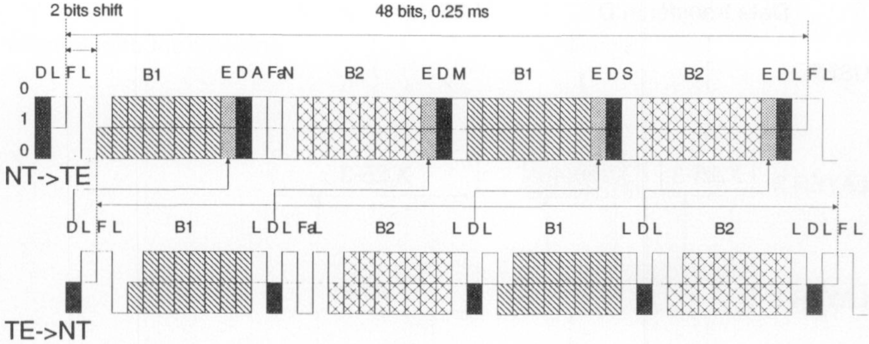
Fig. 6 A protocol implementation example:
Signalling in D (mandatory), X25 in D and B1, transparent transfer in B2

It may use point-to-point or point-to-multipoint configuration. The physical bearer requires 4 pairs of wires, in which one pair is used for the NT to TEs direction, and one for the TEs to NT direction. The 2 other pairs may be used for power supply.

Each terminal retrieves the 192 kHz clock from the incoming bit stream (from the NT), and uses it to transmit. The bits are contained in consecutive 48-bit frames, represented in Fig. 7.

In the TE to NT direction, the frame contains:
- the frame lock (F) bit with its DC balance bit (L),
- two B1 bytes with one DC balance bit each,
- two B2 bytes with one DC balance bit each,
- four D bits with one DC balance bit each,
- the auxiliary frame lock bit (Fa) with its DC balance bit.

In the NT to TE direction, the frame contains:
- the frame lock (F) bit with its DC balance bit (L),
- two B1 bytes,
- two B2 bytes,
- four D bits,



F: frame lock bit
L: DC balance bit
D: D channel bit
E: echo channel bit
Fa: auxiliary frame lock bit

N: =not Fa
B1: B1 channel bits
B2: B2 channel bits
A: activation bit
S: 0 (further study)
M: multiframe bit

Fig. 7 Frame structure at S and T reference points

- four echo bits (E), in which the NT puts the value of the preceeding D bit received from the terminals,
- the activation bit (A),
- the auxiliary frame lock bit (Fa) and the associated N bit,
- the multiframe bit (M),
- one unused bit (S),
- one DC frame balance bit (F).

The bits are coded in a pseudo-tristate scheme. A ‘1’ produces no signal, while a ‘0’ is alternately coded as a positive or a negative pulse. Within a bit sequence (one or more bits long), the number of zeros may be even or odd.

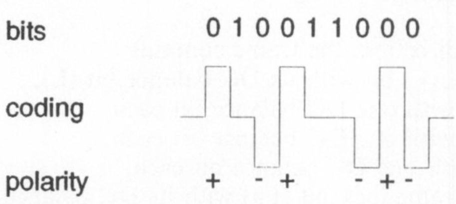


Fig. 8 The pseudo tristate scheme: no signal for "1" bits, alternated polarity pulses for "0" bits

If it is even, the number of positive pulses equals the number of negative pulses. As the pulses have the same duration, the continuous (DC) component of the sequence is nil.

If it is odd, supposing that the first pulse is negative, the latest one is also negative and creates a negative continuous component. An additional positive zero, appended to the sequence, will set the continuous component to nil. This bit is called "DC balance bit".

In the NT to TE direction, since the NT alone is to transmit, there is one DC balance bit following the frame lock bit (F), and another one balancing the rest of the 48 bits frame. In the TE to NT direction, since the frame is the result of transmission of sections by different terminals, each section is balanced individually.

The frame lock bit (F) is a positively coded '0', violating the rule of pulse alternation. It is immediately followed by a DC balance bit. But this violation has to be compensated by another violation. This is done by the first following '0' (negatively coded). This '0' may be one B1 bit, the E bit, the D bit, or the Fa bit (this bit ensures that the second violation occurs at least 14 bits after the frame lock bit). The DC balance bit is '0' if there are an odd number of '0's following the previous balance bit.

The main characteristic of the D channel is that **it is shared by the terminals** (when in point-to-multipoint configuration). There is a protocol for handling priority and collision, ensuring a correct access for every terminal.

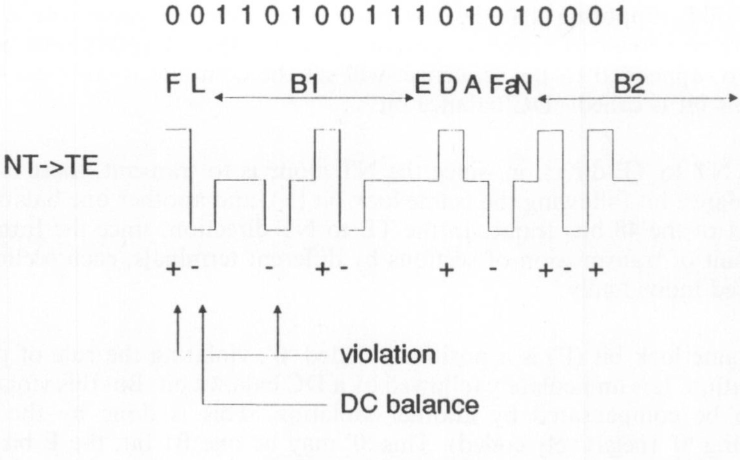
This protocol uses the E channel, which is the echo of the D channel. When a terminal "sees" that the received E bit is different from the D bit it sent, it immediately stops transmitting. Once a terminal accesses the D channel, its priority becomes lower, giving more chance of success to the others in their turn.

When there is no active communication on the interface, no signal is sent on the line (INFO0). This is the deactivated state. As soon as a TE wants to make an outgoing call, it starts transmitting a special pattern ('00111111', INFO1) until the NT responds with a 48-bit frame containing zero bits in B, D and E channels (INFO2) and with the A bit equal to zero. This INFO2, with its many zeros (ie many pulse edges) allows the TEs to synchronize their clocks, and so normal exchanges (48-bit frames as above) can start: TEs sending INFO3 and NT sending INFO4.

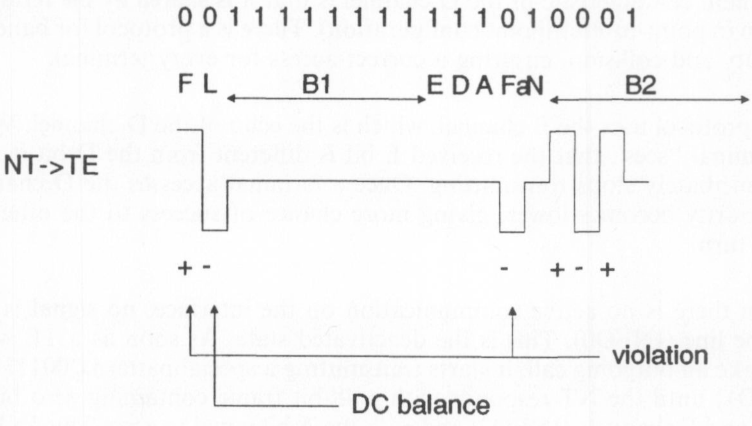
Note that the A bit of INFO4 equals 1.

The same activating procedure occurs when the NT wants to deliver an incoming call to the terminals, except that there is no INFO1 sent.

In order to reduce power consumption, the NT (not the TE) can decide to go back to the deactivated state when there is no longer an active call: the NT stops sending signal (INFO0) and the TEs do the same.



Example 1



Example 2

Fig. 9 Two examples of alternation violation:
- in example 1, the violation occurs in B1
- in example 2, as B1, E, D and A are only "1" bits, the violation occurs in Fa (the 14th bit of the frame)

3.3 The data link protocol (I.440/441 or Q920/921)

The layer 2 protocol in the D channel, usually called LAPD (Link Access Protocol in D channel), ensures:

- the setting up and releasing of one or more data links between the NT and the terminals. The distinction between the links is made by an identifier contained in each frame,
- the bounding and alignment of layer 2 frames (HDLC frames),
- the sequencing of the frames through a link,
- error detection and recovery (if possible),
- flow control.

The LAPD is very similar to HDLC (High-level Data Link Control) but it is not compatible.

Fig. 10 gives the frame structure. The Flag byte ('01111110') is the frame delimiter.

Flag	Address	Command	Information	FCS	Flag

Fig. 10 The layer 2 frame structure in D channel

The Address field (see Fig. 11) contains two bytes and permits identification of the destination for a command frame or the origin of a response frame. It has the following form:

8	7	6	5	4	3	2	1	
SAPI						C/R	EA	→ 0
TEI							EA	→ 1

Fig. 11 The address field:
- the first byte contains 6 bits for SAPI, one bit for C/R (Command/Response), one for EA (Extension of Address = 0)
- the second byte contains 7 bits for TEI and one bit for EA (= 1, meaning "end of address field")

The SAPI (Service Access Point Identifier) and the TEI (Terminal End point Identifier) have a distinct value on a data link.The SAPI is used to identify a particular service point (in the terminal or the network) and the TEI identifies an end point in this service point.

The SAPI values are:
- 0 for a call control link,
- 16 for an X25 packet switched link,
- 63 for a management link.

The SAPI value is chosen by the terminal, according the service it wants to use.

The TEI values are:
- 0 to 63 for non automatic TEI assignment equipment,
- 64 to 126 for automatic TEI assignment equipment,
- 127 for broadcast data link.

Some equipments can negotiate automatically (with the NT) their TEI values, while others can only propose a programmed value. The negotiation uses frames with a SAPI equal to 63 and a TEI equal to 127:

- The TE sends an "identity request" with a TEI value (127 for automatic assignment TE, programmed value for other).
- The NT replies with an "identity assigned" with the assigned (or accepted) TEI value, or with an "identity refused".

The Command field may be one or two bytes:
- one byte for the mode with no acknowledgement, or for the frames with no sequence number,
- two bytes for the sequenced frames in multi-frame mode.

The Information field, if present, contains information bytes used by the addressed service point. It is present in frames (UI) requiring no acknowledgement, often used for broadcasting (for example, on an incoming call), or in acknowledged frames (for point-to-point connections).

The FCS (Frame Control Sequence) permits verification of the quality of a received frame.

Each link is handled in a similar way to HDLC protocol, with I (Info) frames, S (Supervisory) frames and U (Unumbered) frames. The main differences between LAPD and HDLC are:

- LAPD handles link multiplexing, broadcast data links, unacknowledged frame transfers, permanent link supervision and TEI management.
- LAPD does not handle FRMR and TEST frames.

3.4 The call control protocol (I.450/451 or Q930/931)

Call control is at level 3 of the OSI model, and uses the call control link (SAPI value is 0, see layer 2). Its main function is to set up, control and release the B channels. The messages handled by the protocol are:

- during the call setting up: ALERTING, CALL PROCEEDING, CONNECTION, SETUP,...
- during the call active phase: SUSPEND, RESUME,...
- during the call releasing: DISCONNECTION, RELEASE,...
- others: INFORMATION, STATUS,...

Fig. 12 is an example of the establishment and release of a call: The terminal X calls an ISDN subscriber where there are two terminals (Y and Z) ready to answer. Z takes the call and Y is released.

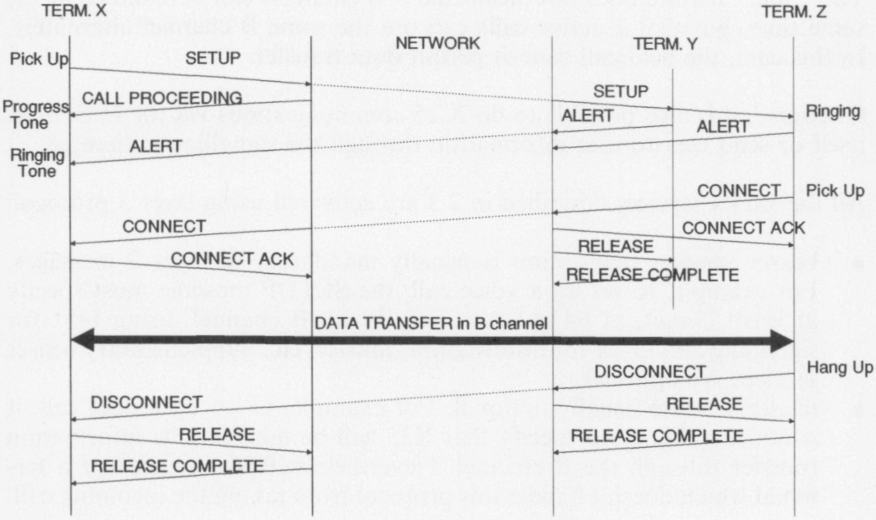


Fig. 12 A call set up example: signalling messages in D channel

Terminal X sends a SETUP message, including bearer service description, destination address, etc...

After having controlled the SETUP, the network sends it towards the destination and acknowledges X with a CALL PROCEEDING. When the SETUP arrives in the destination area, it is received by both Y and Z (broadcast feature), that ring and acknowledge with an ALERTING (which is sent back to X). At this stage, both Y and Z are ringing and displaying the caller's address, and X sounds a ringing tone.

When Z is picked up, it sends a CONNECTION. Then the network transmits the CONNECTION to X, acknowledges Z with a CONNECTION ACK, and advises Y that it is no longer involved in this call (with a RELEASE message which Y acknowledges with RELEASE COMPLETE).
X sends CONNECTION ACK, and one full duplex B channel is available for the data transfer between X and Z (for a voice call, voice is digitized).

Once the data exchanges have finished, Z (it may be X) sends DISCONNECTION that the network transmits to X, and the call is released with a RELEASE/RELEASE COMPLETE on each side.

As the D channel is always available, it is still possible for either terminal, when one B channel is busy, to set up another call and establish the other

B channel. After that, although both B channels are busy, it still can receive an incoming call, hold one of the active communications, and take the incoming one.

The "hold" feature does not mean that 3 B channels can be handled at the same time, but that 2 active calls can use the same B channel alternately. In this case, the held call cannot permit data transfer.

Of course, it is also possible to do X.25 communications via the D channel itself or send user-to-user information through the signalling exchanges.

All the ISDN services described in 2.3 are activated using layer 3 protocol:

- bearer services description is usually mandatory in layer 3 messages. For example, to set up a voice call, the SETUP message must specify at least: circuit, at 64 kb/s, for speech, on B channel, using I451 for signalling and G711 for information transfer, etc. Supplementary bearer services are optional.
- teleservices are usually optional. For example, to set up a data call, it is not mandatory to specify that X25 will be used for the information transfer through the B channel. Nevertheless, this may prevent a terminal which doesn't handle this protocol from taking the incoming call.

On the addressing capability, ISDN is very versatile: a terminal can be selected using one or more of the following features:

- **sub-addressing** (supplementary service), with up to 4 digits, which provides a way to select a particular terminal within an installation (incoming sub-address must match with the programmed sub-address of the terminal).
- **direct dialling in** (supplementary service), similar to sub-addressing, except that the incoming digits are extracted by the network from the called address (this service is very often used in PABX installations),
- **low layer and high layer compatibility** (teleservices), preventing for example, a telephone from ringing on an incoming data call.

Furthermore, a terminal can use the user-to-user information for password control, or use the originating address to verify the caller identity.

4 Conclusion

This short description of ISDN techniques, although it is just an introduction, illustrates the many advantages of this new way of communication, even for the private customer.

The integration of the different existing networks, the continuous capability of signalling, the digital transmission quality (even for voice), the possibility of sharing one interface between several terminals, the large number of services and selection features, the high bit rate for data transmission, etc...are all strong points of ISDN that have been obtained because of intelligent protocol specifications, taking into account the existing structures and protocols.

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ISDN in France: Numéris and its market

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Abstract

This paper gives an overview of the French ISDN, named NUMERIS, and its market.

First, it describes the technical story of NUMERIS, the different pre-ISDN data communication networks and the implementation of NUMERIS.

Then, as ISDN is a great change in communication networking, needing a very subtle marketing, this article goes through the strategy elaborated by France Telecom and concludes with the ISDN terminals and applications on offer.

PART 1: THE FRENCH ISDN: NUMERIS

1. The public network's evolution towards ISDN

1.1 Changes in the French telephone network

During the 1970's, the French telephone network went through a number of dramatic changes. In that decade, there was explosive growth in the number of telephone lines (reaching 24 million in 1981, up from 4 million in 1974), accompanied by significant changes in the telecommunications infrastructure. While the quantitative growth in the period was certainly spectacular, the underlying changes in network architecture were, perhaps, much more significant, especially in respect of the introduction of ISDN service.

From early on, the French telecommunications policy was based on the digitization of the telephone network. France Telecom installed in 1970 the first fully digital central office switch. This started a major digitization effort that continues to this day, and has made the French telephone network the most digital in the industrialized world.

According to (DICENET) the digitization stage of France Telecom's network, in 1987, was as follows:

Local switching:	50 %
Transit switching:	60 %
Local Transmission:	70 %
Long distance transmission:	50 %

The charts of Fig. 1 and Fig. 2 show the evolution, past and projected of the network from the mid '70s to 1995.

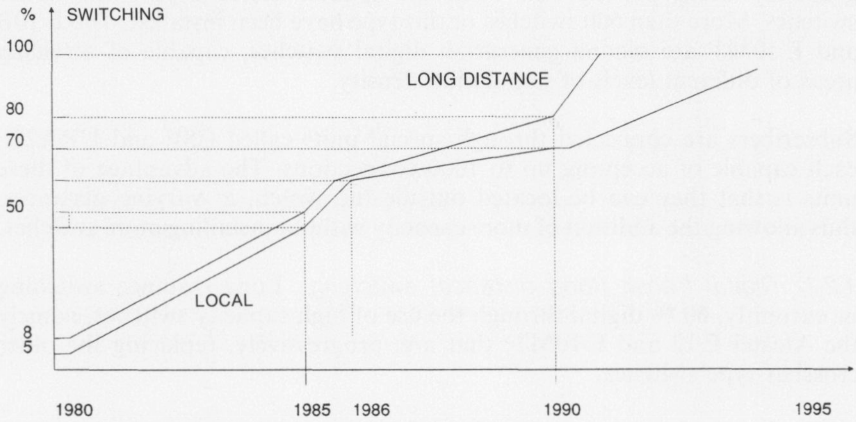

Fig. 1 Switching digitization of the French telephone network

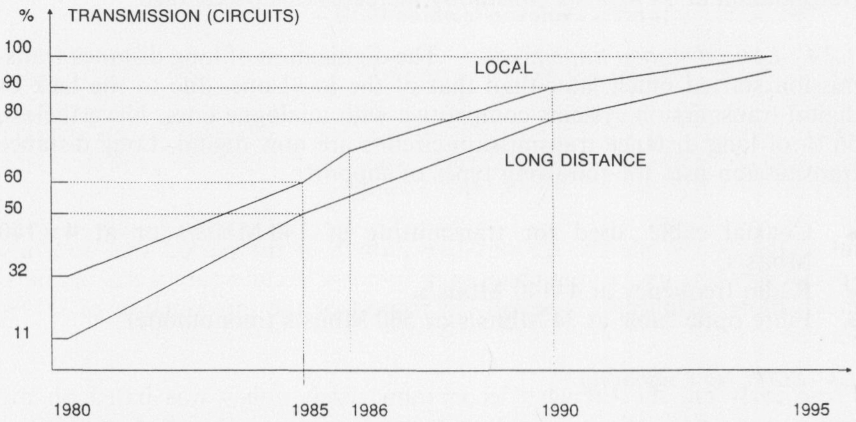

Fig. 2 Transmission digitization of the French telephone network

1.2 Network equipment

In this section we present an overview of the switching and transmission equipment currently in use in the French telephone network. Basic understanding of this infrastructure is essential since the ISDN implementation depends heavily on the network infrastructure.

1.2.1 Digital local switching Since 1970, France Telecom has been installing exclusively digital, time division switches. The systems opted for were the Alcatel E 10B and E 10MT, derived from the Alcatel E 10 A series, introduced in 1970. Currently, 48 % of the 24 million telephone lines in France are connected to either E 10B or E 10MT. All other systems are gradually being phased out, while all updates concern only the newer switches. More than 600 switches of this type have been installed. The E 10B and E 10MT are second generation digital switches, capable of servicing areas of different levels of population density.

Subscribers are connected through special units called CSE and URA2G, each capable of accepting up to 1000 connections. The advantage of these units is that they can be located outside the switch, at varying distances, thus allowing the addition of more capacity without installing more switches.

1.2.2 Digital transit (long distance) switching Long distance switching is, currently, 60 % digital through the use of high capacity switches, namely the Alcatel E 12 and E 10MT, that are, progressively, replacing the older crossbar-type switches.

1.2.3 Local transmission Local end transmission covers the part between a wiring unit, such as CSE, and the switch. This type of transmission is 70 % digital, and the introduction of new techniques such as fibre optic transmission at 34 Mbits/s constantly increases this percentage.

1.2.4 Long distance transmission The digitization of long distance transmission started much later than that of the local one, due to the lack of digital transmission systems competitive with analogue ones. Nevertheless, 56 % of long distance transmission circuits are now digital. Long distance transmission uses the following types of support:

- Coaxial cable, used for transmitting at 140 Mbits/s or at 4 × 140 Mbits/s,
- Radio frequency at 4–140 Mbits/s,
- Fibre optic cable at 34 Mbits/s or 560 Mbits/s (monomode).

1.3 CCITT No 7 signalling

While the improvements described in the above section provide the transmission and switching capacity necessary for implementing a generalized ISDN service, the adoption of CCITT No 7 signalling made available the means to implement the D protocol.

The conventional telephone network uses the same communication channel for both signalling and information transfer. As a result, the signalling possibilities are quite rudimentary, and limited to things like dialling, busy signal, ringing, etc.

The implementation of D protocol requires substantial signalling capacities. CCITT No 7 is a protocol used to manage signalling in a separate "semaphore" channel.

While work on the definition of CCITT No 7 had started long before the definition of ISDN, the resulting signalling system is very well adapted to it, especially by allowing variable length messages. Implementing separate channel signalling necessitates the construction of a separate signalling network, superimposed on the information transfer one. Every local switch is associated with a signalling point (SP), which serves as the local CCITT No 7 handler. Signalling points are connected to signalling transfer points (STPs) through specialized links, running at 64 kbits/s. STPs route No 7 messages to other STPs and can be associated with servers that provide additional information.

The diagram of Fig. 3 illustrates the CCITT No 7 concept.

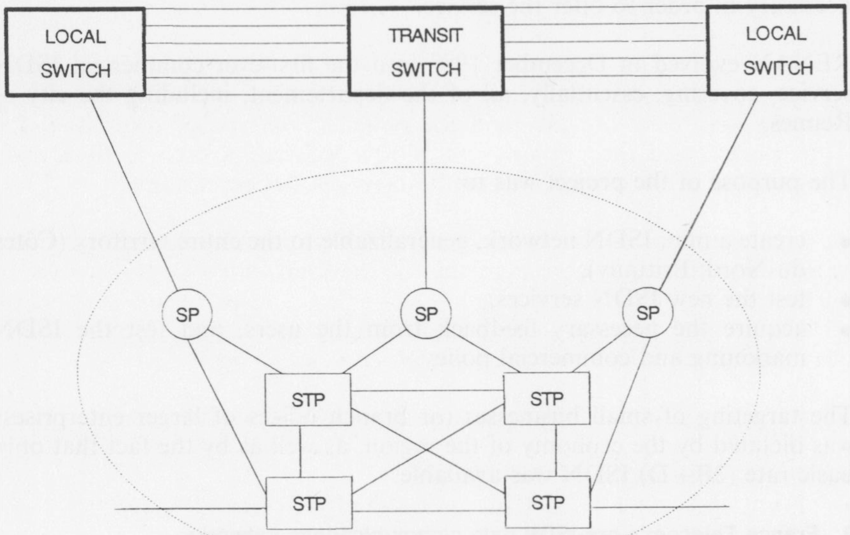

Fig. 3 CCITT No 7 Network

The introduction of CCITT No 7 was started in 1986, through upgrades of the Alcatel E 10 and E 12 systems, with the priority being placed on the long distance switches. By 1989, any two such systems could inter-communicate in message mode. The initial implementation of CCITT No 7 involved point-to-point connection between switches. A separate signalling network was put in place in 1989, that will ultimately include 40 STPs, fully interconnected. The availability, at a national level, of No 7 signalling along with the digital transmission and switching infrastructure made possible the relatively early commercial introduction of ISDN in France.

1.4 ISDN's beginnings in FRANCE: The RENAN project

As we have seen in the previous sections, the network infrastructure has undergone extensive qualitative and quantitative improvements since the early 1970's. These improvements led to the feasibility of offering an ISDN service, in the late 1980's. The first attempt at a public ISDN service was that of the RENAN (RNIS des Entreprises pour les Nouvelles Applications Numeriques – Business ISDN for New Digital Applications) project.

RENAN involved the connection to ISDN of about 1000 mainly small to medium sized businesses, located in the department of Côtes du Nord, in Brittany.

The whole project was conducted by CNET, France Telecom's research arm, and involved all the hardware and software upgrades to local switches, necessary in order to offer the service.

RENAN evolved in December 1987 into the first-ever commercial ISDN service, covering, essentially, all of the departement, including the city of Rennes.

The purpose of the project was to:

- create a mini ISDN network, generalizable to the entire territory (Côtes du Nord; Brittany),
- test the new ISDN services,
- acquire the necessary feedback from the users, and test the ISDN marketing and commercial policy.

The targeting of small businesses (or branch offices of larger enterprises) was dictated by the economy of the region, as well as by the fact that only basic rate (2B + D) ISDN was available.

2 France Telecom's pre-ISDN data communications networks

The development of the digital infrastructure of the network, in addition to improving voice services through more efficient transmission and switching, also gave rise to a number of data services.

These digitization derivatives, known as "pre-ISDN", were meant to provide data services on the telephone network, before the standard protocols were put in place. One important side effect of the pre-ISDN offer, was the development, by third parties, of a substantial number of applications that were, subsequently, ported to full blown ISDN. At the same time, the users of, both, the services and the third party applications were "trained" on the possibilities opened by widely available public data networks. In general, such users were able to accept ISDN once it was put in place.

Also, strictly speaking, the pre-ISDN offer includes the TRANSCOM, TRANSFIX and TRANSDYN services described below. We have however included TRANSPAC in our discussion, even though TRANSPAC is an entirely different network, because of its importance for ISDN in France, especially in respect of its integration with the telephone network.

2.1 TRANSFIX

It consists of fixed point-to-point data links, available with a variety of interfaces and data rates.

TRANSFIX offers 3 groups of options:

- low speed, available in 2·4, 4·8, 9·6 and 19·2 kbps, with a V·24 interface
- medium speed, in 48, 64 and 128 kbps with V·24, V·11, or X·21 interfaces
- high speed, at 2 Mbps

TRANSFIX has been available throughout France since 1980, even though its predecessor, TRANSMIC, had been operational as early as 1977.

TRANSFIX lines are available 24 hours a day, and are fully backed up, i.e. continuity is guaranteed.

The different TRANSFIX lines join the network through analogue or digital links and they are, subsequently, multiplexed into 2 Mbps PCM lines.

2.2 TRANSDYN

TRANSDYN, available since 1984, offers switched medium to high speed digital service, using both terrestrial and satellite links. The major difference between TRANSDYN and TRANSMIC lies in the switched nature of the link. An important TRANSDYN feature is that the line can be dynamically configured, at establishment time, to operate at different speeds. TRANSDYN offers data links of up to 2 Mbps, as well as higher speed links used for video transmission.

2.3 TRANSCOM

TRANSCOM offers circuit switched digital links, at 64 kbits/s. It relies exclusively on the public telephone network, and presents a V·35 or X·21 interface at the subscriber's edge.

TRANSCOM, the immediate predecessor of Numéris, is a very important service, in that its characteristics are similar to those of ISDN, and that its implementation necessitated the solution of a number of technical problems which facilitated the subsequent introduction of ISDN.

As we mentioned above, TRANSCOM relies on the public telephone network for transmission and switching. However, special interfacing hardware was put in place between the customers' premises and the E10 series switches.

At the customer's premises, the X·21 or V·35 interface is provided in a special unit called RA (Régie d'abonné). RAs are connected, through 72 kbits/s links, to multiplexing units called Digital Channel Connection Units (URCN in French), that are, subsequently, linked to the central office switch through 2 Mbits/s lines.

The introduction of TRANSCOM has created a number of technical problems, mainly stemming from the fact that the telephone network is not yet 100 % digital. It was necessary to ensure that a TRANSCOM call was not routed through older, analogue long distance links. This was accomplished by assigning special numbers to TRANSCOM subscribers. This way, the switch can identify a TRANSCOM call once dialling is complete and route it through digital links. This technique is also used for ISDN calls, with the exception that a separate numbering plan is no longer necessary, since data calls can be differentiated from voice ones by examining the appropriate field in the layer 3 SETUP message.

TRANSCOM has demonstrated the feasibility of providing a wide circuit switched 64 kbits/s service, and has prepared the users to accept ISDN, when it becomes available.

2.4 TRANSPAC

TRANSPAC, the French packet switching network, in operation since 1979, has 80,000 subscribers and is available throughout the whole country. It also serves as the backbone for a network of some 5,000,000 videotex terminals, the most extensive network of that type in the world.

Clients can establish X25 virtual circuits at a variety of speeds, ranging from 50 bps to 64 kbits/s, the 48–64 kbits/s class having been made available in July, 1990.

TRANSPAC is used as the communications provider for a number of services such as videotext, X·400 electronic mail, EDI etc. It benefits from connections to other countries' packet switching networks, via the International Transit Node (INT) and InterPac.

While Transpac uses some facilities of the existing telephone network, such as point-to-point lines, it is really an independent entity. Its importance for

ISDN lies in that, in addition to its accessibility from Numéris, described in the next section, it plays the role of an integrated network.

By far the most important users of TRANSPAC are the millions of households equipped with videotext terminals. The wide availability of videotext has benefited the introduction of ISDN in that it has introduced two important concepts.

The first concept is that of a multi-service network. Videotext users are connected to TRANSPAC via the telephone network, through Videotext Access Points (VAPs). Thus, TRANSPAC access seems to be a natural extension to the ordinary telephone service, providing the final user with an integrated voice/data service.

Secondly, the videotext network, as a provider of services, uses both the voice and data network, by exploiting the advantages of both, namely the global availability of the telephone, and the ability of TRANSPAC to handle sporadic traffic. In way, videotext becomes a multi-service network. ISDN is also a multi-service network that, in addition to its own services, is intended to integrate the different existing networks (see section 4).

3 The implementation of Numéris

3.1 Telephone network changes

As mentioned in the previous section, the French telephone network relies, essentially, on the second generation digital switches, namely the Alcatel E 10B and E 10MT. While these switches, in conjunction with CCITT No 7, provide the raw transmission and switching capabilities necessary for offering ISDN services, a number of changes had to be made to the network infrastructure in order to implement ISDN.

The main modifications of the network include the development of a new connection unit, the Digital Satellite Centre (DSC), used as an intermediary between the customers and the switch, as well as the (mostly software) updates of the switches themselves, in order to manage DSC and provide the new services.

3.1.1 The Digital Satellite Centre DSC (in French CSN – Centre Satellite Numérique) is a universal wiring unit, used to connect both analogue and digital customers. It serves a dual purpose: provides ISDN lines and, through its universality and technical capabilities, minimizes the cost of providing new ISDN lines.

DSC is compatible with the E 10 series switch, and connects to it using the CCITT No 7 protocol. It consists of a number of concentrating units, both local and remote, and a command and control unit that also provide the interface to the switch. DSC's general architecture is described in Fig. 4 diagram.

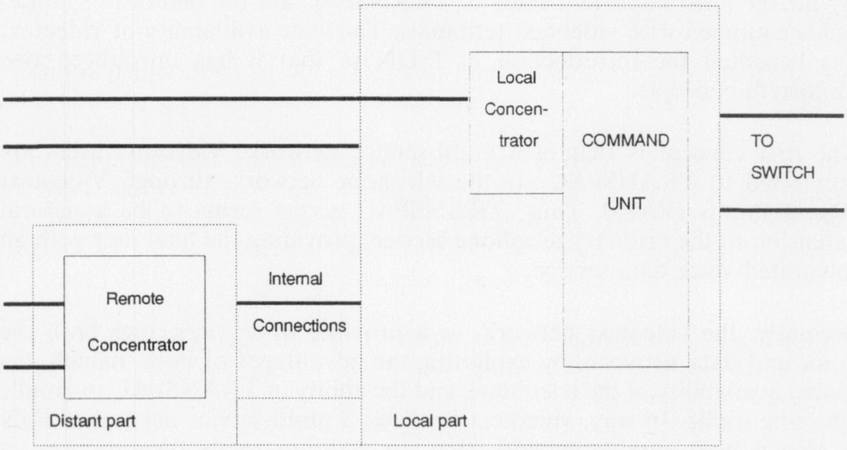

Fig. 4 DSC architecture

In the following 2 subsections we provide a short description of the concentrating and control units included in the DSC.

The concentrating unit:

As shown in the figure 4, a DSC contains 2 types of concentrators: Distant ones, indicated as DDC (for distant digital concentrator), that can be located outside an DSC, and local ones (LDCs). In all, an DSC can support up to 20 distant and/or local concentrating units.

Distant concentrators are linked to the command unit of a DSC via 2 Mbits/s or 704 kbits/s links. Their advantages are that they can be located close to small user populations and, thus, avoid the installation of DSCs, and that they generally decrease the length, and consequently the cost, of the subscriber's line.

Every concentrator is composed of a number of cards, to which subscribers' lines are wired, and an interface to the control unit. This modular approach allows one to put the signalling, digitization, pre-processing, and concentration logic on the cards, and, thus, dissociate the interface from the type and the number of lines attached to it.

As mentioned in the previous section, the concentrator can support both analogue and digital (ISDN or TRANSCOM) customers. This is done through the use of a different card for each type of customer. The maximum number of cards, digital or analogue, supported by the concentrator is 16.

All cards share the resources of the concentrator, which include 1 to 4 2 Mbits/s PCM lines, 1 signalling HDLC channel that communicates with the command unit, as well as a microprocessor and microcontroller. The capacity of the HDLC channel is doubled if more than 2 PCM lines are deployed.

Analogue customers are connected to the TABA 16 card, which supports 16 lines. Each card is, in fact, a motherboard containing up to 8 modules supporting 2 lines each. In addition to these modules, TABA 16 contains a controller, common to all modules, that assures timing and multiplexing as well as a processor and memory. The modular architecture of the TABA 16 allows easy module replacement in case of failure, without disturbing the totality of the lines handled by the card. Each module contains a CODEC, in order to present a digital signal to the control unit.

Digital (ISDN) subscribers are connected to the DSC via the TABN card. Each TABN card can support up to 8 ISDN lines. The functionalities of the TABN card include:

- line interface,
- B and D channel multiplexing/demultiplexing,
- layer 2 of LAPD processing,
- some layer 3 processing.

The physical aspects of TABN are similar to those of TABA 16 and 8.

Primary (30B+D) rate customers are connected to the TADP card, that offers functionalities similar to the TABA ones, with the exception that only one line is allowed per card.

The control unit:

The control unit of a DSC consists of a number of modules, that include:

- 2 command units, of which one is in backup mode,
- one unit for auxiliary control functions,
- the interfaces to the switch.

A command unit includes a processor and 1 Mbyte of memory and assures the exchange of information between the concentrators and the switch through special submodules, dedicated to each function and sharing the processor and memory. The command units hold a dialog with the switch through the CCITT No 7 protocol procedures. Auxiliary control functions include tone generation, pulse tone recognition and line testing.

The switch interface, uses 2 to 16 PCM lines in order to exchange signalling and clock information with the switch. Its implementation differs depending on whether the DSC is a local or a remote one.

As the DSC can contain up to 20 concentrators, each supporting a maximum of 16 16-line cards, the maximum addressing capability of the DSC is 5120 subscribers. A DSC is connected to the switch by a maximum of 16 2 Mbits/s PCM lines. Since all control software is remotely loaded, the successive generations of ISDN described in the following section are easily installed throughout the country.

3.1.2 New switch capabilities As mentioned in the previous section, most of the changes needed to provide ISDN service were incorporated in the new DSCs. However, a number of changes had to be made in the E10-series switches.

The co-existence of the analogue telephone network and Numéris, necessitates a great level of interaction between the two. The interconnection facility was implemented at the switch level. Thus the switch, will, for example, create a SETUP message for a Numéris customer receiving a call from a non-Numéris one, and will include the appropriate support service field to indicate the nature of the caller.

While certain supplementary services do not require any switch involvement, but only concern end-to-end interaction, others, such as hold/reconnect, call redirection, temporary call diversion etc, necessitate some switch involvement, and, thus, modifications to the software of the switch.

3.2 Numéris implementation schedule

The introduction of ISDN in France was done in a series of successive steps, that began in early 1986. The following is a summary of this introduction:

1986: Introduction of TRANSCOM, a pre-ISDN circuit-switched network, offering 64 Kbits/s data transmission, through an X21 interface. TRANSCOM had more than 500 subscribers by the end of 1987.

1987: Beginning of installation of CCITT No 7 signalling throughout the telephone network. CCITT No 7 was strategic for the subsequent introduction of ISDN.
Installation of the synchronisation structure of the network, necessary for quality transmission.
Beginning of the installation of Digital Satellite Centers. By the end of the year, a number of preliminary-version terminals became available, which included terminal adapters, telephones and NT1s
A preliminary Numéris version became available in the Côtes du Nord department (RENAN).

1988: Expansion of ISDN service to the city of Rennes and, subsequently to Paris, Neuilly and La Défence by the end of the year. TRANSPAC access, via the B channel, at rates ranging from 2·4 to 64 kbits/s.

1989: Commercial ISDN, including primary rate, was available in Lille, Paris, Lyon, Marseille and Rennes.

1990: End of CCITT No 7 signalling installation. Every administrative zone (France is divided in 90 administration zones) is equipped with an DSC, which allows national ISDN coverage.

The progressive introduction of Numéris necessitated different versions of switch and DSC software. There have been two versions to date, with a third one to be introduced shortly.

3.3 Numéris Services

In this section, we present the services offered by Numéris, and their availability in each of its different versions.

These services were introduced in the article "Introduction to the technical characteristics of ISDN" in this issue (Orange 1991).

The services offered by ISDN belong to three categories:

- bearer services,
- teleservices,
- supplementary services.

3.3.1 Bearer Services Numéris offers 2 types of bearer services, that relate to the possibilities offered by a B-channel connection:

- Transparent, switched B-Channel (CCBT). This is a point-to-point, circuit switched connection at 64 kbits/s, established on demand, and with a guaranteed end-to-end digital connection (TRANSCOM-style). Such a service is normally used for data transmission.
- Non-Transparent B channel (CCBNT). Similar to the transparent one, with the exception that the connection may pass through non-digital circuits. It is meant to provide voice transmission.

In addition to the 2 fundamental services above, available in the VN2 version of Numéris, VN3 will offer a number of other services that will include:

- X25 packet switching in the D channel
- a small volume, secure data transmission service, in the D channel, the purpose of which is remote action and control.
- access to the telex network, via the D channel.

3.3.2 Supplementary Services The supplementary services specified by CCITT were presented in (Orange 1991). Here we present the services actually implemented in the VN1 and VN2 versions of the network, along with a short description of each service.

VN1 and VN2's set of standard supplementary services include:

1 *Sub-addressing*. This allows a Numéris customer to add 1–4 extra digits to the called address. That enables the selection of a particular terminal (programmed with the same sub-address) within the called installation. The sub-address's interpretation is up to the terminals, since it is transparently carried by the network.

2 *Caller identification*. This allows a terminal receiving a SETUP message to know the calling number, by examining a field in the message that includes this number, along with an (optional) sub address. While the caller identification is possible even for analogue callers, it is restricted to ISDN-to-ISDN calls for legal reasons.

3 *Suspend/Resume*., This supplementary service allows a subscriber to suspend a voice communication, and resume it up to 3 minutes later. It is meant to permit terminal portability.

In addition to the above services, the following are provided at additional charge (either on a call-by-call or a subscription basis):

4 *User-to-user messaging*. A user is allowed to include an information field of a length up to 32 octets, in setting up and releasing call messages. This field is transparent to the network, and is charged on a call-by-call basis. It allows a user to send a message on another ISDN terminal (useful for passwording, or personal messaging).

5 *Direct Inward Dialling (DID)*. It consists of allocating to the subscriber a part of the national numbering plan, and of transmitting the last 4 digits of the called number in a separate field. On receiving these 4 digits, the called party can select a particular terminal to present the call. This feature is commonly used by PABXs (Private Automatic Branch Exchanges).

It is charged on a subscription basis, depending on the number of telephone numbers attributed to the subscriber.

It allows direct selection of an entity (terminal, person, service) inside an ISDN installation.

6 *B Channel specialisation*. It specifies a number of channels as outbound or inbound only. It is charged on a subscription basis.

7 *Restricted connection*. Allows restricting outgoing calls depending on the number selected, or the communication's cost.

8 *Calling number identification restriction*. It offers the possibility of not including the calling number field in a SETUP message when not wished. It is available on subscription, and concerns the whole installation at the subscriber's site. This service is available for protection of civil liberties.

9 *Real time charge information.* Informs the caller in 'real time' of the units spent during a connection, by sending a FACILITY message every time a unit is consumed. It can be charged either on a subscription or a call by call basis.

10 *Total cost information.* It informs the caller of the total communication cost, in units, in a special field of the RELEASE message. Charged on a subscription basis.

11 *Call forwarding*: Allows the user to forward the whole installation to another number of the national numbering plan. The forwarding is done at the switch level. Charged on a subscription basis.

12 *Temporary call diversion.* A terminal can divert a call towards a different number, upon reception of the SETUP message. It differs from call forwarding in that it is done and charged on a call-by-call basis.

13 *Itemized billing.* Supplied on a subscription basis, provides details of each long distance call made along with the bi-monthly bill.

14 *Double call.* Allows calling another number while another call is in progress. The original call is, automatically, placed on hold.

15 *Call alternation.* It permits alternating between a held and an active call.

3.3.3 Teleservices The teleservices defined in VN1-VN2 are:

- group III fax on a non-transparent (CCBNT) B-channel,
- videotext-teletext on a CCBNT channel,
- X·25 on a B channel,
- group IV fax on a transparent (CCBT) B channel.

3.4 Network Equipment offered by France Telecom

France Telecom's standard end-user equipment offer contains both network terminations and terminal equipment (see the description of these equipment in Orange, 1991).

The user can rent or buy these equipments from France Telecom, or buy them directly from the manufacturers. Details of the market offer are given in Part 2 Ch.4.2.

3.4.1 Network terminations There are two types of network termination currently available. The basic one, that requires one basic rate access, is called unique bus network termination and essentially comprises an NT2 and a bus similar to the one described in (Orange, 1991). The bus connects up to 8 terminals.

This type of network termination allows internal inter-terminal communication, as well as Direct Inward Dialling (DID). It also processes locally a number of supplementary services, thus playing the role of a rudimentary PABX.

The second type of network termination is a multi-bus one. On the network side, there are 1–6 basic rate accesses, while on the user side several busses are allowed in a star configuration. In addition to the supplementary services that are processed locally, ie without the intervention of a switch, the network terminations are capable of offering a number of services which are not available in the public network, such as 3-way conference (voice only), call waiting and call transfer.

3.4.2 Terminal equipment available The standard terminal offer includes telephone and adaptor terminals (allowing connection of a terminal to ISDN). A telephone terminal includes a microprocessor, memory and the S0 circuitry that allows it to connect to a ISDN bus.

In addition to the usual functionalities of an office hands-free telephone, it contains features, implemented in software, permitting use of supplementary services of ISDN, such as a mini-telephone directory, a facility to send user-to-user messages, a small database containing recent call information etc.

Among the first adaptors to be developed were the X21/S and V35/S ones, in order to allow Numéris to connect to equipment previously connected to the TRANSCOM network. In addition to these the following adaptors are available:

- analogue/S0 (ISDN interface) for modems, telephones, fax machines etc,
- X25/S0,
- V24/S0.

4 Numéris and the existing networks

As we have seen in section 2, a number of data communication networks existed before ISDN, namely TRANSCOM, TRANSPAC, TRANSMIC and TRANSDYN, in addition to the telephone and telex networks. These networks, while independent of each other, were already able to interconnect, through gateways. For example, a gateway connects the telex and TRANSPAC networks, and PADs (packet assemblers/disassemblers) allow telephone subscribers to connect to TRANSPAC.

In section 3, we briefly mentioned the facilities, existing or envisaged, used to provide connectivity between Numéris and the telex (through the D channel) and TRANSPAC networks.

A Numéris subscriber can, in this way, gain access to all the services (such as X400 electronic mail, on-line databases, videotex etc) available through TRANSPAC.

While TRANSCOM will be eventually phased out, since it has now become redundant, TRANSMIC, TRANSDYN, and TRANSPAC will remain in place. These networks are not directly competitive with ISDN.

Numéris, as we mentioned in section 1, will serve as a "backbone" network offering a basic set of services (switched voice and data) and, at the same time, access to more specialized networks, such as TRANSPAC (see Fig. 5).

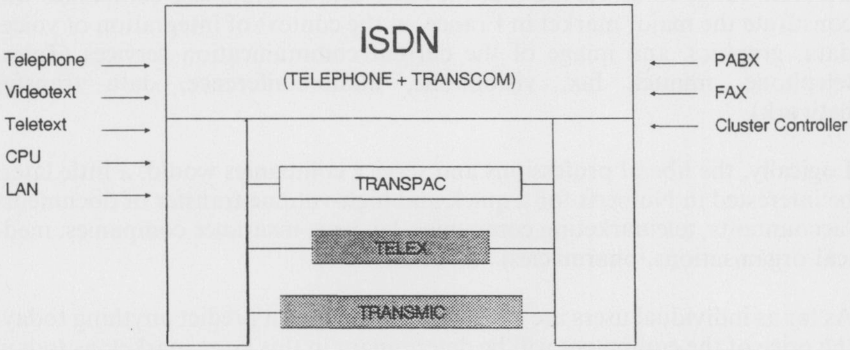

Fig. 5 ISDN and the existing networks. Note: Telex and Transmic are not yet available for ISDN subscribers

PART 2: THE FRENCH ISDN MARKET

1 Introduction

France Telecom launched Numéris (the French ISDN) in December 1987 (RENAN Operation in Brittany); since 1988 the French operator has been maintaining a very aggressive marketing policy:

- Advance commercial launch and nationwide availability by end of 1990.
- "Attractive" price.
- Development of partnership between customers, suppliers and installers.

In spite of all these efforts France Telecom has signed about 400 PRA (Primary Rate Access) and 5000 BRA (Basic Rate Access) in 1990 and hopes for a total of 7000 BRA by the end of 1991.

From the beginning, the supply of end user terminals and specific applications exceeded the demand; however ISDN is now arriving in favorable context, and the next few years will see a strong growth of the need for data transmission, linked to further development of computing equipment and to more and more advanced forms of interconnection.

2 The Numéris target

At the beginning, Numéris involved only the professional users, and particularly all the computing companies which very quickly understood the economic sense of such a link. Large companies were also very quickly involved, in priority, the banks, the large press groups, the administrative and public services, and some specific organisations (like statistical bureaux and reference libraries with on-line access).

Medium-range forecasts are that the small and medium size companies will constitute the major market in France, in the context of integration of voice, data, graphics, and image of the current communication services (Telex, telephone, minitel, fax, visiophone, audio-conference, data transfer network).

Logically, the liberal professions and service companies would, a little later, be interested in Numéris for a quick and high-volume transfer of documents (accountants, telemarketing companies, lawyers, insurance companies, medical organisations, pharmacies).

As far as individual users are concerned, nobody can predict anything today; the price of the equipment will be determinant in this large market; as today, most of the products remain for professional use.

3 France Telecom's aggressive marketing policy

As we said in this introduction, France Telecom has concentrated its effort on three main axes, since the launch of Numéris in 1987.

3.1 Advance commercial launch

According to Franch Telecom, this advance commercial launch will enable end-users to be quickly involved in ISDN and its different applications. France Telecom plans to reach 150,000 Basic Rate Access (BRA) users by 1992, and at this date, Numéris should become profitable for France Telecom. In 1995, France Telecom plans that between 500 000 and 700 000 lines "equivalent to Basic rate access" will be installed in France.

3.2 Development of partnerships

In these partnerships, three parties are concerned:

- The customer who expresses a requirement for improvement to or development of a specific application (using ISDN).
- France Telecom which examines the requirements of the customer and provides its experience and its consultancy (sometimes, its money).
- An information provider (IP), who provides his competence to realize or supervise the project.

Four main criteria of a partnership may be distinguished:

- Economic realism: the three partners will support the cost of the development.
- Feasibility: the expert analysis must lead to an economically viable project.
- Subsequent commercialization: the developed application must be commercialised, meaning that it must correspond to a significant market.
- Innovation: the Numéris potentialities must meet the customer requirements.

A financial contribution from France Telecom is not automatic. This contribution can partially cover the costs of development, but not those of equipment.

SICOB 90 allowed France Telecom to sign nine new contracts, bringing the number of "Numéris partnerships" signed to about 50. Now every main IT manufacturer, as well as the eight first French SSII (Information Providers) are involved in this process.

ICL and France Telecom signed their first Partnership Agreement for ISDN application development on 21 June 1989. This agreeement shows the special commitment of both companies to the growth of ISDN applications. "Cooperative working", using ICL's ISDN Workstation and Desktop Conferencing (an ICL ISDN product), was selected by France Telecom as the first development under the agreement (Fuller, 1991).

3.3 "Attractive" price

Two modes of traffic pricing are offered. Telephone traffic is tariffed as the normal current telephone service. Data traffic is tariffed as TRANSCOM, which is approximately 1·8 times the telephone service (Price in September 1990).

It is a very "attractive" tariff for data transmission, largely below the current dedicated line tariff. For example, a fax of ten pages costs three times less using NUMERIS. Fig. 6, 7 and 8 give an idea of the price positioning of Numéris.

4 Numéris's offer

4.1 The slow start

Although Numéris is currently taking its first steps, many people think that it will transform their company organisation, their working methods, their communciation strategies.

BASIC ACCESS

initial cost	
access price to NUMERIS	665 F *

basic subscription	
supplementary services proposed and invoiced at a fixed price: monthly subscription	
calling party identification to the called user subaddressing for selection of a specific user terminal systematic offering of waiting calls terminal portability	300 F *
supplementary services proposed and invoiced as used	
subscriber private meters	1 pricing unit / use
national call forwarding	1 pricing unit / use
minimessage	0 , 45 F *

complementary subscription	
telephone amenity	
total cost double call terminal forwarding	17 F *

* without V.A.T.

Fig. 6 France Telecom ISDN prices

Any innovation, with a national or international significance, must necessarily go through a latency phase because peoples' habits change more slowly than technology advances.

People should be patient, and teach the deciders that they are breaking new ground technologically speaking.

According to France Telecom, the slow start of Numéris is due not to the operator (itself) who has adhered to the time-table, but rather to the manufacturers who are slow to design specific ISDN equipment. It is important to note that the implementation of ISDN specifications is not yet fully standardised, and that manufacturers are waiting for them. This means that the priority for the different national operators is to agree to require manufacturers to work to an international standard.

PARIS/PARIS	2400 Bits/Sec	ISDN
Price (FF/mn)	0,12	1,9
Speed (Kb/mn)	12,8	468
File (Kb)	100	100
Time (mn)	7,80	0,21
Cost (FF)	0,93	0,40
File (Kb)	500	500
Time (mn)	39	1,06
Cost (FF)	4,68	2.,03
File (Kb)	1000	1000
Time (mn)	78,1	2,13
Cost (FF)	9,37	4,05

Fig. 7 Comparative prices (for file transfer) between an analog telephone line and NUMERIS, on a distance inferior to 50 kilometers

PARIS/MARSEILLE	2400 Bits/Sec	ISDN
Price (FF/mn)	2,57	4,86
Speed (Kb/mn)	12,8	468
File (Kb)	100	100
Time (mn)	7,80	0,21
Cost (FF)	20,04	1,02
File (Kb)	500	500
Time (mn)	39	1,06
Cost (FF)	100,23	5,15
File (Kb)	1000	1000
Time (mn)	78,7	2,13
Cost (FF)	202,26	10,35

Fig. 8 Comparative prices (for file transfer) between an analog telephone line and NUMERIS, on a distance superior to 100 kilometers

As we said previously, France Telecom is working in two directions to activate the process; the Information Providers (named "SSII" in France), and the large French companies working closely with these SSII, considered as "pilot sites" in charge of opening a "large public usage of ISDN".

Today, ISDN equipment and applications are still expensive, but already provide a great change in a few companies, especially those which need to be in permanent visual and audio contact; it is a bet on the future of which every current Numéris user is aware.

4.2 The Numéris equipment

4.2.1 ISDN telephones France Telecom asked a few French companies to develop ISDN telephones (SAT – Matra – Alcatel).

We could qualify those terminals as "Super telephones" mixing a lot of functionalities and a high audio quality. A liquid crystal display is provided on the telephone allowing the user to know the caller's identity before picking up the hand-set.

Some functionalities provided:

- Call forwarding,
- Directory,
- Unanswered calls,
- Charging information,
- Sub-addressing,
- Portability.

It is also possible to connect the Minitel to the ISDN phone, allowing two simultaneous communications: Voice and Minitel.

4.2.2 ISDN adaptors A set of external adaptors has been developed, allowing the connection of existing equipment to Numéris.

There are 5 types of adaptors:

- Analogue/S_0: It enables the restitution of a complete analogue interface (feeding, signalling...). Also recreation of a "simple" digital telephone terminal for Telefax service needs.
- X21/S_0: It enables use of any equipment working with Transcom, offering a 64 Kbits/s rate (or 56 Kbits/s for a connection with the U.S.A.). It conforms to the CCITT recommendation.
- V35/S_0: It enables use of any V35 equipment, with the possibility of working in permanent activation (for a Transpac access).
- X25/S_0: It enables management of access at any rate up to 64 Kbit/s.
- V24/S_0: It enables management of access at any rate up to 19 Kbit/s.

Unlike the S_0 interface add-on board, the adaptors do not always reach the 64 Kbit/s rate and furthermore do not allow use of both B channels at the same time. They do not change the maximum rate of the terminal and they only adapt the communication to the ISDN protocols.

4.2.3 PC/PS ISDN add-on boards They turn a micro-computer into an Open terminal, giving it access to the D and two B channels.

Through the B channels, they allow:

- Quick data transfers PC/PC, PC/Host (X25, ECMA 102),
- Sound or image transfer to any standard,
- Digital telephony emulations,
- Local networks bridging (NetBios emulation, TCP/IP gateway).

Through the D channel:

- Back-up of signalling and processing by the PC/PS,
- Under VN3, management of interactive services in packet mode (Videotex, Terminal emulation).

In France, about fifteen boards are on the market (ICL, Matra, OST, XCOM,...), every one different, which is an indication of the wide diversity of possible applications.

4.2.4 Telefax A standard has been specially defined by the CCITT governing the telefax transmission at 64Kbit/s: the Group 4 telefax (G4).

This standard guarantees some multiple services, and ensures the compatibility of a range of machines.

The G4 telefax enables telecopying an A4 page in less than 5 seconds with very high print quality. Still very expensive, the G4 telefax currently concerns large-scale telecopy users (sending a large number of documents).

Some manufacturers enable G4 telecopy on PC, using an add-on G4 fax board (DCS company). The G4 telecopy will certainly be one of the major applications used.

4.2.5 PABX (Private Automatic Branch Exchange) A new generation of PABX is arising in France responding to the Numéris market and exploiting every ISDN possibility. This PABX mutation affects the entire PABX market.

Offering an integrated service for both telephony and data processing, multiservice PABXs are already an important element of the internal communications in a company. The launch of ISDN and its standardized interfaces increases the role of the PABX enabling an extension of its integration possibilities beyond the private area. It implies that the PABX of every company is enhanced to access Numéris directly, with either one or several basic rate accesses (2B+D), or with a primary rate access (30B+D).

To do this, every PABX must first use time-division switching techniques to take advantage of the digital infrastructure potential, and, secondly, implement the ISDN improved signalling (D protocol) to enhance the Numéris facilities and services. In addition, the PABX has to provide a normalized T_0 and/or T_2 interface on the public network side and S_0 and/or S_2 interfaces on the terminal side.

Progressive evolution from analogue to digital:

The greatest technical changes concern the small PABX with a capacity less than 100 terminals. Most of those installed today are analogue, and the evolution towards Numéris implies a development of a new generation of products. The transfer of analogue systems towards digital systems has already started in middle range equipment (a few hundred terminals) and with the aid of new ISDN components, we can expect a quick change for small capacity systems. The launch on the market of small Numéris PABX's at a competitive price is announced for 1991. The price of these PABXs will be approximately the same as of the analogue ones.

Generally, the price of ISDN equipment is still very high, but the various developments implemented by manufacturers will enable ISDN users to be confident of the future. The profit on an ISDN product today is small because manufacturers intend to supply a worldwide market, which is not yet mature. This will be the major factor to ensure a decline in prices.

4.3 ISDN applications

SSIIs (I.P.) and information manufacturers have been developing for more than two years a lot of new applications, that may be divided into different categories.

The partnership elaborated by France Telecom is certainly responsible for so many applications. One can only regret that today these applications are far too specific, and hope that this will change with the increasing demand.

The majority of existing applications use a PC/PS as terminal and it is impossible to consider ISDN technology as a separate technology; if the PC/PS workstations had not progressed at the same time, we could not have imagined all these ISDN applications. But the PC/PS price is still a brake on ISDN development.

The different categories of ISDN application include the following:

4.3.1 Tele-computing or data transmission Data communication is a large field of application of ISDN. As a matter of fact, the new network provides many advantages: speed and cost, with quality (low error rate, fast call setup), security (caller identification, password possibility), reliability (connection control).

Numéris offers a new data transmission network, with telephone pricing and flexibility. With its call-duration-charging and its high rate, Numéris is oriented more towards the short and large data transfers (images, documentation, software).

Examples of tele-computing applications using Numéris:

- Crédit Agricole (French bank):
  Connection between an on-line electronic payment terminal and a bank server, software downloading, statistics consultation.
- Agricultural management centre:
  Automatic transfer of accountancy data files for farms.

4.3.2 Image applications More than a third of the partnerships signed by France Telecom concern image applications. Standard solutions are becoming possible with the advent of compression and decompression boards for VGA screens. Some very sophisticated medical image transfer systems exist. We can also include in the "Image family" the video-conferencing, teleconference and remote monitoring.

Examples of image applications using Numéris:

- FNAIM (major estate agency group):
  Display of photographs of houses for sale, selected from a central database.
- National weather forecast:
  Satellite meteorological images serve for the distribution of images during the TV news (TF1, a French TV channel).
- Kipa (press agency):
  Remote selection of press agency photos to figure in different press reviews.

4.3.3 Multimedia applications These applications mix audio, data, graphics, images and texts. They may be compared to an audio-videographic videotex. They are mainly used as public applications, either for remote teaching (formation à distance), for general information (use of public access terminal), for image catalogues with texts, or EDI.

Several applications for specific needs are already packaged as standard products.

Example of Multimedia application:

- FNAC (major French record retailer)
  Record-listening and photographic displaying (of the record cover), weekly downloading of new records.

Conclusion

France can today be considered as the leading country in terms of the availability of ISDN lines and also the number of applications running on ISDN. For this, there is a considerable amount of initial experience mostly gained with the techniques associated with the ISDN (NUMERIS) development, i.e.: Transpac, Videotex.

The real take-off of the French ISDN market is happening now. In the minds of decision-makers, NUMERIS is slowly becoming the best solution for data communication networks (e.g. Multimedia applications); but the real dimension of ISDN will be perceived when all the ISDN in different countries are connected and operational. The second important step for the market will depend on the effort of innovation, in terms of terminals and applications, that the manufacturers and information providers will be able to give.

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The Telecomms Scene in Spain

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Abstract

The growth of the Spanish Telecomms Market.

Spain has to be ready for the challenge of 1992. Both users and suppliers seem to be expecting this year to increase the use and development of communications products. However, the ISDN service looks like the largest question mark ...

1 Introduction

As far as the EEC countries in the 1980s are concerned, the development of the telecommunications services market in Spain has been one of the largest. This growth is expected to continue at least until 1992, the year in which events are going to take place in this country such as the Olympic Games in Barcelona and the World Trade Fair in Seville, which will both require a large communications effort.

Value Added Network Services (VANS) are one of the most important fields in which demand has increased. The last decade has shown technical consolidation of these services and of user knowledge. The 90s will begin with a great demand for these services, both from users and private companies. The actual state of the Videotex or X.400 Electronic Mail markets prove that things are moving fast in this direction.

Things are moving in the ISDN direction as well, but we will probably have to wait a few more years to substitute the actual network with what has been called "the universal socket".

When discussing the past, present or future of communications in this country one is immediately led to Spain's telecommunications provider, the powerful PTT, Telefonica, which has embarked on a major expansion programme in order to meet the demand for new telephone lines and additional services. In fact, the plans for 1990 were to expand the public network by investing £3,200 million and adding one more supplier AT&T, to its base of Alcatel and Ericsson.

2 Networks and Services

2.1 Bit of history

The National Telephone Company of Spain (called Telefonica since 1984) used to be owned by ITT before it was nationalised in 1946. It has the responsibility for telecommunications services, except telegraphy, telex and message switching, which are provided by the Ministry of Transport, Tourism and Communications.

Telefonica currently enjoys a monopoly over all network services, including the value added ones, as well as telephone handsets. The connection of any equipment to the national network is not allowed without the approval of the PTT.

2.2 Status of the current network

By 1990 only 15% of local lines were digital, with the aim of achieving 40% digitisation by 1992 (73% of trunk lines). By the end of 1993, the forecast for local exchanges is to have 8,100, ie half of them, digital.

In terms of fibre optic cable, Telefonica has planned the installation of 3,628 km for 1990 and 900 km for 1991 capturing 85% of the Spanish market, with a forecast for 1992 of 11,600 km in all.

2.3 Network Services support. Data communications.

A) *IBERPAC.*
IBERPAC was the first packet switching system installed in Europe, operating since 1982 and supporting X.25 technology. In the beginning the service was used mostly by banks and financial organisations. Nowadays, it supports international data transfer (conforming to international standards allowing it to be connected to the packet switching networks of other countries), Teletex and Videotex. Basically it provides data traffic services between terminals and computers of different types and operational modes, and acts as support for additional data communications services.

It offers two basic communications services, permanent virtual circuits (PVC) and switched virtual circuits (SVC), with some optional user facilities like *closed user groups* with outgoing or incoming access, *reverse charging*, *fast selection*, *PAD*, *multilink access*, *network user identifier*, *multichannel access*, etc.

Iberpac is organised in two areas, the area of the carrier network on which the operation is in packet mode and the access area where different types of terminals co-exist, connected with different operational modes.

For various reasons Iberpac charges are the highest in Europe, one of the most important being the fact that they are using their own packet switching technology, TESYS System, designed and developed by Telefonica Sistemas with considerable cost in R&D. This system accommodates the connection of data terminals with different protocols as well as packet terminals conforming to CCITT standard.

Another of Iberpac's problems is the slow transmission rates available, up to 9,600 bit/sec in theory, but not always ready to work at that speed.

SERVICE	SPEED	FEATURES
IBERPAC (X.25)	2400 bits/sec 4800 bits/sec 9600 bits/sec	Duplex and Synchronous. Modem included.

The Iberpac main nodes are located in Madrid, Barcelona, Seville, Leon, Valencia and Bilbao and there are 71 local access points to other cities and industrial areas.

IBERPAC CONNECTIONS

1990	1991	1992
104,640	139,520	152,000

Source: Telefonica Sistemas.

B) *IBERCOM*.
IBERCOM is defined by the PTT as an advanced integrated telephone and data transmission service, and is being developed to provide ISDN eventually to businesses at 64 Kbs, integrating the basic services of Iberpac and RTC (PSTN).

Ibercom is a multi-user service digital network, interfacing with both the public switched telephone network and the public switched data network. Furthermore, we can consider it as a global telecommunications concept developed in three different areas:

- Offering typically private network facilities, specific for each company.
- Providing real cooperation between the technical departments of every company and the PTT, in order to find the most cost effective telecomms solutions, speed them up and update them if necessary.
- Access, from the start, to integrate voice and data, knowing that the solutions achieved will be accepted by the future ISDN.

As everybody recognises, the "bridge" to the future ISDN service is not as important to Ibercom success as the real commitment to the customers' business needs. The possibility of designing their own solution together with the high speed of digital transmission seems to be reason enough to justify its acceptance.

The Ibercom network has 425 terminal centres MD 110, 35 frontal centres AXE and 3 frontal centres 1240. The installed base of lines was 170,000 in August 1990, of which 80,000 were installed in 1989. The network is used in more than 250 different companies (mainly large organisations) both in the private and public sector. Telefonica's forecast is for 250,000 lines by Q1 1991.

C) *Text Communications Services.*
C.1) Telex.
The Spanish Post Office (CORREOS) is the body responsible for telex services, leasing the necessary lines from Telefonica. The Spanish telex network comprises eight transit exchanges, 60 regional exchanges around the country and two international gateway exchanges one in Barcelona and the other in Madrid. The telex network can interface with Iberpac.

C.2) Telefax.
The installed base of facsimile machines is estimated to be 128,700 machines. The terminal equipment has to be approved by Telefonica, but supply to the market is directly through private suppliers.

C.3) Teletex.
This public service uses the Iberpac network and a converter to obtain connection to the telex network. The service provides alphanumeric transmission and its features include access to international networks through the X.75 interface. The forecast for the end of 1990 was for 13,600 users.

C.4) Ibertex. (See Videotex in VANS)

3 Value Added Network Services (VANS)

The Value Added Services offer many more facilities than the ordinary basic services, using them, but increasing their resources and making the user interface much simpler and more friendly.

The current movement in Spain towards these services makes us believe that the technical users consolidation of the eighties will be followed by a strong demand in the nineties.

I would like to review briefly the most popular VANS in Spain.

3.1 Mobile telephony

Spain was one of the first countries in Europe to offer the NMT 450 service, back in 1982. The estimated subscriber base is 50,000 at the end of 1990.

Telefonica has recently awarded a number of contracts for mobile cellular networks. Two companies, Intesa and Telcel are each to supply the basis of a cellular network, looking forward to 1992 with the World Trade Fair in Seville and the Olympic Games in Barcelona.

Nowadays, the service covers most of the country, which is the main reason for the increase in demand. Two other reasons are; the lower cost of the mobile telephony equipment (TMA) and the greater understanding of this service by the users. The forecasts are for growth up to 15% of the global telecommunications bill by the end of the decade.

3.2 Ibertex, the Videotex Service

Usually known as Videotex, the telematic service which relates and interconnects the Spanish PSTN (RTC) with the X.25 public service (Iberpac) for data transmission, has experienced one of the biggest growths in the telecomms world. We find many reasons for this but we always see the first one as the PTT's commitment to the service.

The interconnection between the PSTN and Iberpac is called the Ibertex service, available anywhere in the country at the same cost. The VTX user will find different levels in the Ibertex Service, depending on the type of information to be accessed.

IBERTEX SERVICE LEVELS

Level	*Telephone access*	*Characteristics*
B1	031	Charge Type 1
B2	032	Charge Type 2
B3	033	Charge Type 3
B0	030	Services Guide
B4	034	Free Information
B5	035	Reverse Charge
B6	036	Internat. VTX link

The Services Suppliers are based on a UNIX hardware platform and a set of software modules.

Within the VTX software we find the Kernel (managing X.25 and ASCII comms, statistics, languages external processes, ...) and a set of standard applications generally including order entry, professional electronic mail with X.400 interface, multicriteria method of searching for data, ... etc.

Due to the many different DBs to be accessed, it is impossible for software companies to develop interfaces for every single DB as a standard solution. A result of this is the market's demand for useful tools to be included in the software packages, which will allow users to develop their own applications corresponding on their own specific requirements (type of DB, hardware which contains the DB, number of records, frequency of modification, method of accessing the DB, ... etc).

The growth amongst market agents (Service Providers, VTX terminals, general public telematic knowledge) together with the PTT's commitment leads to the conclusion that Spain will be the second European telematic country by 1992, with a forecast of more than 400,000 terminals.

VIDEOTEX GROWTH FIGURES

	1990	1989	1988
Number of connections (Average per month)	–	120,000	30,000
Number of DB	175	120	35
Services Suppliers	70	45	20
Terminals	200,000	45,000	5,000
Average connect time	–	12 min	–
Connect time	42,922 hours (Feb)	7,900 hours	–

Source: APV and Telefonica

3.3 Electronic Mail, X.400 and X.500 standards

With the X.400 and X.500 standards, the CCITT is looking for the interconnection of the electronic mail services all around the telecomms world. In Spain the most similar thing to an X.400 electronic message system is called Mensatex, first introduced by Telefonica in 1988, which allows end-to-end data communication through the Iberpac network or the PSTN. The market's interest is enough to convince the Post Office to start implementing their own service by the end of the 1990. This will solve the problem of many private electronic mail networks working separately and without the possibility of interconnecting to each other. It looks as if X.400 standards will be the basis for the first global messaging system. To achieve this it is necessary to complement the rules with the X.500 ones, and for these rules to be completed, solving the message security problems, the access control and agreeing the global directory.

3.4 EDI

Linking the various parties in the EDI chain are invariably the value added networks (VANS) or value added data services (VADS). In Spain we will find the same problems as in the other European countries. First of all standardisation; the communication rules must be the same for all the computers involved in the electronic data interchange. The internationally recommended standard is EDIFACT, generally accepted by the vast majority of the European countries.

Another important aspect relates to the software packages and the physical transmission support. There are some products solving the elecronic interchange problem, and the network used in Iberpac, which is not enough but is helped by three compensation centres owned by General Electric, IBM and Telefonica, working as mailboxes, storing the information.

An important effort is being made by AECOM, the association which controls the product bar codes. The first step is to agree to a common language between buyers and suppliers as far as bills and orders are concerned. Once they achieve this, Electronic Data Interchange between suppliers and supermarkets will become a reality.

A further effort was made in 1984 with the implementation of the Odette project using EDI in the Spanish automobile industry. The problem is that being born before EDIFACT, it works to another standard, although there are plans to change it in the near future.

4 The Future: ISDN

ISDN is known in Spain as RDSI; Telefonica decided to implement Ibercom in 1985 as a first step, due to the lack of international agreements. The MD 110, AXE and 1240* digital switches will have to be able to change towards ISDN (plus the 5ESS switches) once Telefonica has announced the ISDN commercial capability by the end of 1991 and the country-wide service by the end of 1992; these seem to be extremely optimistic predictions.

The first stage towards the full implementation of ISDN in Spain was in 1985 with a pilot service using AXE and 1240 systems. This was useful as a first experiment but without real value, due to its lack of compatibility with the CCITT recommendations.

The second stage included real users, with two pilot AXE digital switches supplied by Intelsa in 1989. The project suffered a big delay and by September 1990 it was still not working.

The third stage was planned by 1991 and included the commercialisation of the service, but the delays make us think that the Spanish ISDN network is still a long way from full implementation. However, it will be interesting to see how quickly Telefonica attempts to manage this transition while Ibercom continues to have commercial success.

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*AXE: Ericsson product
1240: Alcatel product
5ESS: AT&T product

5 Objective: 1992

The telecommunications field is not left out of account in a country which is looking forward to the year 1992 in most financial, commercial and political areas. For in that year, not only will Spain host the Olympic Games in Barcelona, but also the 1992 World Trade Fair in Seville.

There will be significant increases in the demand for digital main lines, fibre optic cable installations, Iberpac and Ibertex connections and finally ISDN service lines, most of them preparing the country as the world becomes connected to Spain through telecommunications.

6 Acknowledgement

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Future Applications of ISDN to Information Technology

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Abstract

The paper first examines the special advantages of ISDN for computer users. It indicates the scope of ISDN for innovative applications, especially those which it would be too difficult or too expensive (if not impossible) to achieve by any other means.

It then describes by way of example, a system for "DeskTop Conferencing" developed by ICL. This is a multimedia system enabling two or more persons, using both speech and vision and at remote locations, to cooperate on drafting text or on some engineering design.

The paper ends by sketching some of the possibilities opened up by ISDN for future applications.

1 Introduction

The fundamental technical principles underlying the architecture of ISDN and its use for information transmission are discussed elsewhere in this issue of the journal (cf. Orange, Calot & Spiracopoulos, and Larraz). Sufficient description of parts of ISDN is included here for clarity and ease of reading.

Most observers of the telecommunications industry over the past decade have viewed ISDN with some scepticism. We should not be too surprised that, even today, the uses and the perspective of the potential value of ISDN tend to be limited.

Noting that the acronym "ISDN" stands for Integrated Services Digital Network, if we take common dictionary definitions for these words, we might expect a linking of the following ideas:

Integrated:	combination of parts into a whole
Services:	provision of what is necessary, possibly in return for some payment

Digital: representation in discrete form by digits
Network: arranged in the form of a lattice structure

Since ISDN has such a wide-ranging definition, it is not surprising that it means all things to all men. More notably, it is easy to see how different people see ISDN as something different. For example, a telecommunications manager whose life revolves about reducing the cost of telecommunications service to users will tend to emphasise the *network and physical level integration* aspects of ISDN. On the other hand, a telecommunications engineer might consider ISDN to be, in the main, a *digital transmission system.*

Again, an operator of a network (e.g. a PTT) might consider the features of the *services* provided within ISDN to be more important than any other issue; in other words the scope for flexibility in the provision of services may well be uppermost in his mind even though it may not yet be known just what services will be provided over an ISDN.

ISDN is examined in this paper chiefly as the USER will see it and its applications; by contrast ISDN is briefly analysed as a means for the transfer of information.

2 Transfer of information by ISDN

Ever since the beginnings of the telecommunications industry (with telegraphy in the late 1870's), telecommunications engineers have applied a fertile imagination to innovation. To send information over long distances has been one of many goals. While this was usually quite costly international telegraphy demanded long distance cables. When they could not be laid overland, undersea cables were installed. Later of course radio links were added. Whenever a new frontier was reached, new technologies were exploited. The new technologies were always expensive to deploy initially, which was perhaps the most important factor the telecommunications engineer had to contend with.

Consequently, the telecommunications industry has become renowned for the number of different techniques it employs to reduce costs. Although other factors matter too, cost has been the dominant factor giving rise to diversity in telecommunication. There are today a plethora of encoding/decoding techniques, many different techniques of modulation and types of physical transmission media and a variety of methods of multiplexing.

In the field of *data* communications a further diversity exists: there are many different communication protocols suitable for different forms of network topography. All data communications and telecommunications methods are constrained by the technology employed while the various techniques can be characterised in turn by a set of attributes which are important since they can determine the most economic solution to a business problem.

Any business problem makes a number of demands on data communication and on the telecommunications infrastructure. The technology available to solve these particular business problems is well established but it is instructive to understand some aspects of why the technology was selected. For ISDN, considered as a simple telecommunications technology, the same principles apply as a couple of simple illustrations will show.

For example, *authorisation of credit cards* typically requires the exchange of alphanumeric data between a card reader and a remote computer holding a credit card information base. In this case immediacy is important, in other words the whole transaction has to be completed in a short time while the customer waits. Transmission speed is not a major factor because the amount of information transferred is relatively small; but the cost of credit card verification is always important.

Similarly, to transfer, for instance, a street plan by *facsimile* requires transformation of the input image into a series of codes which on reception can faithfully reproduce the original with appropriate definition and grey scale. Here immediacy is not so important but speed of transfer can often determine how many pages of information are sent. Hardcopy from the output device is obviously essential while the cost involved in transmission is, as always, an important consideration.

Thus the various attributes of available technologies must be matched with the demands of the problem, and, after suitable compromise, appropriate data communications and telecommunications technologies selected to solve it. If ISDN is regarded as no more than another telecommunications technology with particular attributes and cost parameters, it will meet the requirements of many present-day business problems.

3 Benefits of ISDN for Information Transfer to the Business User

Because of the tremendous business benefits to be obtained, the most exciting prospects offered by ISDN to the user are where new applications become possible – and where old applications can be completely re-implemented. Its special advantages arise from its many facets, described in more detail elsewhere in this issue in the papers referred to in §1. Amongst these special advantages are the following:

3.1 Because the information transferred by ISDN is in digital form, it may represent speech, data, text and images (including slowly changing images). ISDN is not restricted, as are networks using analogue methods, to speech with the limited capability of sending data imposed by a modem.

3.2 Because ISDN was designed to employ digital transmission of high quality speech the user is provided with digital transmission of data and images at far higher speed and at much lower cost. In due course this high speed transmission will be available as widely as the present PSTN.

3.3 Because digital techniques are used, information is transferred considerably more accurately and more reliably.

3.4 ISDN is actually built on a digital infrastructure that is already in use by the PSTN–in the exchanges and inter-exchange links – so that, when it becomes universal, there can be economies of scale with every prospect of very economical transfer of information.

3.5 Access to an ISDN is via a well defined interface, in fact a telephone line as now used. However, over this one telephone line a user can employ two independent channels for information as compared with only one on existing lines.

3.6 A third channel is also provided, primarily for signalling, but it can also be used to transfer a limited amount of information; in fact it can send data at speeds comparable with the current Public Switched Telephone Network.

3.7 ISDN employs messaging techniques for establishing voice and data calls, ie for signalling. As a result of the rapid data transfer, call set up times are at least an order of magnitude faster than with current PSTN. The messages are no longer simply of the form "connect me to subscriber X", but offer a much more comprehensive scope. The progress of a call across the network is signalled in detail and the reason for failing to make a connection is indicated with greater clarity. In simple terms, the ISDN can say not only *when* a call fails to connect but, more importantly, *why* it fails to connect.

3.8 The signalling messages can indicate who is making the call – Calling Line Identification. Presentation of this information to a user receiving a call can provide an important measure of security – one not readily achieved using the current PSTN.

Comparing costs per "data packet" using different techniques, even the cost of sending a letter by ISDN rather than traditional post is very attractive. It can be sent person-to-person with an immediacy simply not achievable by the regular post.

Indeed ISDN offers vast improvements over many other technologies. Its attributes taken together open up the possibility – using switched ISDN for transferring information – of applications that would otherwise simply be quite uneconomic.

4 The impact of ISDN on current telecommunications generally

One or two examples may illustrate the impact of ISDN on current applications of telecommunications.

For voice communications, the apparent impact is fairly small. In most western industrialised countries, the present telephone network provides adequate service, but in many second world countries the networks are very old and in dire need of modernisation. ISDN will be seen to provide a telephone service comparable with what we have today in say the UK and USA.

However, the ultimate impact of ISDN on voice communications is much wider than this. In the USA, the telephone is used for a far wider range of purposes than in most other countries, one of which is to access data-oriented services via the telephone.

Again, in private companies, PABX systems have for many years offered a wide range of facilities simply in order to make the telephone easier to use as well as to make better use of a caller's time. For example, *call divert* to another number, *call barring* and, *call back when free* are features present on all modern PABX systems.

ISDN offers the scope for most of these facilities to be available also on the public network offering all their advantages to the private user that were previously available only to the business user on his PABX.

Using ISDN, simple transfers of text will be much faster than with PSTN. Bulk transfer of filed data is a well-known technique practised for many years but subject to significant constraints when using the PSTN, namely a low effective throughput of data and the unreliability of the transfer. Both of these are vastly improved with ISDN. Through the PSTN, a data rate of 9600 bits per second (bps) is theoretically possible. However, the reliability of a connection at this speed is often poor and reliable data transfer at rates above 2400 bps may not be possible. ISDN immediately offers a higher reliability at a data rate of 64000 bps. Typical bit transmission errors are of the order of less than 1 in a million.

Thus large files can be transferred much more reliably using ISDN than with PSTN, and, since both ISDN and PSTN tariffs are based on usage, i.e. proportional to connect time, the higher transfer rates of ISDN mean much shorter calls and hence much lower charges.

The high data rates will mean not only that text and binary information can be transferred, but that files containing *images* can also be transferred cost-effectively. The recent enormous growth in use of facsimile bears out the truth of the saying "a picture is worth a thousand words" but this growth is predicted to grow even further when Group 4 facsimile is introduced. Group 4 is specifically designed to exploit ISDN. The impact of Group 4 facsimile on the end user may be simply appreciated: it takes 30 seconds to send the information on an A4 sheet using the Group 3 standard, but only 3 seconds using Group 4 facsimile over ISDN.

5 ISDN and new application areas

So far in this paper the specific advantages of ISDN have been mentioned. The preceding examples could be regarded as applications of ISDN which use the features of ISDN but via existing forms of service.

There are however examples of applications which are genuinely novel; ICL's DeskTop Conferencing is one such application.

5.1 Cooperative Working

In a telephone conversation between colleagues each has a set of mental facts and images. For the conversation to succeed many of these must be shared; in other words it has to rely on well known language and vocabulary. If, say, the conversation concerns the inter-relations between numeric items – in a spread-sheet say – the discussion can become quite abstract. The exchanges could be much more productive if the participants could both *see* the information being discussed: paper is the most common and obvious medium. One method is to refer to documents (which could include diagrams) interchanged previously.

For a more immediate response, one may resort to "mark up a copy and fax it to me". Where the matter discussed is complex, as for example a set of engineering drawings, cooperation may be very limited unless the parties can both see the *same proposed changes* to the drawings. Such a result could be achieved if both could see the same modifications to a drawing on the screens of their workstations.

5.2 The ICL ISDN DeskTop Conferencing (TM) Application

The technique of providing simultaneous voice, data and image capability at multifunction workstations is not new but sharing multimedia information amongst users of workstations is, and so too is its exploitation in the business community. What facilities are needed to make such an application a success?

Pairs of multifunction workstations connected by ISDN allow colleagues to discuss information presented on their workstations and because they have the same image (screen sharing) they have a common perception of the information being discussed. But they need much more than this to be effective. Although the use of speech is implicit, they also need to be able to identify particular objects on the screen to avoid ambiguity. A mouse or light pen is an ideal device enabling colleagues to point to or highlight information. Both a light pen and a mouse may be used with ICL DeskTop Conferencing.

Working in a cooperative manner, colleagues can rapidly develop proposals and agree changes that may be necessary; typically there is a requirement to transfer information between the PCs in bulk fashion. ICL's DeskTop Conferencing Application incorporates a file transfer process which can be used either in isolation (i.e. screen sharing stops temporarily) or in parallel with other activities (i.e. screen sharing will continue but take priority over the file transfer which appears as a background task).

5.3 Multi-person Conferences

Simple two-party conversations are probably the commonest, but, increasingly, multiparty conferences are held by groups of colleagues who are geographically separated. Ordinary telephone conferences have been found to be most productive when conducted in a disciplined manner. One of the conference participants typically acts as the chairman and an agreed agenda is found desirable to achieve a common approach.

A similar discipline is necessary, it is argued, when several multifunction workstations are connected through ISDN to form such a multiparty conference. Therefore ICL has incorporated such multiparty features in its DeskTop Conference Application.

Typically one participant acts as the chairman and exercises overall control. The information on his workstation screen is seen by all the others who may point to and highlight an item of the shared information on their screens. Only the chairman may decide what information is seen by the conference. He obviously needs the power to allow other participants to take over control (just as in a normal voice conference) and features are provided to allow this delegation of control. The specific computer application whose output is being shared can of course be nominated and changed during a conference.

The individual contributions of those taking part in a multi-party conference will clearly need to be identified in various ways. Information on screen pointed at by any participant is identified by a different coloured pointer; a contribution drawn with a light pen leaves a trace in a different colour corresponding to each participant.

5.4 The ICL Technical Approach to DeskTop Conferencing

In ICL's DeskTop Conferencing, a pair of personal computers, each equipped with an ICL ISDN interface card, are connected via an ISDN, as shown in Figure 1.

Users can set up data conferences in the same simple way as making a telephone call. The computers are now linked by the DTC application running as a background process in each of the two personal computers. The DTC applications are linked using an ISDN B-channel for information transfer. (When the call set-up has been completed, the DTC applications

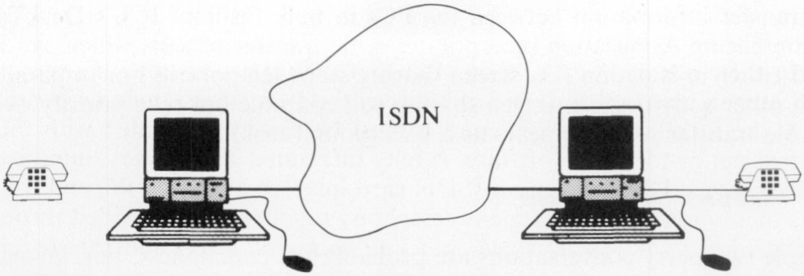

Fig. 1 Facilities needed for Multi-Media working via ISDN.

use the 64000 bps data transfer path effectively as a point-to-point data link and ignore the fact that the data link has been set up via a switched network).

The DTC applications provide what may seem a simple capability: whatever is written to the screen of one PC is "read" by one DTC application and transferred using ISDN to its peer application and written on the screen of the other PC. In this way screen sharing is effected. The DeskTop Conference Application uses standard Presentation Manager to read from and write to the screen and handle the keyboard.

HDLC protocol is used to achieve integrity of data transfer over the physical link between the computers. ISDNs in most countries are in their infancy as a commercial service and generally not integrated with other forms of data networking; but this is not the case in the USA and some Scandinavian countries, where there is a greater degree of integration with other networks. Further, the reliability of the ISDN as a sub-network is high. For these reasons, network and transport layer protocols have not been incorporated although it would be fairly simple to do so.

There is no accepted standard for the application layer protocol for sharing screens and therefore ICL has employed the encoding techniques which do exist for Group 4 facsimile.

Once the DTC applications have established the conference link then its use is automatic and does not involve the user in any further process. The users of course can talk to one another about the information they both see on the screen.

The information which is the subject of the conference is of course independent of the DTC application which sets up the conference. That information may come from industry-standard applications, for instance, spreadsheets, word processing packages, packages for computer aided design, even packages which communicate with other computers and databases.

5.5 The ICL Product Package

Since there are in effect two simultaneous conversations, one between the two human beings and the other between the PCs, which must be coordinated, the functions of the telephone must be closely integrated with those carried out by the DTC software. A fully Integrated Telephone is interfaced, both to the ISDN through an ISDN card inserted into each PC and to the PCs themselves. A wide range of telephony functions are provided through a single key stroke such as *call hold*, *call back*, *call divert* and *transfer call*. Although the telephone is integrated with the computer to provide many of the functions, it behaves in much the same way as a normal telephone. However its features allow more cost effective use of the user's time.

The ISDN PC card plugs into the PC-AT bus and is therefore supported by all ICL Personal Computers based on the Intel 80286, 80386, 80486 microprocessor family. Because it conforms to the industry standard PC-AT interface, the card may also be used with a wide range of industry standard PCs which are fully IBM-compatible. The card is driven by the PC using a set of device drivers.

The package marketed by ICL includes the ISDN PC card, the integrated telephone, the DeskTop Conference Application, and the Telephony Application. It can upgrade a standard PC to a full function ISDN workstation and has been marketed in the USA for over 12 months. It will be marketed in other selected countries within the next 12 months.

Because the DeskTop Conferencing Applications run in the background of the computer while the user uses his own application, a multitasking operating system is required to support the processes involved. ICL currently employs the OS/2 operating system since it best fits these multitasking requirements.

6 New integrated application areas

In previous sections several examples of different types of integration of facilities in one application have been mentioned. Such integrated applications could be categorised in terms of the type of integration involved.

For example:

a) Integration of functions at the physical transmission level. This is probably the most obvious feature of ISDN since it is its fundamental concept.
b) Integration of applications which have previously been considered as discrete functions (possibly employing different media) but now integrated in their use of common features and services. A typical example is the integration of Fax with a directory used for generation of distribution lists – as described in outline in a previous section.

c) Integration of applications previously considered as being similar functionally but employing different media. A typical example is voice-annotation of text and a related electronic mail service.
d) Integration of applications which are integrated both at the media level and with other application areas. One example is a voice-annotated document system which can generate addresses for a distribution list. Another example is ICL's DeskTop Conferencing Application.

These last two application areas are of particular interest since they offer the scope for the most valuable ISDN applications which can make very significant increases in productivity in the immediate future.

7 Applications of ISDN involving Multimedia

A few voice-annotated text systems have been implemented but few have had access to advanced communications facilities. Thus, because of the low transmission rates, transfer of voice-annotated text documents has been very time consuming – if not totally impracticable. ISDN makes such systems viable with reasonable transmission times for such multimedia documents.

There are no well known, commercially available multimedia applications which have been integrated with other network-based applications. It is interesting to suggest why such multimedia applications have not so far been developed. One reason may be that a switched network is frequently required but the bandwidth of such a network is too limited.

ISDN bandwidths make such applications possible. Further, it is probable that until the advent of powerful desktop computers the human to computer interface for multimedia applications has also been limited.

Today's powerful microprocessors can represent multimedia images (e.g. text integrated with images) typical in desktop publishing applications. Further, with the use of WIMP techniques, the human interpretation of voice annotations is readily comprehensible and multi-media applications are therefore ready to take off.

Other facets of the human-to-computer interface ripe for exploitation (because the microprocessor power can now support it) include "context dependent actions". Consider for instance editing a letter which includes a telephone number and a reference to another document to be sent as an attachment. If the user highlights the telephone number with a mouse, one could expect an integrated workstation of the future to take contextually defined actions. A window with a menu could appear offering the user the option to dial the number on the integrated telephone. Alternatively, highlighting that part of the text which refers to the attachment could present a window with options to use the text as a filename for a whole series of database actions. ISDN has a special role to play if the data referred to is both voluminous and stored elsewhere.

8 Conclusions

To users the benefits of adopting ISDN for *data* are significantly greater than they are for *speech*, if only because we cannot talk faster but can readily accelerate the transmission of data to take advantage of the greater bandwidth of ISDN. Recognition of the benefits of ISDN for sending multimedia documents will further encourage its introduction throughout the world. Its rate of growth however will be constrained by the large capital investment needed.

ISDN technology allows facilities to be provided complementing those offered by related technologies. Taking its specific facilities individually it may be that no one of them has such profound impact on applications that ISDN is the only economic solution to the business problem.

However, taken in combination, its facilities can stimulate new and innovative applications, limited only by the imagination of the developer. In the examples quoted in the later paragraphs, it is suggested that the multimedia application areas are potentially the most rewarding. The success of such applications will, as always, be determined by their take up in the market place but the main factor determining success will no longer be cost alone; it will be primarily the perceived value of the application to the end user and of the business benefits derived. Already, users of the ICL DeskTop Conferencing Application are beginning to reap the rewards of an integrated approach.

OTHER PAPERS

A Geographical Information System for Managing the Assets of a Water Company

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Abstract

The paper describes how information technology is helping to address the business problems that arise from the management of a Water plc's fixed assets which have a current value of £2,469 million at 1989 prices and a rolling capital investment program in excess of £160 million per annum. The assets are distributed below and above ground across a geographical area covering 10,500 square kilometres with a resident population of 4 million.

The chosen IT solution is to exploit a geographical information system (GIS). The GIS has been evolving since 1988 and is due to be completed in 1995 approximately. The GIS exploits SUN workstations, high bandwidth data transmission networks, ICL mainframes and a range of application packages. When complete the databases associated with the GIS system will be in excess of 150 GBs and will be attached to the mainframe and distributed SUN Microsystem servers.

1 Introduction

The assets within utility organisations such as Southern Water continue to absorb vast quantities of resources and as such the pressure to improve the management of the assets to optimise the call upon those resources continues to grow in order to ensure that the best use is made of the finite resources available.

Southern Water covers a geographic area of 10,500 square kilometres located in the southeastern corner of England. The Southern Water area of responsibility covers the counties of Hampshire, Isle of Wight, Sussex and Kent. Within this area the water distribution system covers an area of 4,450 square kilometres, the black areas shown in Fig. 1. The sewerage system covers

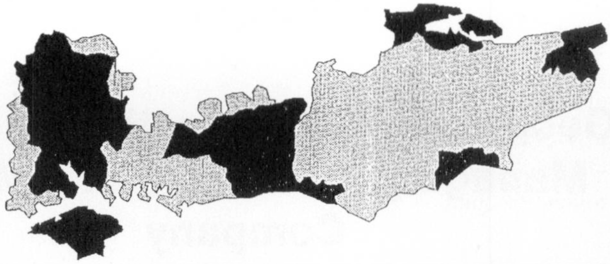


Fig. 1 Southern Water plc – Areas covered

10,450 square kilometres that is the combined grey and black areas shown in Fig. 1. Within this area there is a permanent resident population of 4 million people with seasonal variations of up to 4.6 million people.

The number of premises receiving water within this region is 946,000 which on average receive 700 million litres of water each day via 11,500 kilometres of pipe work from 125 water sources. Some 73% of the water put into the supply is abstracted from underground sources or aquifers. Water is pumped into the system using electrical pumps after treatment and disinfection. Up to 30% of water put into the supply is unaccounted for and over the past decade the demand for water has increased by 15% [Schroder 1989]. The variations in the weather pattern, which are a current topic of discussion, are also placing extra demands on the resources and the assets.

The number of premises connected to the drainage system within the region is 1.696 million. The waste water is mainly drained by gravity through 24,600 kilometres of pipe work to 393 treatment works which treat a daily average of 965 million litres of effluent [Schroder 1989].

The "Current Value" of the assets is 2.5 billion pounds at December 1989 prices upon which a rolling capital program of 160 million pounds per annum will continue to be spent over the next ten years. The environmental pressures continue to grow which together with the growth in demand and renewal program put great pressure on the limited financial resources available.

The underground assets have been placed in the ground over many years and as such the knowledge and records about these assets have passed through many people and organisations with the result that the currency and accuracy of the data about these underground assets is low. The Water

Industry is heavily regulated and monitored which in itself demands accurate data. This is no bad thing as the health of the nation is heavily dependent the quality of the product delivered and the safe removal of the waste products.

2 Business Problem

The business problem to be resolved is to improve the management of the assets and services provided via these assets. Large quantities of information about the assets are held on paper, microfiche and in employees' heads and private note books with minimal information held on computers. Access to information is required by a large proportion of the employees, which was achieved by duplication of the paper records. The records held by office staff were often different from those held by field staff as were the records held by different field staff servicing the same geographical area.

In order to improve the management of the asset the first task is to improve and make readily available the information about those assets, both the static and dynamic data.

The assets, premises served, customers, etc; are all geographically located or dispersed and as such the records are mainly geographically referenced. The information is predominantly held on paper maps, plans and forms dispersed throughout the organisation. Over the past decade a considerable amount of data has been collected by surveying the assets from above ground and from entry points such as the 450,000 manholes on the sewers and via 'moles' that travel through the pipework enabling video recordings to be made on the internal state of the pipe.

The data held or collected about the assets can be divided into four categories, i.e. Associated, Attribute, Knowledge and Pictorial; which is best shown by the example of a short length of pipe in the A27 trunk road as shown in Fig. 2. The information about the pipe is of two forms in the example, the spatial information which shows the physical location within space, that is the Easting, Northing and depth below the surface, and the attribute information about the pipe itself. Two examples of associated data are shown in this example, first the attribute information about the road, and secondly the attribute information about the land the pipe has been laid in. Both of these data sets provide additional information when considering say bursts or pipe material. For example pipes burst more often when laid in clay than in chalk. The physical construction of a pipe laid under a trunk road carrying heavy vehicles needs to be stronger than pipes laid within say a minor road or footpath. Within the attribute information references can be made to pictures, video images, or documents containing text.

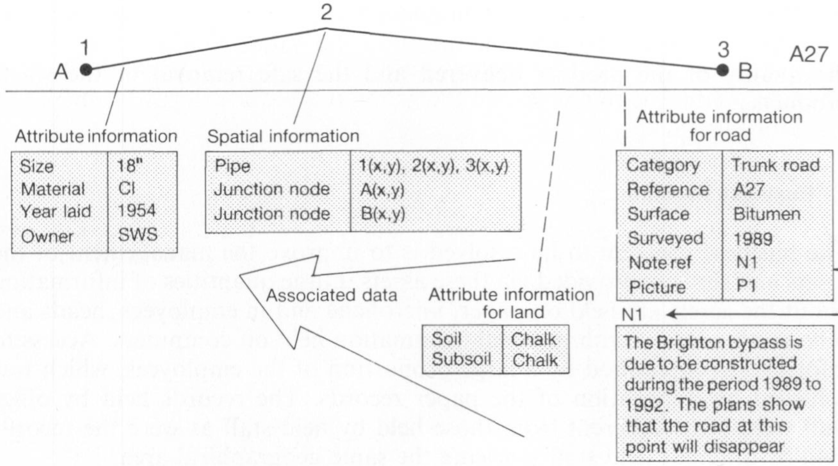


Fig. 2 GIS Architecture-Data Categories

In order that improvements can be made all the information about the assets together with the associated information needs to be rationalised, integrated and maintained. A number of solutions exist to achieve this. One is to employ a large number of people to maintain the records and disperse them to all those that require the information. Although this may be feasible the integration and aggregation of data would be difficult. The preferred solution would be to computerise the information. One snag with computerisation is the quantity and type of data involved. Putting information into a computer is one thing but being able to retrieve and understand it is another, not to mention the cost of storing and maintaining it.

In 1983 Southern Water initiated a feasibility study which in 1985 recommended a ten year program to build a computerised Geographical Information System (GIS) which would cover all aspects of the business throughout the Southern Water region. The GIS would be built incrementally over the period with each increment being subjected to a cost benefit analysis. It was also recommended that a pilot system be established for each major step to check that the requirement was correct as well as the cost benefit analysis. The Southern Water management of that day stipulated that any computer technology acquired for the phase 1 pilot system should be capable of redeployment for other tasks should the pilot demonstrate that it was not cost effective to proceed with a region-wide implementation. In 1985 tenders were let for the first stage pilot digital mapping system which was installed at Otterbourne in Hampshire for computerising the water records for the City of Southampton and the surrounding urban area, which is equivalent to 365 1:1250 Ordnance Survey(OS) map sheets. By 1986 the pilot had demonstrated that the first phase, that of data conversion, was feasible and that the specification and the cost benefit analysis were correct. In 1987 the

Southern Water board approved the implementation of phase 1 region-wide, as part of a Management Information System Strategy (MISS) that included as a subsystem the GIS and the integration of the regional telemetry system. The first phase was to convert all the water and sewer records to the digital mapping system.

In 1989 the phase 2 pilot was approved, that of building a prototype of the asset database and linking the digital mapping system to it. It is expected that phase 2 will receive approval for full implementation towards the end of 1990.

3 The Chosen Solution

For GIS to be effective the information must be accessible wherever the employee is located at the time the need for the information arises. The phase 1 implementation has established the information within the first line water depots. Phase 2 will include all main offices and drainage depots. Subsequent phases will extend the access to the field employees' homes where required and to a vehicle. The extension to the vehicle will require the integration of the corporate electronic mail system with the digital radio system. This integration is one of a number of parallel activities which when all have been implemented will make up the Water Services Management Information System.

The computerised system must allow for incremental development and be able to deal with the requirements arising from converting the work force from localised standards to a corporate standard and ultimately to a national standard which would then allow utilities to electronically interchange and interpret information in a coherent way. The computerised system as always must be equal to or better than the existing system otherwise the average employee will not use it. The paper records had a data currency ranging from 3 months to 25 years or more, where currency is defined as "how up to date are the records in reflecting the real world system in any one particular time frame?". For phase 1 of the project the target was set at one month. This may sound rather relaxed but it means that any permanent change that has occurred on the real world system must have been included within the computerised system located in the first line depots and that any paper records produced from those systems for field operatives shall have been produced and despatched within one month, that is 20 normal working days. The ten year target is to reduce this to 24 hours once integration of the telemetry system and vehicles has been accomplished.

The decision was taken to convert the records to the computerised system "as is", but with an accuracy or quality flag attached which would indicate the status of the information, such as unreliable, surveyed, etc. Converting the records as they existed was not considered to be a detrimental step as once on the computer the records could be amended with ease. Accuracy is defined as "the exact location in space for all assets to within the nearest centimetre". Here again, improving the accuracy of the information was considered a long task and may take over 100 years if the current manual practices are adhered to. By the end of this decade it is expected that technology will become available to assist with this task.

A further requirement of the system was that of converting or capturing data at the lowest resolution which for a pipe would be for each individual length of which in any one street there may be many. However the computerised system must allow the aggregation of pipe lengths such that the pipe running the whole length of a street or between valves can appear as one pipe if this is required by the viewer. This is a facility which exists on the paper records but is not immediately apparent to the viewer.

Different job functions require information once requested to be delivered or displayed at different speeds. For phase 1 the specification was set at 5 minutes or less. 5 minutes was established as the mean time it took a water inspector to locate the maps required from the filing cabinets, copy them and invariably glue portions together as the paper records are not a continuous mapping system but made up of discrete tiles of say 500 metre squares that is 1:1250 OS map sheets, or one kilometre squares, that is 1:2500 OS map sheets. Again 5 minutes sounds a long time but it was still a tight time when one considers the amount of information that had to be retrieved, painted on the screen at the required scale and then put out to paper for use in the field. The 10-year target is to reduce this time to 5 seconds.

The type of data that has to be displayed ranges from alphanumeric data, with which most people are familiar, via TP systems, textual information such as that entered from Office Systems such as ICL's Office Power, through to raster data (pixel images) for displaying sketches, builder's plans and OS maps that have not yet been digitised, vectors for drawing the pipes and the various attachments, as well as the digitised OS maps, video images from either the CCTV surveys or real time remote scanning to annotation of documents by voice. The specification was for each data type to be displayed either combined or singly within concurrent windows on the screen if required in colour, where applicable.

Due to this range of data types it is clear that computerising the data and storing it in a structure that enables fast processing, retrieval and display is pushing the boundaries of today's computer technology. Table 1 shows the relationship between the Data Categories and the types of data.

The quantity of data to be converted and captured is large and will take a number of years to achieve, by which time the database management systems will have developed to hold GIS data.

Table 1 GIS Architecture Relationship between Data Categories and Type of Data

Type	Associated	Attribute	Knowledge	Pictorial
Alpha-numeric	*	*	*	
Raster	*	*		*
Text	*	*	*	
Vector	*	*		*
Video	*	*		*
Voice	*			

To convert the water and sewer records for a land area of 10,500 square kilometres with the population density as in the Southeast of England, using 30 people, will take approximately 3 years. To capture the attribute information to the depth required at a rate that is cost effective will probably take 5 years. As the data is being computerised the data will then need to be integrated with the other data sets which in itself will trigger off a data rationalisation process. Throughout the 10 year period the data will undergo continual rationalisation due to the need to remove historic reference keys used in previous systems, exploiting improved methods of storing information, converting graphical or pictorial data into objects, and lastly to enable automated maintenance of the data to occur. This is summarised in Fig. 3.

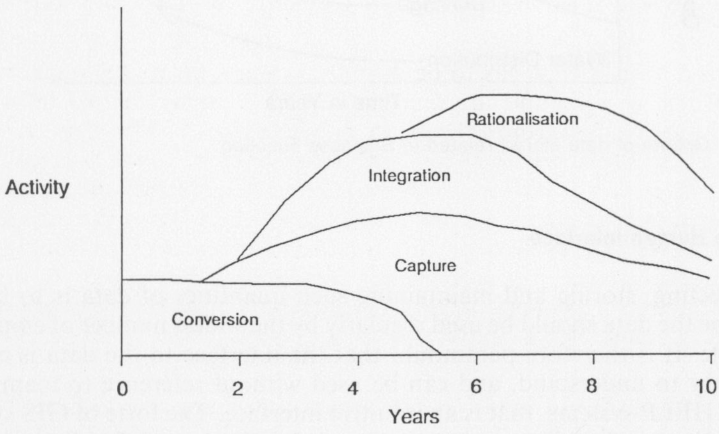


Fig. 3 Data Related Activity Profile

During the first 3 years data definitions will be set up, which currently stand at 800 definitions plus, and then the business rules or knowledge base, which together enable the integrity of the data to be maintained, will permit the automatic updating process and exception reporting to be implemented.

The growth in data as shown in Fig. 4, for a minimum set of alphanumeric information about the assets, is estimated to be of the order of 30 to 40 GBs. This would describe the pipework both spatially with the attribute data, the connectivity of the pipework, the connectivity to the property and the customer within the property, and in terms of performance, that is data about the flows, quality, pressure, bursts, etc. When the OS data for the region is added to the spatial database the total data stored would be in the region of 60 GBs. It is estimated that the GIS database would home in after 10 years at the 100 GBs level. If the video images, textual information and rule base are added the data storage is estimated to be in the thousands of GBs.

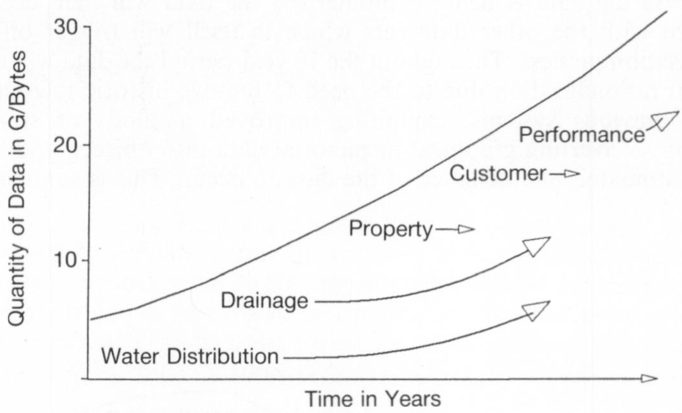


Fig. 4 Growth of data stored related to Business Function

4 The Human Interface

If collecting, storing and maintaining such quantities of data is to be cost effective the data should be used regularly by the widest number of employees possible. It is therefore paramount that the interface to the data is easy to use, easy to understand, and can be used without reference to manuals or online HELP systems, that is an intuitive interface. The forte of GIS systems is that they exploit pictures or images as a window on to the data which, if combined with the ability to issue instructions or data selections by pointing or preferably speaking, will bring the interface into the realm of the everyday human thought and decision-making processes.

With today's technology one can achieve the display of pictures, albeit not as fast as the brain's visual processes, pointing by use of a mouse for high resolution selections, or perhaps touch screen for low resolution selections, with minimal use of the keyboard. Different functions within the interface may call upon different applications behind the interface and it is imperative that a consistent "Look and Feel" is maintained across applications if confusion is to be avoided or minimised. The interfaces where possible should encapsulate the job function of the employee logging onto the system and should permit adaptation by the employee within the bounds of the data access rights set for a particular job function. For example if an employee is involved with one particular sewer catchment area there is little point in offering the ability to select any of the 400 plus sewer catchment areas and the 138 water distribution zones throughout the region.

To display the picture requires facilities such as a gazetteer to be included in the interface which would contain street names, property names, local names, business related names, or employees' personal names for localities or premises. Selection by OS map reference number or an Easting and Northing, (both of which are references from a position East and North of a point situated to the west of the Isles of Scilly), are transient methods provided in the main for conversion purposes; they are after all not a natural reference system for the everyday display of data. The GIS displays data as a continuum in that the viewer can pan across the surface of the earth without interruption as well as zoom into or out from the surface of the earth. As the viewer zooms in, ever greater detail can be displayed if required and as the viewer zooms out the finer details are dropped from the display. The viewer is even provided with the unnatural facility of panning and zooming under the surface of the earth! All of these functions are akin to moving one's head or walking towards or away from an object; an interface containing such facilities could therefore be considered natural and thus should be easy to use. Again speed of operation is very important if this easy interface is not to frustrate the viewer.

Utility services laid under the ground are located within a multi dimensional space that is x, y, z, t, etc; where x is the Easting, y is the Northing, z is the Height, t is time, all of which can be positive or negative. For example the flow in sewers is in the main by gravity which is achieved by laying the sewers with an incline. In the future the requirement exists for the multi-dimensional view of the sewer to be displayed especially at complex road junctions where many utilities services converge. The raster display of the ground is a more natural method of display than that of vectors thus the system needs to be capable of displaying and processing "pixel" images; this has the added advantage that it enables satellite technology to be exploited in the future.

The interpretation of data can be greatly assisted by the use of colour or grey scales as differentiators. The ability to interpret information displayed is faster by the use of an area infill of colour rather than the colouring of specific features. For example the Water Controller for Brighton may be interested to observe the current water pressure throughout the Brighton water distribution system and therefore asks the GIS system to display the pressure map. At least two methods could be used, to colour each individual pipe length with a colour representing a pressure band, or for the system to translate the spot pressure information into pressure zones, isobars or polygons and to in fill these polygons with colour. The latter method is undoubtedly faster to assimilate but requires powerful technology in comparison with the first. The second question the controller may ask the system is to display those areas where the pressure is abnormal or out of limits; again the system uses a different colour to attract the viewer's attention to the areas concerned. This simple query has been used to demonstrate the various methods of display which have an impact on speed of assimilation. Again the eye finds it easier to assimilate blobs of colour than lines of colour. To accommodate both methods requires display technology that has a high resolution, a large colour palette together with the ability to display a large number of colours concurrently. The number of colours that can be used side by side is small when the quantity of information displayed in a geographical area is dense and when using colours for line work; this is not the case when colour infill is used.

From this brief review of the interface requirements it is clear that the technology required must involve powerful computers, with good graphic display capability that can handle vector, raster and video formats, large attached disc capacity and good networking. Due to the need for the system to be built incrementally the technology involved must have a strategic development path that matches Southern Water's GIS build program.

From the outset the decision was taken to acquire workstations that had the ability to deliver the responsive system required and that the operating system should not be proprietary but UNIX.

5 System Selection

During the period 1983 to 1985 a number of manufacturers' workstations were evaluated which included PERQ, APOLLO, SUN, HARRIS, PRIMAGRAPHICS, etc; of these the SUN Microsystems offering was preferred due to the openness and the planned forward strategic path. In 1985 when Southern Water went to tender for digital mapping phase 1, 22 companies responded of which only three offered a solution based on general purpose workstation server architecture; of these only two offered a UNIX based solution.

None of the bids at the time offered a solution based on SUN Microsystem equipment which probably was due to SUN being new to the market place. The remaining 19 digital mapping applications were based on time-shared mini computers, and the majority of these applications could not support raster data. The mini-based solutions were not as modular as required and also came in more expensive than the workstation based solutions. It is interesting to note that of these 19, the majority of whom are still trading in the Digital Mapping GIS market, nearly all now offer applications systems based on networked UNIX workstations and servers.

The contract in 1985 went to ICL for the hardware and ALPER Systems of Cambridge for the digital mapping software. The ICL hardware offered was the AGW3300 which was under development at that time. ICL supplied in early 1986 PERQ 2 hardware with attached Metheus colour screens as an interim measure pending the arrival of the AGW3300 in the summer of 1986. In the event ICL terminated the development of the AGW3300 in July 1986 after investing in excess of nine million pounds on its development and instead chose to sell SUN Microsystems workstations and servers as an added value reseller. So more by luck than by design Southern Water ended up with a digital mapping GIS solution based upon its preferred workstation server platform that is SUN. By the summer of 1987 all the interim PERQ 2 systems had been replaced by SUN 3/160C workstations and servers. By that time the pilot system in Hampshire had demonstrated the feasibility of Digital Mapping.

The conversion from PERQ to SUN went well; the majority of the work was that of transferring the application from PNX to SUNOS. The most noticeable difference once the switch had been achieved was that the SUNOS communications software was far more resilient than the PERQ PNX offering. The performance of the system also improved together with the added advantage that the number of software and hardware problems fell dramatically. So the move proved to be beneficial and the results of the change confirmed Southern Water's original workstation evaluations and benchmark results carried out prior to 1985.

6 Achievements

From 1988 the region-wide implementation of digital mapping for the prime purpose of "data conversion" commenced. Four implementation teams were established in each operational division, and became part of the division reporting to the Divisional Manager. These teams were provided on the mainland with seven SUN 3/60C workstations attached to a SUN 3/260 server with one gigabyte of filestore and an EXABYTE drive. The peripherals included three CalComp A1 digitisers, a CalComp 5836 electrostatic plotter with an automatic paper cutter attached, a CalComp Colourview plotter which could either act as a screen dump device or as an A3 electrostatic plotter. The prime purpose of these implementation teams was to convert first the water distribution records and then the sewer records. The team on the Isle of Wight was somewhat smaller than the mainland divisions with only three 3/60C workstations. The number of staff involved was 30, none of whom were IT people or IT literate except for the managers. The managers were recruited from the operational side of the water business, that is they were previously performing such job functions as Water Controllers, Sewer Catchment Managers etc.

The integrated digital network which was already in existence was extended to the first line depots as shown in Fig. 5. The objective here was firstly to provide enough capacity such that files containing raster or vector maps could be despatched around the organisation with the minimum of delay and secondly to enable the divisional implementation teams and the IT staff based in Brighton to support the systems remotely that would be installed in the Water depots.

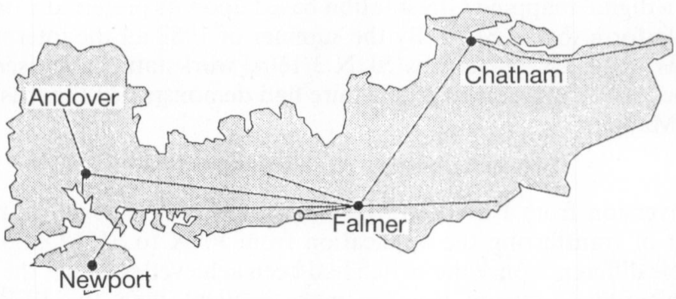


Fig. 5 Data Communications Infrastructure

All four operational headquarter campuses had all the buildings interconnected using fibre to create a campus-wide local area network, each of which were then connected to the wide area network using OSLAN bridges operating at 64 kilobits per second; some were operated at 256 kilobits per second. These were changed on the main bearers in 1989 to the 2 megabit per second OSLAN bridges. The end result was one organisation-wide "ETHERNET" network carrying both OSLAN and TCP-IP traffic.

Attached to the "ETHERNET NETWORK" are 73 systems which have the UNIX software mounted as shown in Fig. 6, over 120 SUN workstations, with the ICL DRS systems supporting 200 plus M303 dumb screens and 82 Model 30 MSDOS heads. The 122 SUN workstations are used for civil engineering design using PAFEC "DOGS", Water Resource modelling including above- and below-ground and estuary modelling using UNIRAS graphics software, water and sewer network modelling, engineering surveying using MOSS, as well as digital mapping.

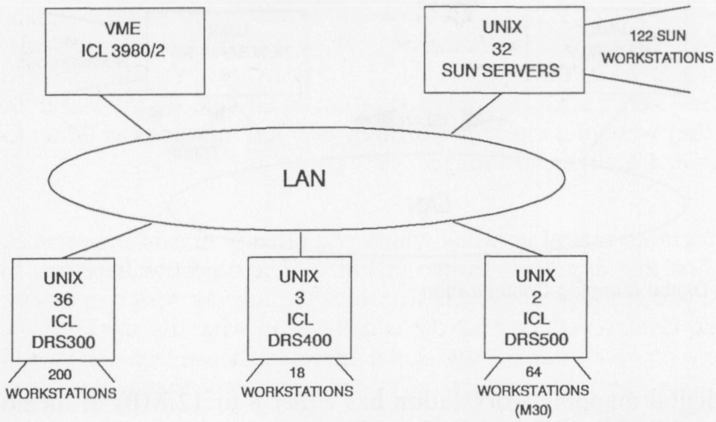


Fig. 6 UNIX/VME Configuration April 1990

All SUN workstations have a high-level window environment installed, produced by IT Southern which enables the running of applications, administrative facilities, electronic mail, etc and ensures that the persons using the SUN workstation, once they have identified themselves to the system, can work entirely by the use of the mouse if they wish.

Over 31 GBs of filestore, which is made up of over 70 physical discs, is attached to the 32 SUN servers. The data on this filestore is protected by dumping the entire disc to tape each morning at 0200 hours automatically. During the working day the system prompts the local staff to load a normal SUN cartridge tape and an EXABYTE cartridge tape into the SUN cartridge and EXABYTE drives respectively. The system checks that the correct tapes have been loaded, and if not prompts the staff to correct the situation. After the discs have been dumped to the EXABYTE tape which can hold approx 2 gigabytes of data, the log of the dump is transferred to the VME mainframe by the use of the file transfer facility. Once VME has received the logs, they are scanned and exception reports are produced if required and despatched to Technical Support for action to be taken. The VME system then files the logs for subsequent reference. The use of the EXABYTE tape drives has given significant savings in the time to dump and restore, storage space for tapes, reduction in the cost of the tapes and lastly minimised the time the system is out of use. The installation of the dump tapes daily is the only administrative task, staff in the depots have to perform.

Of the 122 plus SUN workstations 45 are for digital mapping which are connected to 16 servers as shown in Fig. 7. The communications traffic between the SUNs is TCP-IP and OSLAN when they communicate with the VME mainframe services.

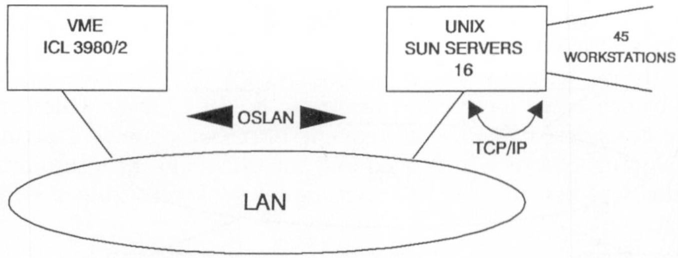


Fig. 7 Digital Mapping Configuration

Each digital mapping workstation has either 8 or 12 MBs of memory and runs the ALPER "RECORDS" application.

By the spring of 1989 the implementation teams had completed the conversion of the water distribution system to the digital mapping system and the data could be deployed to the depots. 19 SUN 3/60C workstations and their associated servers were installed in the first line depots during the summer of 1989. The filestore on these systems was either one gigabyte or two gigabytes dependent upon the geographic area served. Each geographic area had its own data base which at this stage of the GIS build was the only copy of the database.

The training of the depot staff was carried out gently over a number of months. During conversion of the water distribution data the paper records were taken on loan by the implementation teams, each map for a period of five days. Once the data had been converted to the digital mapping system, overlay techniques using a light table were used to pick up the obvious transcription errors. Plots of the converted map together with the original were then returned to the depot for correction or amendment. The depots were allocated 14 days to turn each batch round. It took one year to convert the 11,500 kilometres of water network, during this time all water depot staff were invited into the implementation team offices for "happy hours" where they were allowed to observe and play with the system. Water Inspectors were also invited in at regular intervals to perform quality checks for their patch. During this period the demand for the digital mapping system to be installed at the water depots grew to such an extent that the depot staff became impatient. When the systems were dispersed in the summer of 1989 each system was set up with a training database to enable training to occur and also for the water staff to play on a system where no lasting damage could occur.

Water staff then went through a rolling two-day training course provided by the IT Training section. The course was held on site in order to have the minimum affect on the day to day operations. The operational experience from this training period is that water staff can become comfortable with the system within four hours. After the formal training period the IT trainers withdrew from the depots. The team leaders from the Implementation Teams then performed a ten day period of "hand holding" after which the depot would be considered fluent. Subsequent refresher courses are run as the digital mapping system is enhanced and the GIS build program progresses. During the deployment over 170 operational staff were trained throughout the region.

All system administrative and quality assurance tasks are performed on the depot systems by the Divisional Implementation teams who now have the dual role of first line support as well as carrying on with the conversion of the sewer records.

The filestore attached to each depot system is used for a number of purposes as shown in Fig. 8. The swap space or virtual memory for each workstation is of the order of 45 MBs. The largest part of the filestore is utilised for the back ground data or OS map database holding a mix of vector and raster maps. The associated data is held on the VME system.

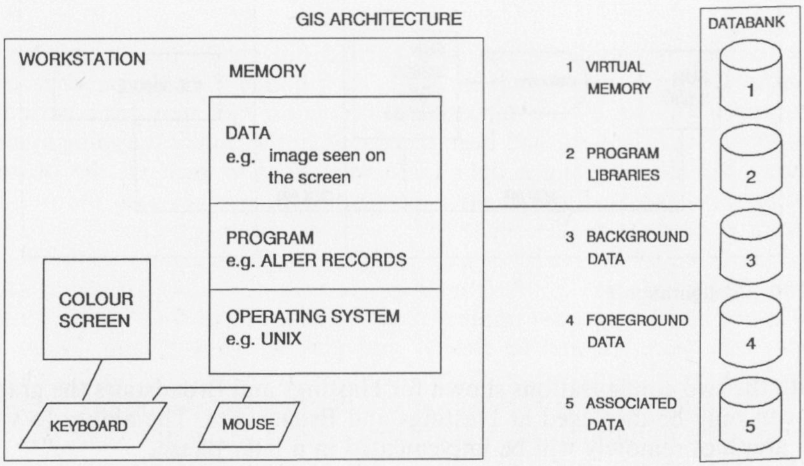


Fig. 8 GIS Architecture

The systems installed in the water depots vary depending upon the number of workstations or size of the depot. For small depots such as the one in Hastings in East Sussex the system is built around one workstation typically with one gigabyte of data held in two "shoe boxes" as shown in Fig. 9.

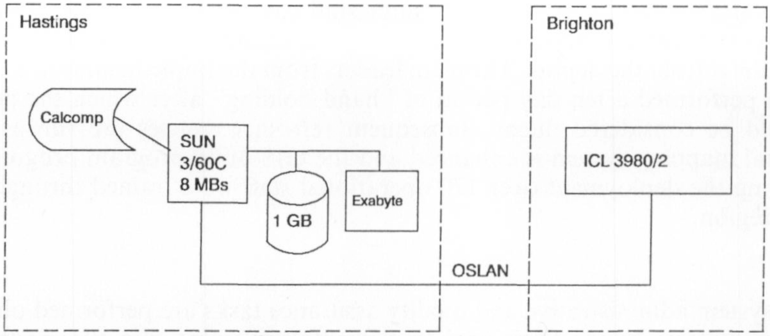


Fig. 9 Configuration 1

For larger depots such as Broadstairs in Kent, where there are three workstations a SUN server is also present, the work stations being disc-less as shown in Fig. 10.

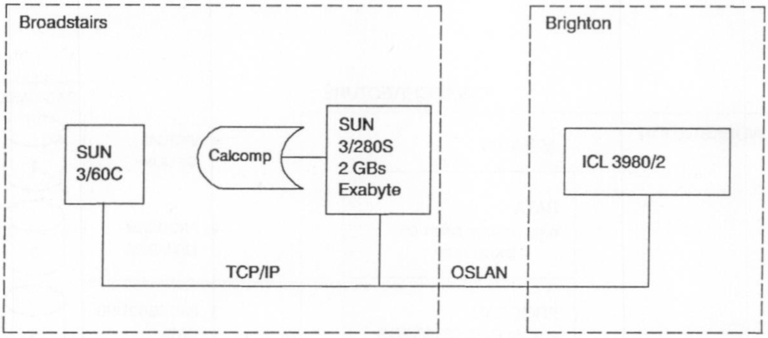


Fig. 10 Configuration 2

With the two configurations shown for Hastings and Broadstairs the graphics can only be displayed at Hastings and Broadstairs. The ability to view the graphics remotely will be implemented in a later phase.

To overcome the problem where two different offices have the requirement to display the graphics, such as in Southampton and Otterbourne in Hampshire, one location's workstations remotely load the map background and the foreground databases across the network as shown in Fig. 11. UNIX and the programs reside locally. The SUN server in Otterbourne serves a number of disc-less workstations at Otterbourne as well as those at Southampton. The bandwidth allocated between Southampton and Otter-

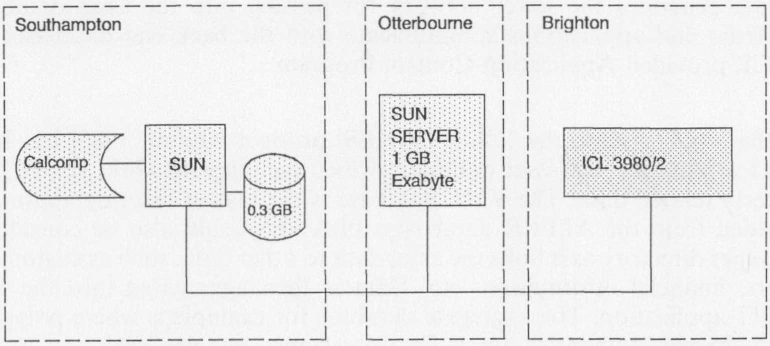


Fig. 11 Configuration 3

bourne is currently one megabit. This method functions well and is acceptable as an interim solution.

The quantity of software implemented for the GIS system at phases 1 and 2 is large as shown in Fig. 12. The facility-rich combination of UNIX and VME supports a growing number of application systems. On the SUN workstations either the ALPER 'RECORDS' application, which is predominantly for data conversion, capture, and update or the ALPER 'ENQUIRY' application for viewing with minimal update facilities has been implemented. Also on the SUN workstations are applications which process field survey data entered from portable computers. An example of one of these is that for sewer manhole survey data, which besides processing the manhole data received from either a Husky Hunter or bulk data from a data preparation

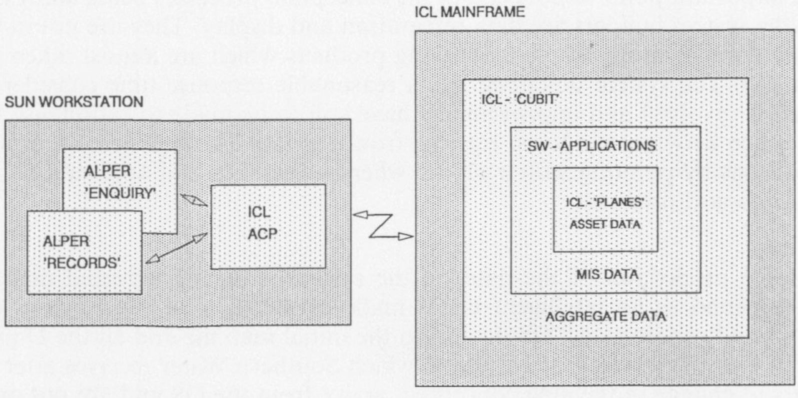


Fig. 12 Software

bureau, generates the sewer network for passing into the asset database. The front end applications communicate with the back end databases via an ICL provided Application Control Program.

On the VME system, the ICL 'PLANES' product [Quinn, 1989] has been used for handling the asset database, which includes network, spatial and property related data. The VME database is the master asset database and is loaded from the ALPER databases. PLANES could also be considered as a super directory as it links the asset data to other data, such as customers, meters, financial information, etc; Data is then aggregated into the ICL CUBIT application. The aggregate database for example is where polygons for catchment boundaries, totals for water zones, etc; are held.

What this combination of software provides is a good first cut at the GIS build. A viewer can view a picture containing Southern Water information which has been integrated not just in itself but with other externally acquired data such as the OS Map, census data, etc;

By pointing at a valve on a water distribution network for example the viewer can bring up a window containing say a detailed plan or picture of that valve, or connect to the VME databases via PLANES. The viewer can walk the network or the asset either from the front end or the back end; in other words they have been synchronised. For example starting from pointing at a sewer manhole displayed at the front of the system, connection can be made if the viewer wishes to enter (unknown to them) the asset database on VME, walk down stream towards the sewerage treatment works looking at the data as the viewer goes. On returning to the picture at the front it would now be displaying the sewerage treatment works the viewer had walked to.

An important point to note is that the conceptual processes being addressed by the system builders are data integration and display. They are not in the main concentrating on the underlying products which are almost taken for granted. The system described has a reasonable response time considering what is involved and improvements have still to be made to rationalise the interface between windows. e.g. the front end applications heavily exploit selections by pointing with a mouse whereas the back end applications are all keyboard oriented.

A large proportion of the data on the system is the background maps – background as no intelligent use is made of the data at this stage in the GIS build program. All OS data both the initial map file and all the Digital Field Update Service (DFUS) data, which Southern Water receives after 30 units of change in the area concerned, arrive from the OS and are put onto a database on the VME system. Currently over 6500 digital OS maps have been acquired with a monthly inflow of approx 120 new maps For DFUS the inflow is typically of the order of 35 per month. This is as one can imagine a considerable investment in itself, the OS data acquired for the region to date having a current replacement value of three quarters of a million pounds. For this reason the VME system is considered to be secure and a well controlled environment to store this data in as the master set.

Raster maps are produced in house by the Sussex Implementation team. Raster maps are made from good paper or film OS maps. Over 6000 raster maps have been produced and are held on the SUN map databases. The production rate for raster map units, at the peak data conversion point in late 1988, was of the order of 60 per day. Once produced they are despatched to the appropriate Implementation Team Supervisor, who has the responsibility of generating the required maps from the VME master OS data set and placing either the vector or the raster map into the appropriate SUN system map database. The communications system is using VME IPA facilities between VME and SUNOS, and SUNOS facilities between SUNs. This is summarised in Fig. 13.

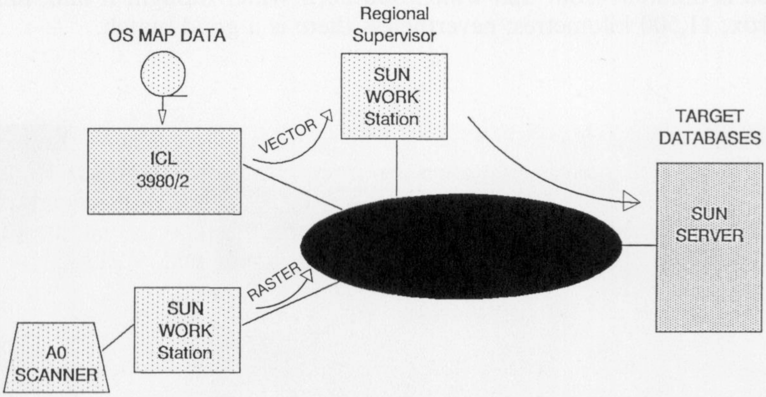


Fig. 13 Ordnance Survey Data Flow

7 Conclusions

The phase 1 implementation of the GIS has been successfully implemented across the Southern Water region at each of the locations shown in Fig. 14. As the sewer data is converted further deployments will occur as part of phase 1.

The quantity of data converted or acquired and loaded into the various databases is substantial and contains 580,388 features (excluding the OS map features) within an equivalent land area of 3897 sq kms. The data is

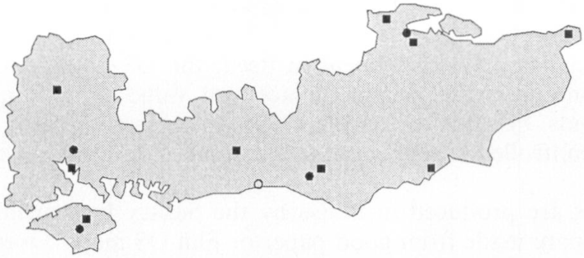
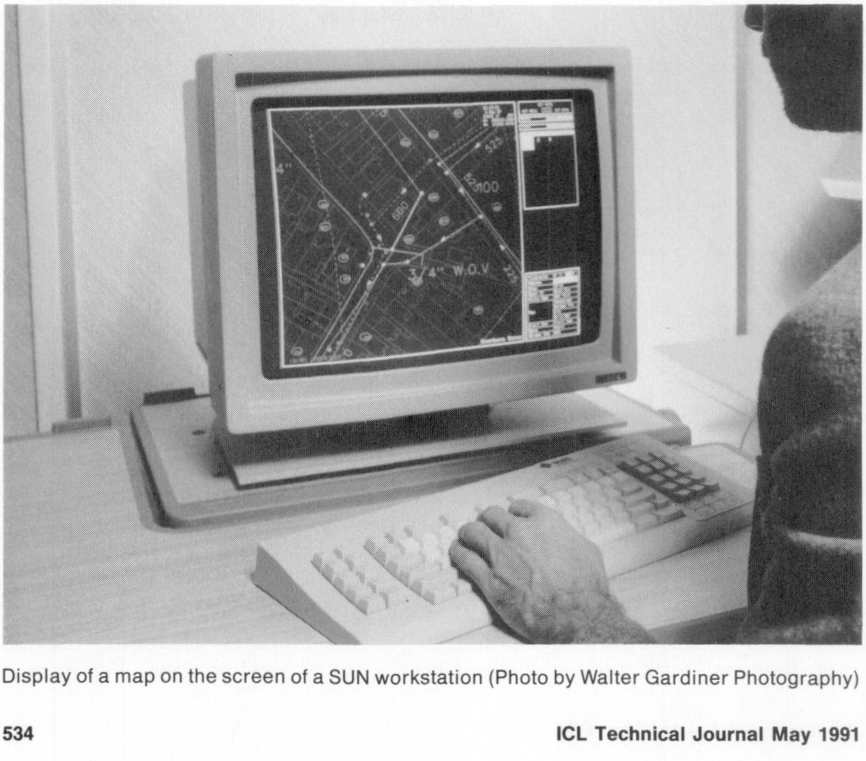


Fig. 14 IT Southern – Principal locations

held at nine locations on 11.7 GBs of filestore. The water data converted to date does not include the connection pipes between the water main in the street and the property, but only the water distribution system itself together with the trunk mains. The length of pipe as computerised is 12,121 kms which is different from that which Southern Water thought it had, namely approx. 11,500 kilometres; nevertheless there is a good match.



Display of a map on the screen of a SUN workstation (Photo by Walter Gardiner Photography)

The reliability and availability of the system is very good, which is a tribute in itself to all the various parties involved, many of whom are unaware that their technology is being used in the way it is.

The system described is no doubt both large in all aspects as well as complex and utilises a substantial amount of technology. The size and complexity however is not perceived or commented upon by the 170 plus operational staff using the system daily. Initially these staff were thrilled and very happy, but now they have become used to the system they are demanding more GIS facilities, a more responsive system and are frustrated because the system providers cannot deliver their requirements at the drop of a hat. There lies the challenge! It however does confirm that the complexities have become transparent and that this form of technology can be used by the average man and woman in the street.

8 Acknowledgements

The paper is based on a presentation made at the ICLCUA Conference held at Birmingham during May 1990.

The GIS implementation described in this paper was awarded the CADCAM International GIS award on the 27 March 1990. The award was given in recognition of the fact that Southern Water had "shown vision and determination together with superb technical and managerial skills in this vast and complex area of computing".

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2 QUINN, J.M.P. *Towards a Geographic Information System.* ICL Tech. J. Vol 6 no 3 p 542 May 1989.

Appendix

A number of the names used in this paper are registered trademarks; these, with their owners, are as follows.

APOLLO	Apollo Corporation
dbase II	Ashton-Tate Inc.
ETHERNET	Xerox Corporation
EXABYTE	Exabyte Corporation
IBM	IBM Corporation
PERQ	Three Rivers Corporation
POSIX	The Institute of Electrical and Electronic Engineers
SPARC	Sun Microsystems Inc.
SUN	Sun Microsystems Inc.
SUNOS	Sun Microsystems Inc.
UNIX	AT&T in the USA and other countries
X/OPEN	X/OPEN Company Ltd.

Using Constraint Logic Programming Techniques in Container Port Planning

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Abstract

This paper deals with the problems of resource management within a large container terminal. It describes a system developed at Hong Kong International Terminal (HIT) the largest privately owned container terminal in the world. The paper deals with the techniques and tools used in the development of the system in particular the use of ICL's DECISIONPOWER incorporating a constraint logic programming language.

1 Introduction

This paper describes the problems of scheduling ships and managing resources within a large container terminal. It describes a system which has been designed and implemented at Hong Kong International Terminals Limited (HIT). A particular problem with which this yard is faced is the optimisation of land resources on which to store containers and so a major function of the system described is to make the best economic use of storage space. In solving these problems a revolutionary new software tool called DECISIONPOWER was used. This tool combines the declarative aspects of Prolog with the efficiency of constraint solving techniques. It is in effect a logic representation of a problem using constraints in an *a priori* fashion. This technique leads to greater control over the scheduling process and permits a more efficient use of resources. The system developed at HIT optimises the use of yard space and berths while allowing the user to override its decisions as judgement dictates.

The system works by defining the problem in terms of constraints on the total problem search space. Example of constraints include: 'Roll on Roll off vessels must be berthed at berths 4 or 6', or 'There must be at least 25 metres clearance between any two berthed ships'. These constraints are used in an 'active' way to find a optimal solution where 'optimal' has been defined as a function to be minimised.

2 Planning Issues

The container terminal currently (November 1990) has six berths in which to place the 300 ships per month that arrive and it has to allocate space to the many thousands of associated containers (see Photo). The planning problem is dealt with by two departments and broken down so as to be manageable using mainly human resources; the yard planning department manages the usage of the yard by allocating an area (called a Preferred Area or PA) for the use of the containers associated with each voyage; the berth allocation department allocates vessels to berths. A new terminal has just been opened at HIT which, with its extra berths and increased space, makes the planning task significantly more complex.

2.1 Berth allocation

In order to make the problem manageable, berth allocation was formerly performed 2 or 3 days in advance. Maximum usage of the berths was ensured by allocating as many vessels onto each berth as would fit, taking into account vessel lengths and statutory clearance. For the berthing department minimising the time at HIT (waiting time and time on berth combined) for each vessel was and is the top priority. Hence resources allocated to the ship (such as cranes) would be varied to maximise the usage and ensure that the vessels were not kept waiting for lack of resources.

2.2 Yard planning

The yard is organised so as to minimise the time taken to move containers on (and off) vessels. This is to ensure that the vessel's time on berth is minimised. Containers may arrive seven or even more days in advance of the arrival of a vessel. Hence HIT takes great care in allocating space in the yard. A number of factors are taken into account in planning yard usage, these include:

1 *Scattering*: if containers associated with a particular voyage are scattered then more resources have to be allocated to ensure that delays do not ensue.
2 *Marshalling distance*: it is important that the vessels are as close as possible to their associated containers. This is because if movement distances are large then the vessel will be delayed on berth.
3 *Clashing*: if the resources allocated to two or more vessels in port at the same time were working in the same area then congestion may occur, delaying the vessels.

The planning department allocates a preferred area for each voyage in advance for the vessel which should be large enough to contain all the associated containers. An optimal preferred area is chosen by taking into account all the relevant factors affecting the time taken to load (and unload) the ship.

3 DECISIONPOWER

A system was designed to produce satisfactory solutions to these problems making use of DECISIONPOWER*. This software tool incorporates a new generation programming language CHIP which combines the declarative aspects and ease of programming of Prolog with the efficiency of constraint solving techniques. CHIP was developed from research at the European Computer-Industry Research Centre (ECRC) at Munich in West Germany. ECRC is owned by ICL, Bull and Siemens.

Logic Programming (eg Prolog) is an attractive language for scheduling problems (such as the one at HIT). This is due to its relational form, its backtracking capability and its non-determinism. The relational form is a convenient way of expressing the constraints on the scheduling process; the non determinism frees the developer from explicit tree-searching and the backtracking capability is crucial for solving discrete combinatorial problems.

Unfortunately most logic program approaches suffer from a major problem of inefficiency. This is because standard backtracking is undirected in that the whole search space is traversed in seeking a solution.

A number of approaches have been taken to avoid this problem (eg [5,6]). The approach taken by CHIP is to use the constraints in the system in an active way to prune the search tree in an *a priori* fashion (eg propagating forward the effects of constraints as soon as possible). It does this by embedding the consistency techniques inside Prolog thus relieving the programmer of concerns about them. Thus CHIP aims to combine the efficiency of 'hand crafted' programs with the ease of logic programming.

For example consider the (unrealistically simple) problem of allocating ships to berths with just the following 2 constraints:-

1 Length constraint. Ships cannot be allocated to berths that are shorter than the length of the ship.
2 Crane constraint. For each vesel there is a contractual minimum number of quayside cranes which must be allocated to it.

Now consider the case of allocating 3 ships to 4 berths as described in tables 1 and 2. There are 24 different arrangements of ships to berths. Using the constraints given above CHIP immediately allocates Ship 1 to Berth 4; Ship 2 to Berth 3; and Ship 3 to berth 2 without any searching, whereas traditional AI techniques will tend to try very many of the available combinations before arriving at a solution.

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*DECISIONPOWER incorporates CHIP (Constant Handling in Prolog).

Table 1

	Length	Contractual number of cranes
Ship 1	550	2
Ship 2	350	2
Ship 3	370	3

Table 2

	Length	Number of cranes
Berth 1	300	3
Berth 2	400	3
Berth 3	500	2
Berth 4	600	2

There are facilities in CHIP not only to find a solution but to find an optimal one through the availability of a number of predicates such as *minimise*. Once a solution has been found that satisfies the constraints a new constraint is generated that ensures that any new solution must be better than the one obtained. For example suppose that the aim is to minimise a function f and that a value, A, is found for f. Then a new constraint is generated that $f<A$, and the search continues.

4 Constraints

There are essentially three kinds of constraints within the system:-

1 *Hard constraints*: these are constraints that must always apply, for example the clearance between vessels must be at least 25 metres; stacks of containers must not be more than four high.
2 *Soft constraints*: these are priorities which planners would like to hold but which can be relaxed if no solution can be found.
3 *Procedural constraints*: these are constraints that are built into the search strategy (see below).

The hard constraints fall into three categories: physical constraints such as restrictions and safety regulations (eg roll-on-roll-off vessels must be berthed in particular berths, draughts of vessels on berth 8 must be less than 10 metres), contractual obligations and ad hoc constraints (normally user overrides) generated by the user for a particular voyage such as the fixing of a berth or preferred area.

Much work has been done on constraint relaxation (eg [3]). In practice we may have to decide not merely which constraints to relax and the extent of the relaxation, but the number of constraints which need to be relaxed and the best way of relaxing them to obtain an optimal solution. The CHIP approach is to examine the relationship between the costs of relaxing constraints, for example:-

– Consider the following diagram (Figure 1) where A is the berthed ship and B, C and D are potential preferred areas (PA's) in which the container density at B would rise to 98%, at C would rise to 85% and at D would rise to 92%. Consider next the following constraints:-

- The PA should be as close as possible to the ship
- Container density should be less than 90%

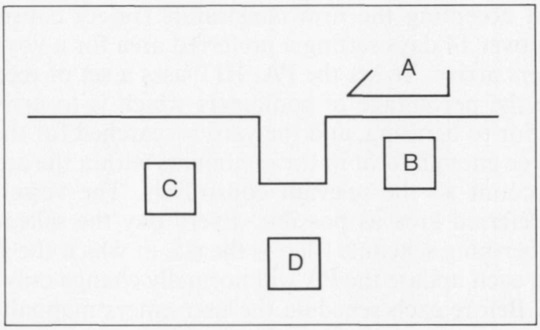

Fig. 1 Illustrating the choice of a preferred area for containers. A = ship; B, C & D are possible areas

Table 3

	Distance	Density	Total
B	0	10	10
C	10	0	10
D	3	3	6

Preferred area B obviously conforms to C1 but does not satisfy C2. C conforms to C2 but not to C1. PA D on the other hand conforms to neither but may on examination of the costs involved prove the best solution. Yet D may be a difficult PA to obtain using an ordered relaxation technique where a list of the order of constraints to relax is kept. The approach adopted to these soft constraints is to represent them in cost tables (eg table 3) and build the costs associated with the selection of a particular PA into an optimisation function. This has a number of advantages in that it allows:-

- Degrees of relaxation
- Comparison between constraints
- 'A little of a lot' as well as 'a lot of a little' (ie a comparison of the effects of small relaxation of several constraints with the larger relaxation of the few).

In the case of HIT this approach works well as many of the soft constraints are constraints on distances, times and densities which are easily quantified. However the comparative costs involved in assessing the importance of constraints are more difficult to arrive at and involve a process of cost weighting, which is decided by the expert yard planners. The expert yard planners are able to easily modify the cost tables given the declarative nature of the representation.

5 Strategy

The intention of the system is to optimise the total efficiency of the container terminal whilst accepting the firm constraints (safety considerations etc). HIT schedules over 14 days setting a preferred area for a voyage before any of the containers arrive. To set the PA, HIT uses a set of receiving patterns which provide the percentage of containers which is to arrive at the yard on each day prior to berthing, and the yard is searched for the best location for an area, large enough to fit in the containers within the area at any time, taking into account all the relevant constraints. The vessel is berthed as close to the preferred area as possible. Every day the schedule is updated but, while the berthing schedule (that is the site at which the ship will berth) may change on each update the PA will normally change only in exceptional circumstances. Before each schedule the user enters manually any changes or ad hoc constraints to ensure that the system has up to date information.

During the search for a schedule a number of techniques are used. The optimisation facilities of CHIP are used to find the best solution, but in addition a number of heuristic and procedural techniques cuts down the size of the space searched. It is the search for an optimal solution (rather than just a feasible solution) that distinguishes CHIP style solutions from some others (eg see [3]).

6 Procedural techniques

The system organises the search by first finding a preferred area for those voyages that have not already had them set. It then chooses the best berth for all vessels in relation to their PA's using the distance from the PA as a soft constraint on the berthing. It will only consider changing the PA when it cannot then find a suitable berth, given the conformation of the voyage details. This ensures that a good solution is found without backtracking from the berthing into the preferred area setting.

Procedural controls are used as a way of implementing certain constraints; for example it is regarded as crucial that 'vessel clashing' is avoid unless a preferred area cannot otherwise be found. Hence in a search for a PA, the system will first look for one that has no clashing and only if this is not possible will it contemplate one with clashing.

6.1 Optimisation

The system uses the optimisation not only as a way of finding the best solution but also as a way of controlling the relaxation of soft constraints (as above), for example berthing a ship a long distance from its preferred

Picture of a model of the Hong Kong terminals. In reality the number of containers stacked on the quay would be far greater than is shown. (Photo courtesy Hong Kong International Terminals Ltd.)

area against the disadvantages of delaying the berthing. This trade off procedure allows us to link and evaluate the preferred area setting, the berthing and the timings of the berthing.

6.2 Heuristics

Despite using constraints within the system in an active way and using procedural techniques, given the size of the problem, heuristic control of the search is still necessary (see [7]). Two examples should suffice to give a flavour of the types of heuristic used in the system.

1 *Berth searching* is a technique whereby the closest berth to the preferred area is tried first but if there is a need to search further then the search is continued in order of proximity to the PA.
2 *Home berths*. This is a system whereby certain berths were allocated to shipping lines based on statistical analysis of the number of ships berthed and containers arrived in a week. These are known as home berths. Although the home berths concept is no longer used as a means of determining berth allocation it is useful as a means of determining a reasonable statistical starting point for a preferred area search since it demonstrated a method of distributing shipping and containers evenly throughout the terminal. This gives a chance of an early solution to the problem of finding a preferred area which could then be used as a constraint on finding other solutions.

7 Conclusions

The system is used to produce yard planning information quickly both over the medium term (up to two weeks in advance) and in the shorter term (when for instance an unexpected delay causes a disruption to the operating schedule). The speed with which these plans can be produced permits the planners to compare the effects of different courses of action.

Factors such as staff productivity and maintenance costs are improved by optimising the use of available resources. Improved efficiency in the handling of containers leads to reduced berthing and waiting times. This means substantial savings both to HIT and to its customers for whom delay is a direct cost.

The advantages of using Logic Programming techniques in the scheduling and planning tasks within container ports have been shown. In particular using CHIP as a development tool allows tailored solutions to be provided which make use of the special problem heuristics whilst at the same time freeing the programmer from tedious explicit tree-searching. The advantages of this approach are that the development time of systems is short (a first working model was available within 5 weeks and the full system completed within 6 months) and the code is modifiable and extensible. This is due to the fact that CHIP combines the efficiency of a specialist program with the facility of Logic Programming.

(For a full introduction to CHIP and the whole area of constraint satisfaction problems see Pascal Van Hentenryck's Constraint Satisfaction in Logic Programming [7]).

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Locator – An Application of Knowledge Engineering to ICL's Customer Service

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Abstract

The paper describes how a system providing rapid diagnoses of the likely causes of faults in computer systems came to be conceived and, after some false starts, successfully developed.

The scheme, now in operation, allows operators in telephone contact with users to interrogate them and decide how best to resolve complaints either by advising the customer immediately what remedial action to take or, if an engineer has to call, ensuring that he is qualified to deal with the problem and takes with him any parts likely to be needed. In conclusion the practical benefits of the system are summarised.

1 Background

ICL Customer Services (CS) provides, as a major part of its services, a hardware repair service on-site for many hundreds of types of computer hardware platforms and peripherals that have been delivered to ICL's clients over the years. What ICL (UK) CS aims to achieve is a repair without a site visit if possible. If that is not possible then the aim is to send the right person, with the right part, to the right place to resolve the right problem first time and within target time.

In the computer services business failure to achieve a rapid, first time repair can be not only significant but alarmingly costly in terms of the man hours spent in unnecessary travel, and time on site. There is also the cost of unit modules being returned for repair which are, in fact, found to be not faulty during pre-repair testing. This cost penalty is particularly aggravating when the system which is the subject of the failure report might well comprise fewer than ten exchangeable modules.

ICL customers pay a maintenance premium in order that we maximise the availability of their computer systems. It is vital therefore that we get to site fast, clear the problem and depart quickly so that the customer can get on with running his/her business. Most customers agree that if we can jointly get the system fully operational again without the delay incurred by an engineer travelling to site, that is a more satisfactory repair; provided of course, that the reported fault does not recur.

2 Operation Overdrive

In 1985 the Director of ICL (UK) CS, Roger Burrell, determined to attempt a leap forward in engineering service response times and productivity. There were numerous key driving actions which included the re-allocation and re-disposition of spares etc.

As the, then, Manager Small and Distributed Systems Support, responsible for second and third line systems support activity, the author was tasked with producing tree-structured diagnostic manuals for twelve hardware product types. The challenge was to create the necessary knowledge base in eight weeks and for that knowledge to be distributed in a usable form to the, then, nine UK service desks.

The author appointed a colleague, Mike S. Thomas, to lead teams of product experts drawn from eight of the ICL (UK) CS mainland Branches and from our own unit's second and third line support staff to create the manuals. There was total commitment from all teams to the project. Manuals of high quality were produced and distributed just in time for the start of the Overdrive programme.

The manuals failed to deliver the benefits we had expected from the skill, commitment and effort expended in their production. Worse than this was the fact that the most significant reason that they failed to deliver the expected benefits was that they were cumbersome and slow in use rather than because of any other major deficiencies obvious at the time.

The diagnosticians at the chosen Branch Desks felt either that they knew better than the manuals or that they could get to a satisfactory diagnosis faster without reference to the manuals. This user resistance to the employment of knowledge-based systems was an expensive but extremely valuable lesson which significantly coloured our later approach to the Locator project and contributed very significantly to its successful design and introduction. We recognised that maintenance of a paper-based knowledge system would be a major consumer of effort. In the event, since there was little feedback from the proposed users, in spite of a formal route and methodology having been put in place, the problem of control of updates and distribution never arose.

3 ICL Adviser

The next step taken by ICL (UK) CS was to commission ICL's Expert System Development Group to computerise part of one of the tree-structured manuals, using their excellent Adviser expert system shell tool (Mitcalf, 1988). The Adviser approach works well for many applications but after a fairly brief trial it was clear that it could not meet the requirement for a high speed user interface. It was essential that the system should keep pace with the dialogue an operator conducted with the customer. The reference just quoted gives more detail of the approach using Adviser.

4 Locator

The breakthrough we looked for came with a demonstration version of the Kent University hypertext system 'Guide' which had been delivered, with a 'Kent Tools' suite, to the author's Graphics Workstation Support unit at Kidsgrove. Guide runs on a Sun 3 Graphics Workstation and has the speed of response at the 'user interface' and the capability to display Image which are, in our view, the keys to the diagnostic operations necessary for Small Systems Support.

The first step was to build a working demonstration to show management the power of the user interface based on Guide when running a simulated diagnostic session. The next was to get authority to spend some money on further development. Management were quickly convinced that the idea had potential; at the time senior STC/ICL management were beginning to look favourably on investment in expert systems.

The next step after that was to develop the Kent Guide user interface in such a way that it would fit in, at least passably well, with our field operational procedures. It also had to be totally acceptable to the end-user diagnosticians as well as to our customers' end-user contacts calling for service. It had also to demonstrate its potential to integrate fully with the infrastructures of both current and future command and control systems used by field service operations.

5 Field Trial

In July/August of 1988 we went to field trial, with a well developed and operationally usable Locator system, commissioned from Professor Peter Brown of Kent University. This ran on Sun Model 3/75 Graphics Workstations, at two of our CS Branch Desks. The knowledge database, scripted by our own staff and primed down on to each end user delivery system, was for the ICL 8800 word processor. The knowledge-base had been created using the 'Guide' editor for priming both text and help images.

Now, to create a useable knowledge database there are three or four essential processes namely:-

1 Creation of relevant knowledge scripts from information held by skilled staff. There are two processes here, first acquiring the knowledge from

the experts and then compiling the information in a tree-structured format.

2 Having acquired the compiled information, it has to be input to some database accessible from the Locator delivery system (platform) in order to "prime" the system for operational use. (LTE handles all the above at once, but when the 8800 system database was constructed for a field trial, LTE was not available and the job had to be done the hard way using the 'Guide' editor.)

3 Locator delivery platforms can be at a number of separate locations but often require much of the same information and some which is location specific. The database information is distributed on streamer tapes which have multiple files used to 'prime the local databases' selectively with knowledge trees appropriate to the products.

The trial met its pre-determined criteria for success in full, having been carefully measured on all counts. Not only did it score very highly on diagnostic hit rates but also on its acceptability to the diagnostician users and to our customers' end-users.

6 Further Development

It was only at this stage that we were prepared to ask the management of ICL (UK) to authorise further spending against our original budget for software development. In our specific application, namely creating a tree-structured database for fast information retrieval, the Kent Guide editor required a level of skill and knowledge of Guide structure, Sun GWS and Unix systems inappropriate for use by non-experts. Most of our ICL product experts knew nothing of Guide, Unix or Sun, nor should they have needed to know anything in order to construct a knowledge database in their specialisation.

We therefore had a tree-editor designed and developed for the purpose by the STC AI Development Unit at Harlow. This fully interfaced with the very much modified Kent Guide System and was designed to be fully usable by product specialists having only minimal knowledge of the structure of Guide or of the Sun GWS or its Unix operating system.

The HCI for this tree-editor is the subject of a companion paper by Kevin Lewis of STC Technology in this issue of the Journal (Lewis, 1990).

Product specialists can be trained to use the editor to create the tree-structured logic of the knowledge database and to display the results of their work via the Guide interface in less than half a day. Image 'help screens' may be added to the database from scanned photographs, line drawings or text and additional text titling can be added to the 'help' images. In order to interface fully with any other ICL Systems a Remote Session Access (Tele Processing) interface was developed. This is capable of full

'Copy and Paste' action between appropriate windows on the end-users' SUN workstation system.

7 The User Interface of Locator

The following is a resume of the features of the Locator user interface which runs, typically on a Sun Model 3/75 with 4 Megabytes of store, 16 Megabytes of disc and a monochrome screen.

The Sun GWS screen is near A3 size; imagine it to be so. In the Locator application it is divided into discrete windows as follows:-

- *Left A4 'portrait'* is for Locator keywords, diagnostic trail and diagnosis.
- *The left A4 window* can have an A5 landscape window superimposed on its bottom half with 'help' information. This can be image or text or both. The operator 'buttons' this window in and out at will.
- *Top right A5 'landscape'* is for up to sixteen icons summarising calls in suspense, ie waiting to be resumed. The operator can suspend a call and "iconise it" at will. The operator can only resume an iconised transaction when the Locator screen is no longer busy with a current transaction, whether new or resumed.
- *Bottom right A5 landscape* contains a window into the current ICL Field Services Command and Control system screens.

Locator has been designed to interface, via the Remote Session Access (RSA) service, not only to the current field operations command and control system 'CRISP' but also to any currently foreseeable command and control systems under development. Because of the RSA strategy chosen and the power of the Sun workstations running SUN-OS, it is possible to log in to and to access concurrently any of the appropriate and available on-line corporate systems such as the software Maintenance Database MDB or the spares database MARS etc.

In practice the command and control system window is rather larger than the A5 size previously mentioned, in order to cope with what can be a very busy 25×80 text display; it can, therefore, overlap the Locator screen somewhat. Foreground and background positioning of this window has had to be put under operator button control.

The system is used by an operator (diagnostician) in an interactive dialogue with an end-user reporting a potential system malfunction by telephone. The operator listens for a keyword such as screen, disc, printer, system dead etc. in the responses from the end user, which prompts the next question from the operator. Selection and "buttoning" of the keyword, via a mouse-driven pointer on the screen displays a question and the next logical set of keywords to listen for...

The sequence should terminate after seven or so questions with a diagnosis of the problem and a proposed action either by the end-user, or by ICL field engineering. The action recommended is transferred from the Locator system window by using a 'copy and paste' facility into the command and control system window for action by local field engineering. Help screens are available to the Locator operator which may be image or text or both.

A trail of the keywords and responses for each diagnostic sequence is displayed on the screen. If appropriate the operator can backtrack during the course of the dialogue and resume a forward sequence taking an entirely new path to a different end-point. Once the call is closed the diagnostic sequence is automatically archived to local disc for post mortem analyses, if and as required.

A call can be suspended in flight and displayed with its call number and a brief message in an Icon indicating that the end user will ring back with key information at some later time. A new call sequence can then be commenced. Sixteen such calls can be suspended in this way; any of them can be re-opened at a later time starting from the point at which it was suspended. Restarting can occur days later if necessary though the practice is normally to be avoided. There is full functional capability available to the operator to backtrack etc. until diagnosis is complete, transferred by copy and paste action to the command and control system window and the call closed.

8 Locator Tree Editor (LTE)

The key to the viability of Locator is the LTE system for writing scripts. The minimum viable store size on a Sun 3 GWS running LTE is 8 megabytes. The system is highly ergonomic in operation and enables creation, display and amendment of logical trees by ICL product experts who need have no prior knowledge of Sun GWS systems, Unix or 'Guide' file structures. They must, however, be able to think logically and so create appropriate diagnostic information based on their experience.

In practice the system enables such experts to create and input between thirty and fifty accurate questions per day in an iterative process of creation, via LTE, and display, via Guide. Very little operational training is required and the system can be fully mastered by most users in less than a day. New users can become competent in about two hours.

The system is very popular with product experts writing scripts for the knowledge-base. Their only complaint is that it should go a bit faster. Given that our original criterion was to make LTE ten times faster and simpler than using the original Guide editor in the same application and that we over-achieved this objective by a factor of ten, we might question the original criterion. To make LTE go faster we need more than the current 8 megabytes of store per Sun GWS. To make it go significantly faster we would need up to 16 Megabytes but this would not yield appropriate cost/performance benefits from the authoring process.

9 Conclusions

ICL (UK) now has more than 65 screens in operation, handling over 900 calls per day in Office Systems, Retail, Mainframe peripherals and Networks.

Experience has demonstrated that the system provides the following key benefits:-

- Consistent, rapid and progressively improving approaches to diagnosis of problems.
- Diagnostic hit rates 20%+ better than those achieved by the best human diagnosticians.
- Improved utilisation of spares.
- Knowledge once captured is permanently available.
- It reduces the skill level required for first line fault 'locate'.
- It has a high synergy with other major systems, such as MDB, ENDB, MARS, TEXT etc, which may be used in support of customer service.
- Operators can be trained in less than half a day.
- Experts required to 'script and prime the database' using LTE can be trained in less than half a day.

10 Thanks and Acknowledgements

In acknowledging the many contributors to this enterprise, which has been increasingly widely supported in ICL, the following deserve special mention:-

- The Locator development and trials team as follows: Mike S. Thomas, Des Meehan, and Brian Brough, all working part-time with valuable contributions from Rob Briggs, all based at Stevenage. Managers and Staff from Stevenage, Elstree, Bristol and Manchester also contributed to the Pilot and Field trials.
- Roger Burrell Director ICL (UK) CS and Ed Pedersen his Services Marketing and Development Manager who got us the budget we asked for and enabled us to develop this leading edge system.
- Professor Peter Brown and his team from Kent University for timely development of Guide modifications.
- Kevin Lewis, Clive Hayball and the team at STC Technology, Harlow for timely development of LTE.
- Pete Bolden and team from Bolden James, for timely development of the IPA (Communications) interface to Locator.
- Alper Systems for their contribution to our Image capture experiments.

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Further references will be found at the end of Lewis' paper.

Designing the HCI for a Graphical Knowledge Tree Editor: A Case Study in User-Centred Design

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Abstract

The paper describes the development of the HCI (Human Computer Interface) of a Knowledge Tree Editor. The existing expert system lacked adequate support for knowledge tree building, extension and maintenance. We were approached to build a tool to allow easy construction, editing and maintenance of a large knowledge tree.

The customer's requirement was for a sophisticated graphical editor, suitable for use by inexperienced users, but was somewhat clouded by differing opinions and expectations. The complexity of the requirement suggested the need for rapid, iterative HCI prototyping and evaluation. The HCI design was selected from a set of alternatives, in discussion with potential system users. The final design was refined from the chosen option.

We conclude that rapid, iterative prototyping of HCI alternatives, coupled with informal end-user evaluation, facilitates customer acceptance and the construction of a usable system. The resultant tool has been in use for over a year, and has gained full acceptance from its users across several sites.

1 Introduction

The paper describes the development of the HCI of a graphical knowledge tree editor. A knowledge tree embodies an expert's understanding of a particular domain in a question and answer format. Following a trail through a knowledge tree allows progressive specialisation toward the correct answer, with which is associated a diagnosis of the problem. The editor was designed to enable the easy construction, editing and maintenance of such a knowledge tree.

The knowledge tree is used in 'Locator', a system developed by ICL Customer Services to provide a graphical, easy to use diagnostic facility to support their front line help desk service. The facilities provided by the original Locator expert system for constructing, editing and maintaining the very large knowledge tree were difficult to use, time consuming and did not provide adequate support for a knowledge tree of the size required by ICL.

ICL Customer Services approached us to build a tool to aid the development and maintenance of the knowledge tree. We provided a tool called the Locator Tree Editor (LTE).

2 Overview of Locator

The Locator system provides a graphical hypertext based expert system to be used by a diagnostician at their front line help desk facility. Locator is mouse driven. The monitor screen contains sensitive areas of text which may be selected in order to display further, associated screens of data.

The diagnostician can use Locator to follow a line of questioning about possible computer faults that a telephoning customer may have, to a point where a diagnosis of the customer's fault is produced. Locator displays a trail of the questions and answers and allows the diagnostician to backtrack to previous questions.

The diagnosis produced contains information which is used to select an appropriate course of action. This may be providing the customer with a simple solution over the telephone, or sending out an engineer to fix the problem. As the problem has been diagnosed before the engineer is sent out, little or no troubleshooting at the customer's site is required, thus reducing the time taken to fix problems. This has the effect of reducing the equipment maintenance costs and improving the customer's image of the company.

The original Locator system did not facilitate the easy development and maintenance of the knowledge tree, as the editing features provided by Locator were difficult to use and time consuming. The support for maintaining a very large knowledge tree provided by Locator was not sufficient for the size of tree required to support the extensive ICL product range.

3 Knowledge Trees and the LTE Requirement

We were given the requirement of supporting an expert in an ICL product in the task of developing and modifying the large knowledge tree to be used by Locator. This problem statement is simple, but the solution required to solve the problem was complex. Therefore we needed to investigate the requirements for the editor thoroughly before proceeding with the HCI design. The biggest problem we faced during the project was that the customer did not have a clear vision of a tool that would support the required tasks. This made the design of the tool more difficult as there was no consensus on the anticipated functionality and the HCI.

We were provided with several example user-computer dialogues. The dialogues provided were simplistic in their detail and coverage of the problem area, and did little to suggest a suitable HCI for the system. The dialogues, however, provided us with a basis from which to determine the facilities required in LTE.

Before we could begin any HCI design, we had to understand the way in which Locator operated. The Locator knowledge tree represents the combined expert knowledge on maintaining and repairing a range of ICL products. This is structured as a number of topics, each of which may have a number of associated sections. For example, a topic could be the 'Series 39' computer system. The sections associated with this may be: 'Disc Drive', 'Printer', 'Communications' etc. Using this scheme, it is possible for a knowledge tree to cover the whole of the ICL product range in manageable topics and sections, each of which may be created and modified independently.

Knowledge tree sections are displayed by Locator in two different formats: question screens and diagnosis screens.

A question screen consists, from top to bottom, of an answer trail, specifying how this point in the tree was reached, a textual question, a set of answer buttons, and optional help "buttons". The diagnostician can click with the mouse on an answer button, which causes Locator to display another screen with more questions and answers, or a diagnosis. Clicking on a help button opens a sub-window with a textual or graphical help message.

A diagnosis screen is completely textual, and consists of the diagnosis, and a list of actions for each of a set of actors. In this application, the actors are 'Customer', 'Diagnostician', 'Engineer' and 'Customer Services Representative'. The diagnostician uses the information displayed on the screen to inform the customer of the problem, or to arrange for further investigation or fixing by an engineer.

By understanding the different screens and their contents, we were able to form opinions on the nature of the HCI for LTE. This is described in the following section.

4 HCI Prototyping

The first task in HCI design was to define our user population. The anticipated user was an expert in an ICL product range or individual product. We were able to assume some experience in using computers, and, in particular, WIMP (windows, icons, mouse, popup menus) interfaces. This allowed us to employ a graphical display with which to interact with the user. In particular the ability to make use of the mouse to operate popup menus and buttons was very useful, as we were able to provide popup menus for each of the items displayed on the screen.

It was difficult to understand the user requirement in detail. We had only a sketchy brief from the customer upon which to develop the HCI. We decided to investigate the user requirements for the system by providing an HCI prototype which contained little or no deep functionality. This HCI could be presented to the customer and potential users for feedback and evaluation. Thus we proposed to use an iterative approach to the HCI design.

We examined Locator to determine what knowledge tree objects we required. These related to the two Locator screen types. We distinguished four tree node types: question nodes, answer nodes, diagnosis nodes, and branch nodes.

A question node contains the question text, and an optional help button reference. An answer node contains the answer text itself and the answer trail text. A diagnosis node contains the diagnosis text and, for each actor, a list of textual actions. The branch node contains the part of the tree to which to jump, when the node is reached in Locator.

An analysis of the tasks the user might wish to carry out was performed. We discovered a number of facilities required in the system. These are noted in the task decomposition below:

- Initiative Editor
- Create New Tree
- Load Existing Tree
  - Select Tree to load
- Edit Tree
  - Add Nodes
    - question, answer, diagnosis, branch
  - Delete Node
    - question, answer, diagnosis, branch
  - Edit Text in Nodes
    - question, answer, diagnosis, branch
  - Cut, Copy and Paste Subtrees
- Navigate Tree
  - View from Here
  - View from Previous
- Run Guide
- Save Tree
- Quit Editor

Most of the operations above do not need to be explained. Those that do are the navigation options and 'Run Guide'. The 'View from Here' option causes the tree to display itself from the node on which the operation is performed. The 'View from Previous' reverts to a display one question level back.

'Run Guide' allows the user to see the effect of tree changes on the target Locator system. Guide displays the tree almost exactly as it would appear if it were running under the Locator system. (This is achieved as Locator itself is based on Guide, with a number of additions). The ability to 'Run Guide' becomes increasingly important as the tree approaches completion and the user edits the knowledge to ensure a good on-screen presentation.

From the set of tasks, we were able to distinguish five distinct *types* of processes:

Loading and Creating Trees	–tree selection
Editing Tree Structure	–knowledge ordering information
Editing Tree Data	–the knowledge at each node
Saving Trees and Quitting	–tree update
Running Guide	–tree inspection

We were now able to make an initial attempt at defining the screen areas with which the user could interact. The task structure suggested that we required an area to display the tree, a separate area to edit the text of the tree nodes, another to control saving and quitting, and a final, top-level, area where the user could create or load trees. Running Guide required another window. This window was to be modal, in that it would have to close before LTE would continue.

A further customer requirement was for an 'Audit Trail' which shows the question–answer path of how the current question node was reached. This was to be displayed in another window.

We had to make a number of HCI and development design decisions before proceeding to produce the HCI prototype. These included:

(i) How should the knowledge be displayed?

The data ICL were proposing to place in Locator was in a linear paper-based system, with jumps from answers to other pages in the document. When these documents were developed, the experts employed a tree structure to help understand the questions and answers. It seemed natural to use a tree structure in the tool as this closely resembled the current method of working. This is an advantage as the future users of the tool would not need to modify their thinking considerably.

(ii) Should the tree display be horizontal or vertical?

Again, the experts used a horizontal tree during development, therefore this is the one we chose.

(iii) How to display the detail of the tree?

As there were four distinct node types, we decided to display them uniquely to aid identification. We proposed to use different boxes and font styles to allow the user to distinguish between the node types. A question node was to display its number and the question text in a rectangular box. Its answers were to be linked by lines. The answer nodes were not boxed, but were emboldened to give them emphasis. The diagnosis node was designed similarly to the question node, except that the word 'Diagnosis:' and the diagnosis number were displayed in bold text in the box, along with the diagnosis text. The branch node was a smaller, round cornered box displaying the branch filename.

(iv) How much of the tree should be displayed at any time?

The problem arose because the trees were generally much larger than the screen area, and tree navigation became troublesome. We made the assumption that the experts worked with only one question level at a time. Therefore we proposed to display a root question, its answers and the nodes following the answers. The user could manipulate the whole tree level, and when required, move level up or down the tree as appropriate. This solution seemed most appropriate as it tended to focus the user's attention toward the part of the tree on which he is currently working.

(v) What tools should we use to develop this prototype?

We required a graphical system which ran on the delivery vehicle (Sun-3), and that provided a set of facilities which allowed us to produce graphics quickly and easily. It was important to have a high degree of reusability throughout the system to encourage a consistent user interface. We chose to use a user interface development tool called PCE/Prolog (Anjewierden, 1986) which has these features, and which we had experience in using.

The use of PCE/Prolog allowed us to produce a prototype rapidly. The toolkit also allowed us to modify the window size and position on screen, and to record these for later use. This proved to be an invaluable feature during the HCI design as we were able to modify displays while the customer was watching, and to modify them to the customer's liking.

The first screen layout we designed is shown in Fig. 1.

The second level of the tree is displayed in the right hand window, with different kinds of nodes. In addition to the different node shapes and contents, each type of node has a different popup menu associated with it. Each menu reflects the operations the user can perform on the node or subtree at that node. The figure shows the popup menu for a question node. The Audit Trail is shown with the entry for the first question and answer trail present.

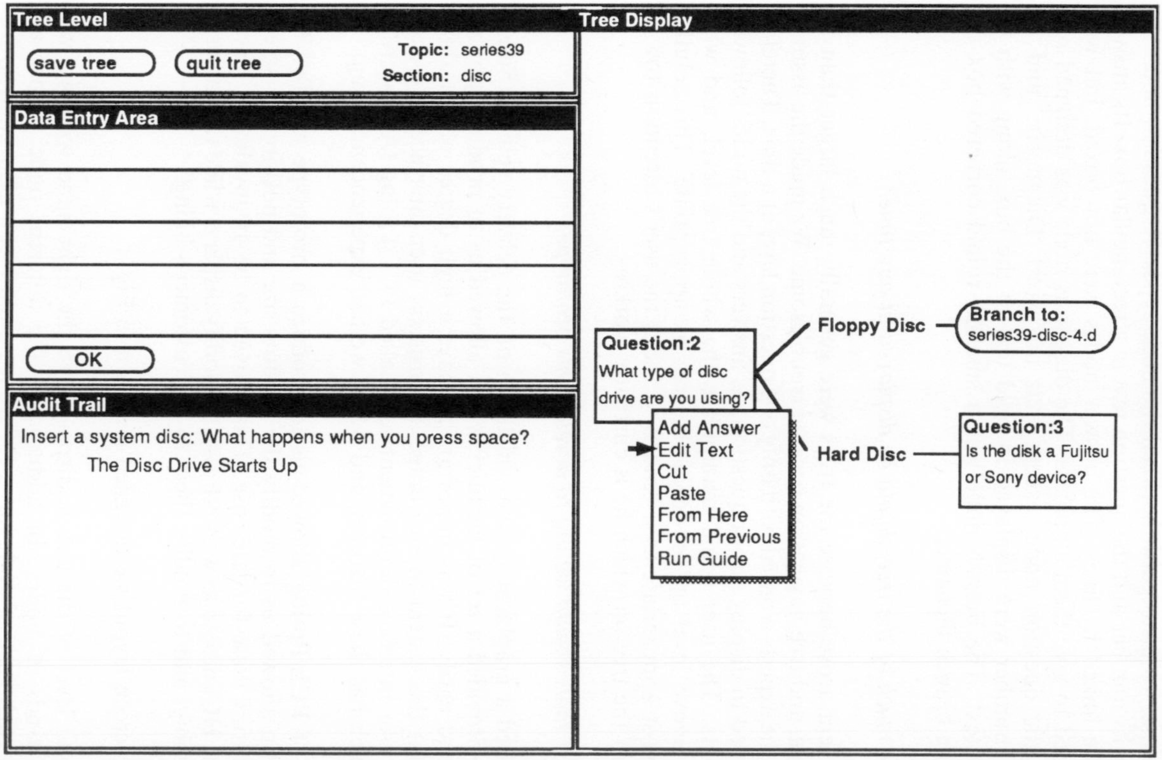

Fig. 1 The Original LTE Screen Layout showing Popup Menu and Audit Trail

This screen layout was built into a prototype around which a simple 'story' was written. This was intended to demonstrate the proposed facilities in the tool.

5 Results of HCI Evaluation

After the prototype had been built, the customer was invited to comment. During the evaluation meeting, the customer and a senior user were present.

This stage of the project proved to be the most important as major differences in expectations and interpretations of the HCI were highlighted. The most important problem highlighted was the apparent need for the user to be able to see as much of the tree as possible. In our scheme, only one level (one question) was visible at any time. In generating these knowledge trees by hand, a whiteboard is used to map out the structure and content of the tree, in order to be able to follow the reasoning of the questions and answers leading to the current tree position. Therefore, we needed to show more of the tree, as the user demanded.

This raised a problem with the current screen layout because it was impossible to see more than one question level at any time. During the evaluation session, we used the toolkit's ability to resize and move windows to redesign the screen such that the tree was displayed in the window which was longer horizontally than vertically. This layout was closer to the customer's wishes than the original design. At one point during the session, we used several monitors to display three different screen layouts.

This helped the customer to see the advantages of each of the different HCIs.

To aid the user in the navigation of the tree, two more facilities were added: Expand and Collapse. Expand causes the question node to display its answers and their children, thus revealing one more level of the tree. Collapse causes the subtree to fold into one greyed out node. These were very useful features which, together with the other commands, help the user to navigate the tree more easily.

The final HCI design was chosen at this group meeting from one of these system alternatives.

As the project progressed, it became clear that the customer's initial unclear vision of the tool had now changed because of our prototyping activity, and that this vision was now converging toward our ideas of the proposed HCI. However, there was still scope for further refinement of the HCI.

6 Implementation of LTE and Use

During the development, a number of minor HCI problems were resolved, in conjunction with the customer and users. These problems included issues such as 'intelligent' pointer positioning after the user had performed a particular operation, the sizes of data entry areas, and the provision of 'hot keys' to allow the user to quickly move the pointer between text areas.

Several more complex features were requested by the users as their requirements modified due to their increased usage of the tool which met almost all their needs.

One example of such a feature was the ability to add more than one answer at a time. In the original design, the user was expected to choose the 'add answer' menu item from a question node for each answer. The users thought that it would be convenient to allow the addition of more than one answer at a time. This facility was designed and implemented and proved to be very beneficial to the users.

Many hours were spent evaluating the usability and reliability of the tool. The reliability aspect became increasingly important as the development progressed, as some of the trees built during testing were intended to be used in Locator. The user's trust in the tool was high by the end of the development.

Several important points came out of the development: incorporating users into the software development life cycle ensured that the tool was usable: extensive testing ensured high reliability, and increased confidence in the integrity of the data the tool produced: involving the customer aided the installation and uptake of the tool adding to the success of the tool in the field.

The final designed and implemented HCI is shown in Fig. 2. The design shows the same tree as the previous figure, of which more is visible. The data entry area is being used to edit the text of the third question node.

7 Conclusions

The LTE system was completed and finally delivered to the customer in February 1989. It rapidly gained user acceptance across three sites, and has since been used intensively with no problems.

A highly usable HCI for the system was developed using rapid and iterative prototyping of alternatives involving both the customer and users. This in turn led to easy customer acceptance of and commitment to the tool and its widespread use.

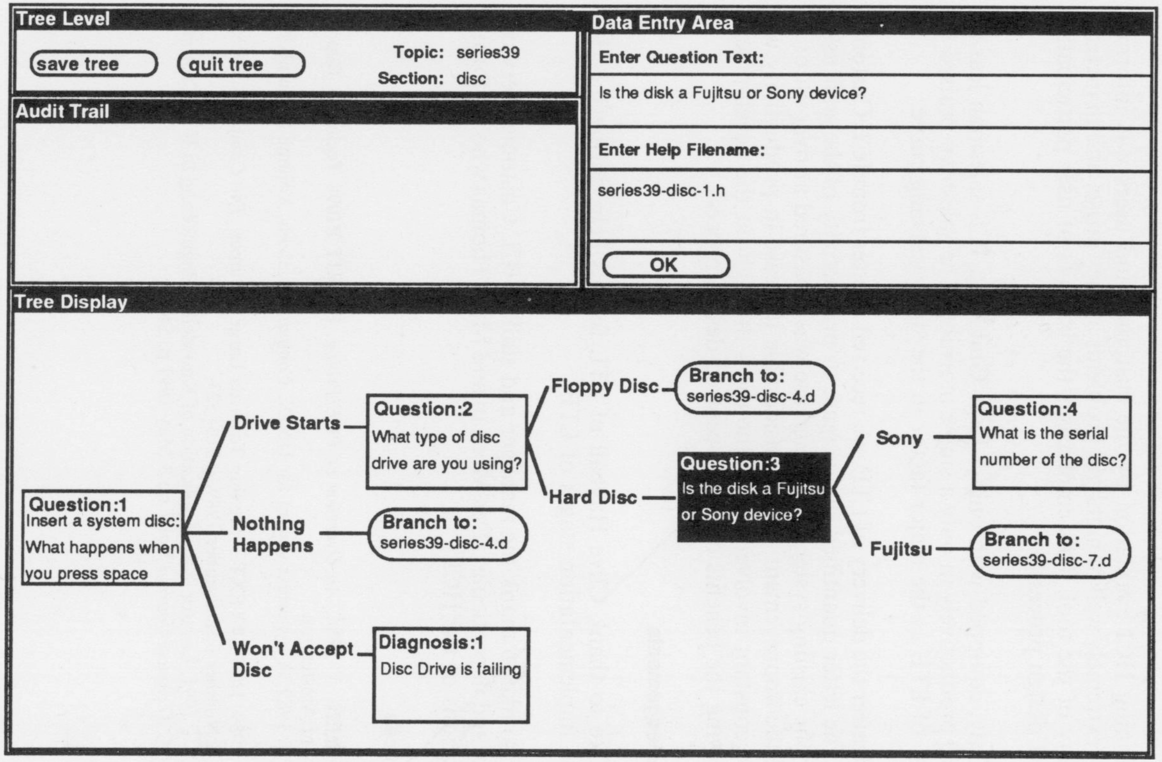

Fig. 2 The Final LTE Screen Layout showing same tree and data entry area

The rapid and iterative prototyping approach was only possible with the use of a graphical toolkit. This allowed us to make substantial changes to the HCI quickly and easily. It also helped to ensure a consistent user interface across the tool.

The continuing HCI evaluation by the customer and users was informal, but served extremely well to highlight problems as they arose, and to increase the usability of the tool. This emphasises the benefits of user participation in the HCI design process.

Subsequently, equipped with only a User Guide, an ICL salesman learned to use LTE productively in only a single morning. The salesman praised the ease of use of LTE as the major factor in the short learning curve.

Some time after the delivery of LTE, we received a letter from ICL Customer Services. The letter quantified the increase in productivity of the staff using LTE over the existing system. This increase was measured at over an order of magnitude improvement. This considerable increase in productivity was due to the constant involvement of the users throughout the development, hence showing the benefits of a user-centred design process.

8 Acknowledgements

I would like to thank Clive Hayball of STL for his help during the HCI design and implementation stages of LTE.

I would also like to thank the manager and staff of ICL Customer Services, Stevenage, and in particular, Des Meehan and Mike Thomas who performed the evaluations of the HCI.

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X/Open – From Strength to Strength

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Abstract

An article in the November 1987 Issue of the ICL Technical Journal described the initiation of the X/Open Group in 1984 and its growth and achievements over the first three years. This current article takes the story on through the following three years, during which time X/Open^{TM} has grown to involve most of the major players in the IT industry worldwide, and has become a very significant driving and unifying force for the success of Open Systems.

1 Introduction

An article in the November 1987 Issue of the ICL Technical Journal described the initiation of the X/Open Group in 1984 and its growth and achievements over the first three years. This current article takes the story on through the following three years, during which time X/Open^{TM} has grown to involve most of the major players in the IT industry worldwide, and has become a very significant driving and unifying force for the success of Open Systems.

The formation of the X/Open Group in 1984 was the result of:

a) a growing user resistance to the long term lock-in effects of proprietary operating systems,
b) an insufficient supply of generally available applications for these proprietary systems, and
c) the hardware technology evolution that lead to the emergence of cheap powerful systems which allowed the "Department" to become a large scale user of information technology.

The Personal Computer explosion had highlighted the virtuous circle created by Industry Standards when the volume cost equations are favourable, and the same phenomenon was underway for the multi-user systems needed to support departmental operation. To achieve this a suitable generally available multi-user operating system was required and many computer manufacturers were turning to UNIX^{TM}, or systems derived from it and/or its interfaces.

UNIX was written in the C language and had been designed to be portable to different hardware bases; it also supported C as a language for writing applications. It therefore had the necessary potential for providing a common operating system and common application language on a wide range of hardware. Unlike the PC situation which standardised at the hardware level (applications in binary), it offered standardisation at the source code level thus allowing the same applications to work across the wide range of different hardware architectures needed to cover the power range of Departmental systems (whilst still allowing the ability to define binary sub-sets where appropriate). However, although UNIX largely fitted the requirement, it had not been rigidly controlled with regard to standard interfaces, and several significantly different flavours were being developed and marketed.

In 1984 ICL approached the other major European computer manufacturers with the view to forming a collaboration dedicated to ensuring not only that there would be a single standard at the UNIX level, but also that a complete Common Applications Environment (CAE) should be defined covering the basic operating system, data management, integration of applications, data communications, distributed systems, high level languages, internationalisation, security and all the many other aspects involved in providing a comprehensive set of interfaces for portable applications.

If this could be achieved it would be to the mutual advantage of Users, Independent Software Vendors (ISV's) and the system suppliers. The Users would be freed from lock-in (investment made in applications, programmer training and operating procedures would be protected) and systems from different suppliers could be mixed and matched. The ISV's would be encouraged to produce applications, as they would run across a wide range of systems from many suppliers; and the system suppliers would benefit from the many applications available for their systems and the availability of operating system components as commodity items. Competition would move into more significant added value areas such as systems integration and industry specialisation.

2 The First Three Years

This section briefly recaps the first three years; the November 1987 article should be consulted for a full description.

The collaboration was started in 1984 by Bull, ICL, Siemens, Olivetti and Nixdorf under the codename BISON, the objective being to develop a Common Applications Environment (CAE) by adopting, adapting and refining international and de facto standards. During the first year the initial phase of work was completed, and published in the "X/Open Portability Guide, Issue 1" (XPG1). Also during this period Philips and Ericsson joined the group and the name X/Open was adopted and registered.

The second phase saw a major influx of US companies (Digital, Unisys, Hewlett-Packard and AT&T), which was a measure of the early success, added significant strength to the Group, and widened the scope outside Europe. It brought the total number of members to eleven. At the end of this period the second issue of the Portability Guide (XPG2) was published approximately doubling the coverage of the CAE.

The coverage of the CAE in XPG2 (Jan 1987) was:

a) System Calls and Libraries
b) Commands and Utilities
c) C Language
d) Internationalisation
e) Terminal Interfaces
f) Inter-process Communication
g) COBOL
h) FORTRAN
i) PASCAL
j) ISAM
k) SQL.

Also over this period a verification suite to test the conformance of systems to the X/Open definitions was developed, and significant work towards further evolution of the CAE was initiated.

3 The X/Open Portability Guide – Issue 3 (XPG3)

As described in the earlier article, the IEEE P1003 committee was working on a standard for a "Portable Operating System for Computer Environments" which defined a set of interfaces largely based on (a sub-set of) those of the UNIX operating System. This standard, known as POSIX, had been issued in trial use form in April 1986. X/Open had expressed full support for POSIX and had declared intent to converge the Portability Guide with it when it achieved "full use" status. Since then the first phase of POSIX, or more precisely the P1003.1 standard, not only achieved full use status, but has passed on via ANSI into the ISO/IEC arena as ISO 9945–1:1990.

The primary focus of the third issue of the X/Open Portability Guide (XPG3) was this alignment with POSIX, and timescale for publication was determined by P1003.1 ratification. In practice many further iterations of P1003.1 took place beyond the original trial use version, and X/Open was very active in this work.

The other significant aspects of XPG3 were the moves into the graphical user interface area with the adoption of the foundation elements of the X-Windows System (the XLIB interface and the reference to the X-Protocol), and into system interconnection with the introduction of the Transport

Interface (XTI). The latter provided a standard application interface to both ISO/OSI Transport, and to Internet (TCP/IP, etc).

In addition most of the functional areas that were in XPG2 were revised, and in some places significantly enhanced. Internationalisation was both enhanced and further aligned with ANSI C and /usr/group (now renamed UniForum) definitions, and the basic interfaces were made a mandatory part of an XPG3 system. The ADA language was also added.

"X/Open Portability Guide – Issue 3" (XPG3) was published as a seven volume set, Volumes 4–7 in August 1988, and Volumes 1–3 (determined by P1003.1 ratification) in December 1988. (Collectively they are often thought of as the 1989 edition illustrating the approximately two year cycle – XPG1 1985, XPG2 1987, XPG3 1989.)

The contents of XPG3 are:

Volume 1:	XSI Commands and Utilities
Volume 2:	XSI System Interfaces and Headers
Volume 3:	Supplementary Definitions
	– Internationalisation
	– XSI Terminal Interface (Curses)
	– Source Code Transfer
Volume 4:	Programming Languages
	– C Language
	– COBOL
	(Due to an editing error the definitions for ADA, Fortran and Pascal were accidentally omitted from this volume. They are given in the "XPG3 Portability Guide Overview".)
Volume 5:	Data Management
	– ISAM
	– SQL
Volume 6:	Window Management – XLIB
Volume 7:	Networking Services
	– Transport Interface XTI
	– PC Inter-connection (rudamentary).

Although not part of XPG3, an X/Open Security Guide was also published in this same timeframe. This well received document is a description of security issues, and gives much advice concerning the use of the security features to be found in most XPG systems and how to manage a secure environment.

4 Growth of Membership

During this period the full membership of the X/Open Group almost doubled (11 to 21), including the addition of some very significant companies and the extension to three major continents (Europe, USA and Japan). This illustrated the impact that was being made and the rapidly growing importance of the operation.

Three events are particularly noteworthy:

a) the application and acceptance of IBM,
b) the entry of the Japanese companies, and
c) the membership of OSF and UNIX International.

The 21 members were:

Bull	AT&T	UI
ICL	Digital	Fujitsu
Siemens	Unisys	Hitachi
Olivetti	HP	NEC
Nixdorf	IBM	
Philips	NCR	
Nokia*	SUN	
	Prime	
	Apollo	
	OSF	

(*The Ericsson membership was transferred to Nokia Data on their acquisition of the relevent part of the Ericsson operation.)

These 21 companies represent most of the major IT companies in the world.

Since the peak of 21 the numeric measure has reduced through acquisitions within the membership. Apollo has become part of Hewlett-Packard, and Nixdorf has been acquired by Siemens. This does not represent a loss of actual support for the X/Open process as the organisations involved are still within the X/Open membership.

5 The X/Open Company Limited

ICL initiated the X/Open collaboration, and up to September 1987 provided most of the extra resources needed to administer the Group. By this time the growth (actual and projected) in scale and scope was such that it was no longer sensible to continue in this mode and a separate company was established to support the operation. This facilitated the growth of the central function to match the increasing requirements of the enlarged membership, allowed the scope to be widened to cover more than just application portability, and it re-enforced the independence needed for interaction with governments, major users and the software industry. The X/Open Company Limited was founded on 10th September 1987 with each of the Group Members becoming a Shareholder and having a seat on the Board of Directors.

The X/Open Company Limited has headquarters at Apex Plaza, Forbury Road, Reading, England, and additional offices in Connecticut, San Francisco and Tokyo. At the time of writing its staff level is about 40 people. It is headed by the President and CEO, and is divided into two main functions, Technical, concerned with the development and publication of the actual standards, and Marketing, concerned with user requirements and the adoption of the X/Open concepts and standards by the IT industry.

The creation of the separate company did not reduce the contribution of the individual members, who are still heavily involved through the Board and its sub-committees, the Technical Managers Group, the Marketing Managers Group and many Working Groups tackling specific topic areas. X/Open is a consensus organisation which means that all have the opportunity to determine the outcome, but once agreed everyone is committed. (The downside of course is that some agreements are difficult to achieve.)

The user requirements gathered by Marketing, are input to the Technical function which then establishes workprogrammes to determine the standards required for specific topic areas. Most work programmes are carried out by Work Groups which are staffed by experts from the member companies, by X/Open staff and by consultants. The Technical Managers Group, which consists of the X/Open Chief Technical Officer and a representative from each member company and each Associate Member Group, oversees the technical programme within an annual budget set by the Board. It determines technical strategy, establishes workprogrammes, acquires the necessary technical experts, and monitors progress against the plans. At any one time something like a dozen work programmes are likely to be active.

This represents a very significant investment from the member companies both financially and in availability of highly skilled staff, and illustrates a great commitment to X/Open and the development of Open Systems. In financial terms, the annual membership fee for shareholders is currently approximately £350K, and, if the contribution of the Associate Members and all the manpower provided by the members at Board, MM, TM and work group level is taken into account, then a total of around $20M per year is probably involved.

6 Councils and Associate Membership Groups

Although X/Open shareholders are primarily system vendors, the objective is to vigorously develop and promote Open Systems to the mutual advantage of Users, Independent Software Vendors (ISV's) and the systems suppliers. It was considered important therefore to ensure that the activity was really aligned with the requirements of the users and ISV's.

The first significant step in this direction was the creation of User and ISV Councils that would meet regularly and advise on the technical direction, major deficiencies and priorities for future X/Open work. They would also be able to influence the proposed standards in advance of publication. The User Council was initiated in 1988 composed of senior representatives of large commercial companies and government procurement agencies. At the same time, the ISV Council was created with membership from well known major software vendors.

During 1989 it was decided that this relationship, although very positive, was too much at arms length, and that a stronger one would be introduced providing a direct involvement in X/Open technical evolution in return for an active commitment from each member of the Councils to support the X/Open aims and objectives. Early in 1990 the Councils were therefore formally re-constituted as Associate Member Groups (AMG's), that could each provide a representative on the Board, the Technical and Marketing Managers Groups and the various working groups.

It was also decided to extend the AMG concept to cover other important groupings. The first of these, the System Vendor Council, has now been formed and gives a voice to the smaller system vendors who would find the cost of full membership prohibitive, or do not fully meet the acceptance criteria.

These Associate Membership Groups, and the XTRA process described below, are very important, as X/Open is often described as a "vendor club" in a context that implies a very closed situation and parochial interests. In fact with X/Open, the users, ISV's and smaller system vendors have a wide channel for requirements input and a direct mechanism for influencing the definitions and priorities throughout the process. The Shareholders do, of course, have a commercial interest, they would not otherwise invest so heavily in X/Open and Open Systems; but they expect to get their return from growing the market and competing in areas of much greater added value (for example industry specialisation and/or systems integration).

7 Worldwide Requirements Gathering (XTRA)

During 1988 it was decided to embark on an extensive market requirements gathering process to ensure that:

a) the requirements and priorities were fully understood,
b) came from a much wider net than that provided on an ongoing basis by the Councils, and
c) were obtained through a planned comprehensive process setting them all in proper context.

This project was called "XTRA", as it was a very significant extra X/Open activity for which the members considered it important to make an extra investment. The wisdom of the decision to initiate the XTRA process has been amply illustrated, as the results now provide a major input to X/Open strategic and annual planning, and are similarly used by other organisations such as Unix International and the Open Software Foundation.

The first cycle took place in 1989 (XTRA89) and consisted of:

i) a set of interviews with over 30 organisations in Europe, the USA and Japan,
ii) telephone market research by the Gallup organisation of 430 respondents in Europe and the USA (80% users from a broad range of industry sectors, 10% ISV's and 10% system vendors), and
iii) a three day requirements conference/workshop in Montreal, Canada, which brought together 104 senior representatives of user organisations, ISV's, government agencies and non-X/Open system vendors.

The results were integrated and analysed, and published to the world at large in a 224 page book called "The Open Systems Directive" – sub-title "Shaping the Future of Open Systems" (ISBN:1 872630 00 6).

Much was learnt from this first round, and it was decided to repeat the conference with a modified perspective in 1990 to validate and further fill out the findings, and thereafter to iterate on a two year cycle. At the time of writing the XTRA90 conference has taken place and the results are being analysed. They will be published later in the year.

8 Full Open Systems

The initial focus of X/Open was application portability, and this was considered to be complementary to ISO Open Systems Interconnection/Interworking (OSI), to which several other organisations were contributing. However it became clear when X/Open got into the areas of interfaces for interconnection, interworking and distributed systems that it was no longer sensible to be confined to application interfaces alone. It all needed pulling together; there was a need to consider more than just OSI because of the systems integration requirements to connect to existing major environments (PC's and Mainframes, Internet and SNA) and there were many more aspects needing attention such as user interface (user portability), data interchange (data portability), systems management, security and Internationalisation. It also became clear that the IT industry was wanting X/Open to be concerned with Open Systems in general.

The X/Open mission was therefore widened to be:

> "To bring greater value to users of Information Technology through the practical application of Open Systems".

X/Open is therefore about a total Open Systems architecture and set of standards, and the promotion of the adoption of Open Systems by users, ISV's and the IT industry at large.

9 Relationship to Standards bodies, other consortia and owners of de facto technology

The X/Open process involves assessing user requirements and priorities, and assembling an architecture and set of standards that will ensure that open systems can be provided that will meet these requirements. The best and most reliable source of standards is the International Standards Organisation (ISO), as these standards have firm international agreement and recognition, and are the most stable. If ISO standards existed, and were complete, in all the required areas then there would be no need to look elsewhere, and the process would be relatively simple. The total picture, however, covers aspects ranging from areas where the technology is very mature and ISO standards have long existed, right through to areas of recent innovation where no standards yet exist. It is therefore necessary to acquire "standards" from many other sources.

The other sources include the feeder bodies to ISO (eg. the national standards organisations, like ANSI), and those well recognised for standards development, such as IEEE and ECMA. If no standard is imminent from these formal bodies then a de facto standard is likely to form the basis of the X/Open definition (probably after tightening up and/or subsetting). Finally if nothing exists then X/Open may do work towards encouraging the production of a "standard".

Even long established standards from bodies such as ISO and ANSI may not be complete for today's requirements, or may have several optional or implementor defined aspects, so X/Open attempts to fill the gaps and select the options. For example the COBOL 1985 standard does not include facilities for communicating with the on-line user at a terminal or workstation, but most of todays applications work in this interactive mode. This leaves a big portability hole if all systems provide different mechanisms to satisfy this requirement, so X/Open adds to the standard to fill the gap.

In specific topic areas, other consortia may exist, or be created, with intent to define interfaces and/or protocols, and could potentially come into conflict with X/Open, and cause a fragmentation in open systems development. However X/Open is about uniting the many players in open systems, and also its own resources are limited. The policy therefore is to work with such other groupings to encourage the work to fit into the X/Open concepts, to leverage the output, and to provide the other body with a ready made publication channel. During the last two years collaborations have been established with the SQL Access Group, the X.400 API Association and the Object Management Group.

Where X/Open adopts a de facto standard, a condition is that the owner of the technology makes an agreement that the interface as published by X/Open is generally available such that competing products can be produced that satisfy the interface. Arrangements are also made that future updates will be made available to X/Open, without any commitment that they must be incorporated, and that X/Open can separately enhance the interface. These conditions make it an open definition (ie. free from single vendor control).

Sometimes X/Open is referred to in articles as "another body working on standards", for example in an article discussing the IEEE POSIX work. This can give the mistaken impression that there is a competition and fragmentation in Open Systems standards. X/Open is not setting out to be in competition with other groups; on the contrary it is attempting to pull all together, to fill the gaps, to speed up the process and to encourage progress towards full International Standards.

10 The Open Software Foundation and Unix International

The Open Software Foundation (OSF) was formed in May 1988, sponsored by several major companies including IBM, Digital and HP, with the objective of providing an alternative source of the basic operating system technology to that provided by AT&T with the UNIX Operating System. Many companies became members of OSF, but many others, including ICL, came together to form UNIX International (UI) to promote and support the continued development of UNIX by the UNIX Software Operation (USO) of AT&T. Much has been written on this industry split, and the attempts at reconciliation, and it is not proposed to discuss it again here, but only to address the implications for, and effect on, X/Open.

OSF, and UI/USO, represented two major competing sources of base operating system technology, each with a very large backing of companies that would build the technology into their own products, which would then be sold in volume. The competition so created was potentially good in that it would tend to speed up progress and drive down prices. On the other hand the large volume of products deriving from each of the two sources was likely to lead to the emergence of equally viable alternative de facto standards. It therefore provided a big potential for a major split in the open systems movement, and a threat to the objectives of X/Open.

The membership of X/Open, being equally divided between the two camps, was faced with a dilemma. Individually each member had an allegiance to one of the competing parties, but at the same time was dedicated to X/Open and the need for a single set of standards. It was therefore important to attempt to ensure that divergences were kept to a minimum and confined to areas of significant added value, that both parties were knowledgable of and in tune with what X/Open was attempting to do, and that this was all in line with what the customers (users and ISV's) really wanted. It was also realised that, although this was a particularly acute case, many of the issues would also be present when any two (or more) competing technology suppliers were involved (eg. database vendors).

X/Open, and the XTRA requirements gathering process (see section 7), did however have the potential of playing a key role in ensuring that user requirements for open systems standards were really known and understood. With X/Open, OSF and UI/USO all working to a common requirements base it would be possible for all parties to work co-operatively during development of their respective new technologies and the potential new interface standards associated with them.

In the event the results from the XTRA process were adopted by both organisations, and big steps forward have been made with respect to the standards development phase in that both OSF and UI have made a strong commitment to conformance to X/Open standards. They have demonstrated this in practice, and both have become full X/Open shareholders and are involved in the various committees and working groups. However difficulties do occur where the parties have made significant investments in differing competing technologies covering the same user requirement, as for example is the case for the Graphical User Interface. Consensus agreement in these circumstances is not easy.

[Note that AT&T USO has recently changed its name to UNIX System Laboratories, Inc. (USL).]

11 Branding and Verification

One of the characteristics of the Open Systems world is the large number of consortia to which a particular supplier can belong, and the many standards to which different types of conformance can be claimed, all of which are used in publicity material regarding the sale of products. This is all very confusing to the would be purchaser, partly because there are so many of them, and partly because in practice the memberships and conformance statements have very different actual values although often presented as though equivalent. For example some are associated with very thorough independent conformance testing of products, and thus are of high value, whereas others just mean the subscription to the consortium has been paid, or that conformance is to a general model not to detailed standards.

It was decided therefore to make X/Open the umbrella organisation covering all aspects of open systems, and that there should be an extremely high value conformance claim mechanism, giving purchasers of X/Open systems a high confidence level in the quality of the implementation of the standards.

As described earlier, development of a comprehensive verification suite was started during the first three years, and it has continued to be enhanced to match the evolving Portability Guide. The suite covers the basic operating system, the C language, and many areas (egs. ISAM, XTI) not covered by an already recognised formal test suites. Where there are already well established formal tests, for example the NIST tests for high level language compilers, X/Open incorporates them into its verification procedures.

Tests alone are not satisfactory without some way of ensuring that they really have been applied to a product, under controlled and repeatable conditions; and, as no test is ever fully complete, there must be a mechanism to ensure that faults discovered in the field are corrected in a timely fashion. An X/Open "Branding" system was therefore introduced which allows a special form of the X/Open trademark to be associated with products that meet these stringent conditions. To use this trademark in conjunction with a product, the supplier must sign a Trademark Licence Agreement (TLA), renewed annually, through which it is warranted that the product meets the X/Open definition, the specified verification tests have been run by an authorised test centre, and that faults subsequently discovered will be corrected. If the licensee subsequently fails to meet the requirements of the licence then the right to use the trademark is withdrawn.

The branding scheme was first introduced in association with XPG2, and the conditions significantly tightened for the XPG3 version, which was launched in June 1990. There are two principle types of branding, "Component" and "Profile". Each functional component identified in the Portability Guide can be separately branded and marketed as an X/Open "branded component". Examples of functional components are Systems Interfaces, Commands, COBOL, and SQL. Defined sets of branded components can then be further collectively branded as a profile. For XPG3, two profiles have been defined, "Base" and "Plus". To obtain Base branding a system must have the Systems Interfaces, the Commands and the C language branded as components. For Plus branding the majority of the XPG3 components must have been branded. All branding is with reference to a particular hardware environment; the same software component in a different hardware environment has to be separately verified and branded.

To date branding has been related entirely to application portability, but it is now necessary to address the branding implications of interconnection and interworking. Although branding is a simple concept, the practical details necessary to ensure the integrity of the trademark as an assurance of quality in all situations are complex. The added dimension of interworking systems is going to need careful attention.

It is ICL policy to obtain X/Open branding for all relevent strategic products.

12 Product Management

A major facet of the X/Open concept is Product Management which ensures that all X/Open systems are at well defined levels, and progress forward in step. It has been implied in the above sections, but it is important to recognise it explicitly.

X/Open definitions are based on a collection of standards (de jure and de facto) which individually are produced by many different organisations with no co-ordination between them. For example the issue of the definition (or update) of a high level language standard from ISO, or ANSI, bears no timing relationship with that for SQL or POSIX. If X/Open just referred to a list of standards that was implicitly updated immediately one of the components changed, then the situation for a procurer would be confusing as each supplier would have to be queried about the level of each component in a particular system. Instead, each XPG level refers to a fixed situation with respect to all the components, thus guaranteeing the same definition of facilities on any XPGn system independent of the supplier. Similarly there is a well defined increment in moving forward to the next product level (eg. from XPG3 to XPG4).

The verification suite increments in these same well defined steps, as it supports the branding quality mark at a particular XPG level. This all means that an XPG level number (eg. XPG3) can be considered to identify a particular X/Open product, which consists of that issue of the Portability Guide together with the corresponding version of the Verification Suite, Branding Procedures and all associated supporting documentation.

Another facet of Product Management is that X/Open will attempt to make the various components of a particular level consistent with one another to aid systems integration. For example if the base is changed to be POSIX conformant, as it was in XPG3, attempts will be made to ensure other components match this.

Over the last year it has been decided to make explicit the difference between release of the definitions for use by product development teams, and the time when they can be used as a Procurement Standard. Up to the release of XPG3 there was no distinction; the Portability Guide was issued although there could not at that time be conformant systems, and sometime later it was assumed that users would procure against it. The June 1990 launch of the XPG3 Branding Scheme, and the announcement of several actual branded system and components, marked the point at which procurement is appropriate, and it is expected that most, if not all, procurements will now specify XPG3. In future (beyond XPG3) the release of "Developers Specifications", which will occur as soon as they are ready, will be separate from the launch of an XPGn. The product launch will group together a number of Developers Specifications into the release, launch the associated verification and branding process, and call for procurements at that level with immediate effect.

It has been decided to have two categories of specifications for development purposes – full "Developers Specifications" and "Preliminary Specifications". The latter are for situations for which there is as yet no working code that has proven the interface to be sound in practice; they will not form part of a branding release until they have been upgraded to full Developers Specifications.

13 Major Procurement Policies

The X/Open concept has from the outset received staunch support from government procurement agencies, in particular in Europe, and indeed they have been very prominent participants in the User Council. Governments have a need to procure from multiple sources, but do not wish to suffer the severe incompatibility problems arising from the use of proprietary systems. However their regulations often made it difficult to refer to a set of standards produced by a group of vendors, and which also included de facto standards, instead of just referring directly to the de jure standards that existed. This is now changing and strong statements regarding use of X/Open in procurement have been published in many areas (particularly Europe, including the UK).

Actual major procurements statements calling for X/Open (XPG3) have been made by specific large government ministries in Germany, Italy and Spain, and by several large Fortune 200 commercial organisations both in the US and in Europe.

14 The next Product – "XPG4"

A great deal of technical standards work has now taken place towards the next Product. At procurement and branding release this product will be collectively known as XPG4, but, as described in the previous section, the individual Development Specifications will be released when they are ready, to allow product planning and development to commence. The first batch is just being released (August 1990). The following is an indication of the scope of the activity and the likely additional components and enhancements. As will be apparent a major thrust is in the area of interconnection and interworking.

Operating System Interfaces and Commands:

A large amount of effort has gone into alignment with POSIX work on Commands (P1003.2 and /.2a), and the updates and enhancements of the System Interfaces (P1003.1a, /.1b and /.4).

Internationalisation activity has been concentrating on the support of Eastern Languages and cultural differences, and of multi-byte codesets in general.

The security group has been working on an auditing interface.

Languages:

The C Language definition is being aligned with the ISO (ANSI) definition.

The COBOL group have been working on Internationalisation, both single and multi-byte codeset support, and it is likely that at least the former will soon be published.

Data Management:

Dynamic embedded SQL has been added, and Distributed SQL is being tackled in collaboration with the SQL Access Group.

Window Management/Human Computer Interface:

Work on the X-Windows Xt_Intrinsics, the X_Protocol and Inter-Client Communication Protocol (ICCM) has been completed, and the XLIB interface has been brought up to the X-Windows Release 4 level.

There has been much activity on the toolkit level, both API and Look and Feel, but a concensus definition has not yet been achieved.

PC Interconnection:

Specifications for connecting an X/Open System as a server to a PC network using SMB protocols, and for connecting PC's into an NFS system have been developed.

Mainframe Interconnection:

A specification of an interface, based on the IBM CPI-C definition, for connection to IBM, and IBM compatible, mainframes has been produced.

Networking:

Byte Stream File Transfer based on ISO/OSI FTAM.

An Application Program Interface to X.400 mail based on collaborative work with the X.400 API Association (X.400 APIA taking lead role).

An Application Program Interface to an X.500 Directory Service based on collaborative work with the X.400 APIA (X/Open taking lead role).

Transaction Processing:

X/Open published a "White Paper" on a proposed TP model towards the end of 1987; and a further Snapshot in 1989 which significantly enhanced the model as a result of comments received and much additional work. This model provides for components from different software vendors to come together on a network of computer systems such that they form a single co-ordinated distributed transaction processing system. Since then work has gone into developing the detailed interfaces necessary for making it a reality. Particular cases are (a) the interface between the Resource Managers that have to be co-ordinated (eg databases) and the Transaction

Manager(s) that has to co-ordinate commitment and recovery, and (b) the interface between the application and the Transaction Manager.

As stated earlier this is not a complete list. Very significant work is going on in other areas such as Data Interchange, including ODA, and Systems Management, and some of this may reach fruition in the timeframe of the next XPG Product.

15 The Future

Predicting the future in this fast moving open systems area is not easy, as there are many players and influences, and a rapidly changing technology base. Many of the changes that have taken place over the last three years, could not have been predicted, in particular the formation of the two major competing base technology organisations OSF and UI/USL. What is certain is that the big growth in open systems will continue, and will accelerate. User demand is increasing rapidly, and is now even starting to grow in the mainframe area.

A big issue will be the tension between standardisation, the foundation of Open Systems, and innovation and added value, which are essential for healthy competition and technological progress. This represents a significant challenge for X/Open as it is important that differences really are confined to innovation that delivers high value to users, rather than being in areas of low value that ought to be standardised. Also today's area of innovation is tomorrow's for standardisation.

The rapid growth in X/Open membership is now probably at an end, as most of the major System Vendors are already participating. Additional Associate Members and Groups can be anticipated, but this seems likely to be counterbalanced by mergers and acquisitions within the existing membership.

There will now be an explosive growth in the number of conformant X/Open systems in the market. UNIX System V.4, which forms the basis of the open system products from a large percentage of the system vendors, is XPG3 conformant; and OSF/1 is committed to follow suit. About half of the X/Open members have already branded systems at XPG3 level, including ICL with UNIX System V.4, IBM with AIX and Digital with Ultrix, and most of the rest have committed to do so by the end of the year. The resulting high volume of XPG3 systems will further encourage the ISV's to produce conformant applications and users to increase the demand for X/Open systems in procurement specifications. The virtuous circle created by this positive feedback will really be underway.

For conformance and branding, the increasing size and scope of the Common Application Environment is such that the simple breakdown into Base, Component and Plus is no longer tenable, so consideration is being given to profiles more related to usage, or possibly even to specific industry. The big move into aspects of open systems other than application portability, in particular interworking, adds a further dimension which has to be taken into account in these profile and branding deliberations.

With respect to increasing the coverage of the X/Open environment, the XTRA User requirements gathering process has put high priority on the Human Computer Interface, Interworking (including heterogeneous systems) and Systems Management, so there will be a high focus on these aspects. There will also be completion of the Transaction Processing work, and all these topics call for data interchange standards.

16 Conclusion

In 1987 an extremely healthy outlook for X/Open was predicted. This was borne out in practice over the following three years with the:

- recruitment of most of the major IT companies,
- extension of membership to three continents,
- formation of the X/Open Company Limited
- creation of the Associate Membership Groups,
- XTRA requirements gathering process,
- membership of OSF and UI
- publication of XPG3,
- comprehensive branding programme,
- major commercial and government procurement requirements, and
- the large volume of work towards "XPG4".

XPG3 systems are now being marketed by many companies. This will soon lead to a high field population, and a positive feedback effect through greater availability of applications and increased user demand.

The rapid growth in X/Open shareholder membership has stopped, as most of the large system vendors are already on board, but a significant growth in Associate Membership, and the formation of additional AMG's, can be expected.

An uncertainty is the degree to which fragmentation can be avoided, as more and more work is in areas that are perceived as having added-value potential. The problems of many interacting standards bodies and consortia, and the more complex technical issues now being tackled all significantly increase the X/Open challenge.

There is now much user pressure for open solutions across the full range of system types; and the more they are delivered, the more this will increase.

Users will not be satisfied until Open Systems do everything that proprietary systems do today (and more).

There is a great deal for X/Open to tackle over the next three years.

Trademarks

UNIX is a trademark of AT&T in the USA and other countries.
X/Open is a trademark of the X/Open Company Ltd.
AIX is a trademark of IBM.
ULTRIX is a trademark of Digital Equipment Corporation.
OSF/1 is a trademark of the Open Software Foundation.
The X Windows System is a trademark of M.I.T.

Reference

TAYLOR, C.B.: *The X/OPEN group and the common application environment.* ICL. Tech. J. Vol 5 No 4 pp 665–679 1987.

Appendix A

This appendix lists the members of the X/Open User Council as at end August 1990:

User Council Chairman:
Walter de Backer, Director of Informatics, Commission of European Communities.

User Council Members:
Amoco Corporation (US)
Arco Oil & Gas Company (US)
Automobile Association (UK)
Bellcore (US)
Boeing (US)
British Telecom (UK)
Central Computer & Telecommunications Agency (CCTA) (UK)
Commission of the European Communities (CEC) (Europe)
Daimler-Benz AG (West Germany)
DHL International (US)
DuPont (US)
Eastman-Kodak Co. (US)
Elf Aquitaine (France)
Ericsson (Sweden)
Exxon Production Research (US)
Ford Motor Company (US)
Gerling Konzern (West Germany)
Harris Corporation (US)
Landesamt fur Datenverabeitung und Statistik (West Germany)
McDonnell-Douglas Corporation (US)
National Institute of Standards and Technology (NIST) (US)
Shell International Petroleum (The Netherlands)
Statskontoret (Sweden)
Swedish Post (Sweden)
Swedish Telecom (Sweden)
Telefonica (Spain)

Union Bank of Switzerland (Switzerland)
US Department of Agriculture (US)
US Treasury

Appendix B

This appendix lists the members of the ISV Council as at end August 1990:

ISV Council Chairman:
Roger Sippl, Chairman, Informix Software.

ISV Council members:
ASCII Corporation (Japan)
Informix Software (US)
Ingres Corporation (US)
Interactive Systems Corporation (US)
Liant Software Corporation (US)
Micro Focus (UK)
Microsoft Corporation (US)
Netwise International (US)
Novell Inc. (US)
Oracle Corporation (US)
Progress Software (US)
Quadratron (US)
Retix Corporation (US)
Santa Cruz Operation (US)
Softlab Gmbh (West Germany)
Sybase (US)
Tecsiel- IRI Finsiel (Italy)
Tietotehdas Group (Finland)
Unify Corporation (US)
Uniplex inc. (UK)

Architectures of Database Machines

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Abstract

Research on database machines has been very active at all times since the '70s; however, only a small number of machines have been converted to commercial products from their research prototypes. In this paper, the architectures of a number of commercial and research database machines are described. Due to the rate of advance in software and hardware technologies, some people believe that database machines are not cost effective. This belief is disputed: from the success of some commercial database machines, it is argued that a database machine is useful, especially to high-end database users who work on very large databases containing over giga-bytes of information. Furthermore, from the study on commercial machines, factors influencing the acceptance of a database machine are identified. Architectures of research database machines are also important. They can influence the design of future machines. From the review on research prototypes, the trends in database machine architecture are outlined.

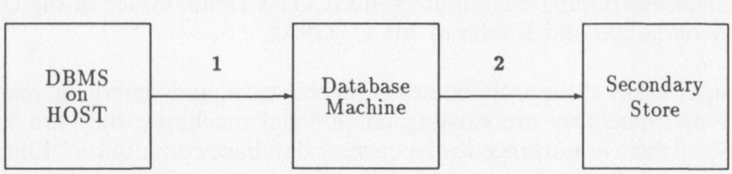
1 Introduction

The increasing complexity of Data Base Management Systems (DBMSs) and the growing size of modern database applications render conventional von-Neumann processors inefficient for supporting them. This inefficiency is mainly caused by a technology mismatch between the DBMS software and the underlying hardware:

- *Computational gap*. Von-Neumann computers were designed primarily for numerical processing. They are inefficient in performing non-numerical operations such as database join, select, project, update, etc. This predicament gets worse as the database size increases. Also, conventional processors support various address modes e.g. index, direct, etc. Although, these addressing modes are efficient for referencing arrays and simple data structures, they are unsuitable for accessing database records. The latter are frequently addressed by content i.e. a specific set of attributes.

- *Semantic gap.* One of the advantages of DBMS is the notion of data transparency. Under this notion, database users are unaware of the physical storage mechanisms of the database. This may require the maintenance of several auxiliary files e.g. secondary index files, inverted index files, etc. The user view of a database is very simple – a database appears as a set of well defined data records, e.g. tuples in the relational model. The mapping from a user's logical view to its physical representation generally involves a series of address translations. This mapping is time consuming and is not efficiently supported by the underlying von Neumann processor.
- *I/O and buffering bottlenecks.* A database is usually kept in centralised secondary storage, discs, shared by a number of users. Database operations are not executed directly at the secondary store. Parts of a database are read from the secondary store and buffered in some intermediate stage memory. The DBMS then operates on the buffered data. The limited size of the stage memory forces paging to take place frequently when dealing with large databases – *buffering bottleneck.* Common operating system techniques for maintaining program/data locality during buffering are not suitable for database applications. Moreover, the load on the secondary storage device increases linearly with the number of users. The rate at which data can be transferred from the secondary storage device is very limited. It is generally much slower than the data request rate of the DBMS. This limitation is referred to as the *I/O Bottleneck* and can seriously affect database performance.

To improve DBMS performance, many special purpose database machines have been proposed [28]. These database machines are designed to overcome the problem of technology mismatch. The design of a database machine involves migrating the DBMS functions from the host to the machine in an effective way (see fig. 1). In doing so, the load on the host is reduced and the DBMS functions can be more efficiently executed on the specialised database machine; hence, the computational and semantic gaps are narrowed. In practice, the extent to which the load of a DBMS is shared varies between different database machines. In a basic database operation, a conventional DBMS accepts a user query, parses it, decomposes and converts it into a database operation tree, accesses the data files on the secondary storage devices and performs the required operations. In an ideal database machine environment, the host handles the user interface, accepting queries



1 *Move DBMS functions to Database Machine*

2 *Move the logics of Database Machine closer to the Secondary Store.*

Fig. 1 Principles of database machine design and handling results, and the database machine caters for the processing of the query. Another principle in database machine design is to move the logic of the database machine physically close to the secondary storage device. This action can be regarded as moving DBMS functions to the data rather than moving data to the functions as in a pure software DBMS environment. This reduces the amount of data returned to the host and effectively, minimises the I/O and buffering bottlenecks. According to how they are integrated into a computer system, database machines can be classified as:-

- *Filters*. These are devices which are attached between secondary and main memory and function at the *operation level* – they accept and execute database operations, e.g. *select*, issued by the host. Generally, filters are 'slave' devices; they are programmed by the host before an operation is initiated. They perform the required operations on the data as data streams from the secondary storage devices to main memory. In order to achieve real time (or 'on-the-fly') performance, only simple database operations are supported. An example of a database filter is ICL CAFS.
- *Database Accelerators*. These are coprocessors which are tightly integrated with the host. They are specially designed to expedite database operations. Similarly to database filters, database accelerators function at the *operation level* and are 'slave' devices. The difference between the two lies on the location of data processing: filters process the data while it is being transferred from the disc and accelerators assume the data to be in main memory. An example of a database accelerator is Hitachi IDP.
- *Backend Database Machines*. These are dedicated machines which function at query level – they accept and execute a database operation tree which is generated by the host upon receiving a user query. These machines achieve *intra-query parallelism* by executing the database operations in parallel. Examples of backend database machines are the Teradata DBC/1012 and the Gamma database machine of the University of Wisconsin.
- *Dedicated Database Computers*. These are standalone computers with a full DBMS capability and function at the *transaction level* – they accept and execute database transactions (a series of queries). These machines are the most complex and achieve *inter-query parallelism*. Examples of standalone database computers are ICOT's Delta, Grace of the University of Tokyo and Bubba of MCC (USA).

This paper looks at the architecture of several 'now' and 'emerging' machines [15]. 'Now' machines are existing commercial machines; they are studied because of their importance to the current database community. 'Emerging' machines are forthcoming machines existing as prototypes in research laboratories; they are studied because the philosophy behind their designs will influence the architecture of future database machines. The main intention of studying the various 'now' and 'emerging' database machines is to find out the trends in database machine architecture and to identify factors which need to be taken into account when designing a practical database computer.

The paper is structured as follows: the architectures of a number of successful commercial machines are described in section two. The states of these machines are reported and the factors which will affect the acceptance of a database machine are identified in section three. Section four reviews some research projects on database machines. From the architecture of the research and commercial database machines, trends in database machine architecture are outlined in section five. Section six – Conclusions – is a summary of the paper.

2 'Now' Machines

2.1 ICL CAFS

CAFS is a filter-oriented database machine developed by ICL (UK) [4, 13, 18, 19]. It is an optional processing unit which attaches to an ICL disc system (e.g. FDS300) in a 'piggy-back' fashion. The CAFS system is used in both formatted and unformatted applications on ICL 29 or 39 series mainframes. The architecture of the basic CAFS is depicted in fig. 2. CAFS consists of the following functional parts:

1 The Data Multiplexing Unit (DMU) is a programmable switch. Depending on the setting of the switch, disc resident data may either stream to the host directly or be processed by the CAFS search engine before reaching the host.
2 The CAFS search engine is the heart of CAFS. It compares disc resident data with some pre-programmed values. Internally, it consists of the following sub-units:
   - *Logical Format Unit (LFU)*. This unit generates the timing control signals which mark the separate fields in a record (or relational tuple). These signals are used to control the operating sequence of the other units.
   - *Key Channel (KC)*. The Key Channel is divided into 16 functional blocks. Each block consists of a 256 byte RAM and a comparator. The RAM contains a specific field which is compared with the input data at the comparator. The comparator compares the content of the RAM with the incoming data a byte at a time; it tests if the two are equal (=), less than (<) and/or greater than (>). Using the comparator, other tests can be achieved, i.e. the positive (e.g. $\geq$) and negative (e.g. $\neq$) combinations of the three basic comparisons. The output from the Key Channel is a 16 bit word derived from the results of the 16 comparators.
   - *Search Evaluation Unit (SEU)*. The function of the Search Evaluation Unit is to monitor the 16-bit word from the Key Channel and test if it contains the desired bit pattern. The result is another 16-bit

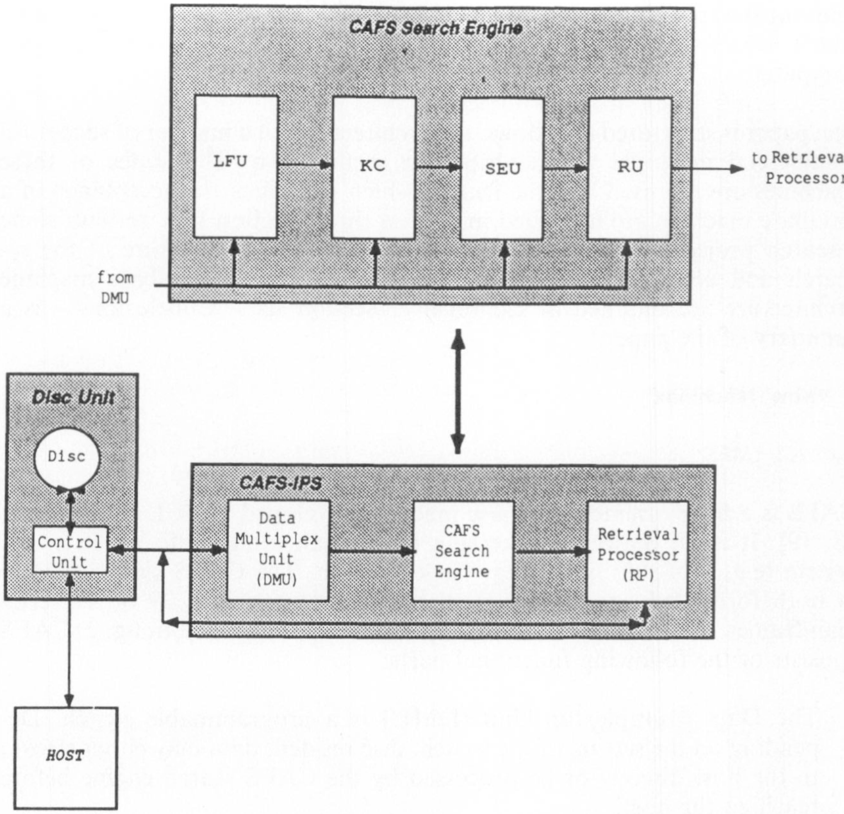


Fig. 2 The architecture of the ICL CAFS

word. If the first bit (b_0) of the output word is set, the corresponding record is a hit.

- *Retrieval Unit (RU)*. Driven by the LFU, the RU informs the Retrieval Processor (RP) which fields of a record should be retained. It also monitors the result of the SEU and informs the RP to overwrite the current entry of the retrieval buffer if the result of the comparison is negative.

3 While a record is being compared, a copy of it is buffered in the Retrieval Processor (RP). This buffer location is overwritten if the test bit from the Retrieval Unit is negative; otherwise the record is stored. Also, the Retrieval Processor is programmable to perform aggregate functions at the end searching a block of data.

During a CAFS session, a user query is translated into a CAFS Control Block. A control block contains the parameter settings and the microprograms of the various internal units.

The design of CAFS started in the mid 70s. Through the years, many additional features have been introduced. The implementation of hashed join using a set of hash coding hardware and a set of bit arrays was introduced by Babb [3, 4]. Babb's bit array expedites join operations which are performed by the Retrieval Unit in the basic CAFS.

A novel hashed join algorithm is achieved using the Babb bit array. During a join operation, the source relation is initially read. The join attributes of every tuple are hashed and are used as addresses to the bit array. If a bit is addressed, it is automatically set. After the source relations are completely read, the target relation is read. The join attributes of every target tuple are hashed as before and used as addresses to the bit array. If an addressed bit is set, the target tuple is retained. CAFS only supports *implicit (semi-) join* – the result of the join is contributed by the target relation alone (on the other hand, in *natural* join, both source and target relations form the result relation). In general, the complexity of hashed join is proportional to the sum of the size of the source, target and result relations (i.e. Join Complexity $= O(C_s + C_t + C_r)$), where C with subscripts s, t and r correspond to the cardinalities of the source, target and result relations.) In CAFS, the result tuple is pre-stored at the Retrieval Unit, therefore the complexity is reduced to $O(C_s + C_t)$.

The bit array is also used for *projection*. During the operation, the source relation is read through CAFS. The projection attribute of a tuple is hashed and used to address the bit array as in the join operation. The corresponding bit position is set if it has not been done; otherwise, if the bit is already set, that means this record is a duplicate and will be discarded. This technique is fast and requires only one scan of the source relation.

Both the join and projection operations are efficient in terms of speed. However, because of the non-unique hashed values generated by the hash coding hardware, the techniques are error-prone. In the case of joins, 'false drops' (or 'ghosts') are generated at each read. The error propagates into target relations; thus the effect amplifies for higher order joins (i.e. m-way join). For projection, the damage is worse and, is some cases, it is unacceptable. The imperfect hashing can lead to loss of data.

Currently, new development proposals have been suggested for the next generation of CAFS. One such proposal is the implementation of a CMOS VLSI CAFS. The existing CAFS, which attaches to a FDS300 disc system, consists of over 10 PCBs and the power consumption is very high. The objectives of the CLSI CAFS are to tackle these problems. Another proposal is to interface CAFS to other ICL computers, such as the DRS series workstations. (A prototype has been implemented for the DRS300 [6].) Most recently, ICL has announced CAFS for its new UNIX machines [1].

2.2 Hitachi IDP

The Integrated Database Processor (IDP) is a SIMD processor designed for database applications [17]. It is a commercial product launched in 1986 by Hitachi. It is sold as an optional processing unit integrated with the Hitachi M680H high performance large scale general purpose computer. The IDP is a database accelerator. It is a purely passive device under the control of the host processor. Query interpretation is performed by the host and the IDP carries out only the execution of the database operation commands set up by the host.

Database operations are executed in pipelines and are based on a technique known as *dynamic vectorisation.* Using this technique, database files on discs, which are logically viewed as tables (or row-major format), are dynamically converted to a set of vectors (or column-major format) at run time. Vectorisation is not a compulsory operation. When a query is entered to the host, it is passed to a query analyser. Depending on the nature of the query, the latter decides whether the database should be processed in 'row-wise' or 'column-wise' fashion. If 'row-wise' processing is selected, the database will be processed by the host using a scalar processor. Otherwise, column vectors are generated and collectively processed by the IDP. 'Row-wise' processing is advantageous for tuple-based queries where database tuples are processed one at a time. On the other hand, for set-based queries where sets of tuples are processed under certain attributes, 'column-wise' processing is more efficient. The query analyser is intelligent enough to work out the optimum processing mode.

The configuration of the IDP/Host system is shown in fig. 3. The Host machine is a Hitachi M-680H. The IAP, Integrated Array Processor, is another optional processor which is used for conventional vector operations (e.g. Vector Element Increment). The IDP utilises the IAP functionality; therefore, the existence of the IAP is a prerequisite to the installation of the IDP. The host system is responsible for all scalar operations, including query analysis and all 'row-wise' operations. After query analysis, if the host decides that a query is best executed 'column-wise', the vector processing software will be invoked. This software initiates a data transfer from the discs and dynamically vectorises the data and stores it as column vectors in the main storage. The operations of both the IAP and the IDP are controlled by the microprograms in the control storage on the host.

Internally, the IDP adopts a pipeline architecture. It consists of a 6-stage pipeline; execution in each pipeline stage can be completed within 1 machine cycle. The IDP appears as a single board system containing 72 ECL LSI components. The IDP hardware is relatively small compared to the M-680H hardware – the former is approximately 5% of the size of the latter. The IDP supports a proprietary set of instructions. These instructions can be used in different database operations as shown in table 1. The execution details of these instructions are described in [17].

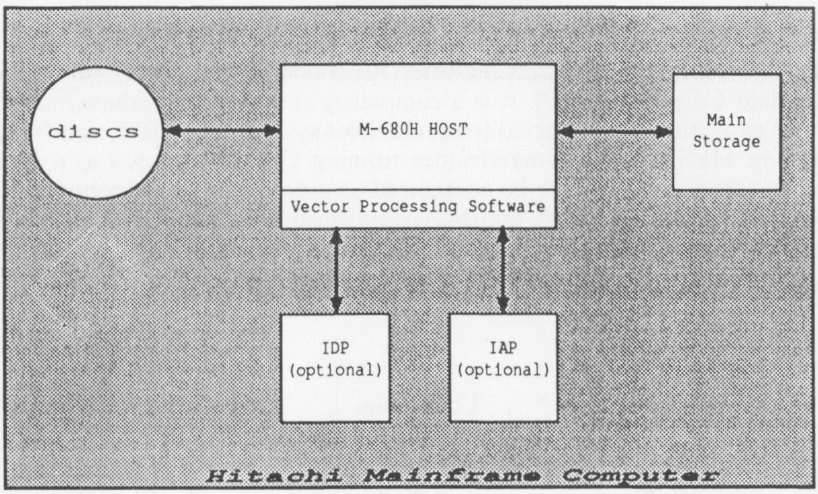


Fig. 3 The Hitachi IDP/Host configuration

Table 1 The IDP instructions and their corresponding database operations.

Instructions	Database operations
SORT	set-union, merge-sort
JOIN	set-product, merge-join
DIFFERENCE	set-difference
SEARCH	restriction, selection, aggregation, duplicate removal

Evaluation of the IDP shows that running a hardware sort using the processor is approximately 10 times faster than the fastest software sort programs based on $O(n\log_2 n)$ sort algorithms. Also, comparing joins using the IDP and conventional software join based on 'row-wise' processing, the former is 15 times faster. However, for performing light-weight operations such as indexed searching, there is no difference in performance between the IDP and software. This is because the vector length (i.e. the index size) is too short for the vector processing of the IDP to be effective.

The idea of dynamic vectorisation is good, providing it can be used efficiently. The result shown for the join operation is promising [17] and cannot be achieved by any software algorithm running on a conventional sequential processor. Also, the IDP hardware speeds up *sort* and *merge* which are frequent processes in database applications. The machine requires a fair amount of working space. In the machine proposed in [17], the M-680H/IDP configuration consists of a 256K byte cache, 1M bytes of working space and 256M bytes of main storage. This amount of memory is necessary to hold the vector tables and intermediate results.

The DBC/1012 (Data Base Computer/1012) is a commercial product from Teradata Corporation [29]. It is a completely standalone database machine which can either be connected to several host systems (e.g. IBM mainframes running MVS, UNISYS mainframes running OS1100, ... etc.) as a back-end database computer or be configured as a database server connected to a number of workstations and PCs via a local area network (LAN). The DBC/1012 is designed to support relational database applications in a shared information environment. The shared information architecture of the DBC/1012 is depicted in fig. 4.

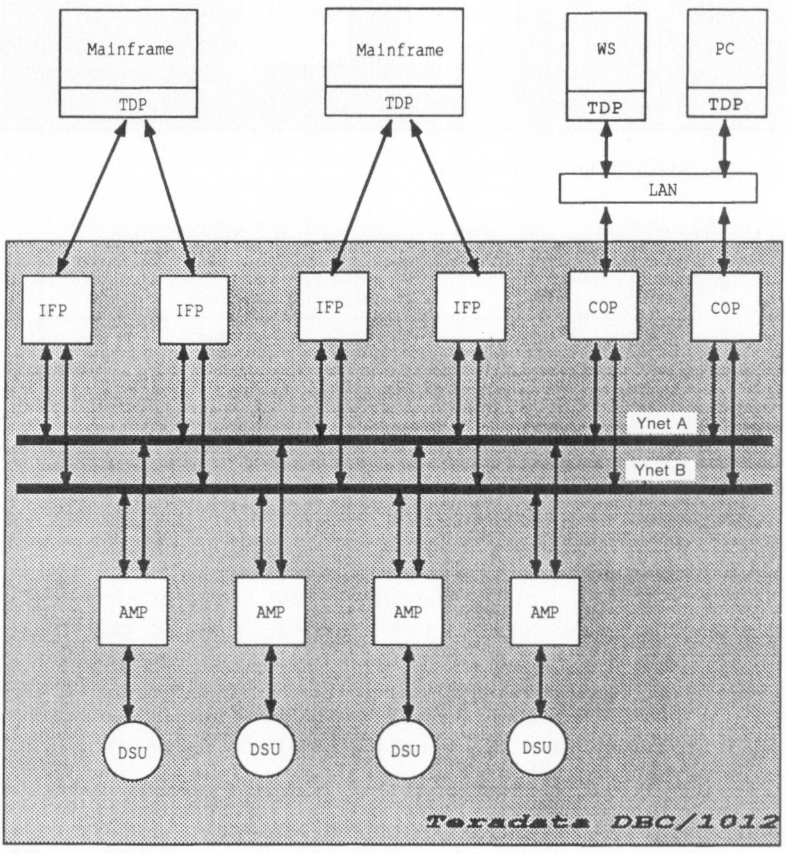


Fig. 4 The shared information architecture of Teradata DBC/1012

1 *Interface Processor (IFP.* The role of the IFPs is to manage the I/O communication between mainframe front-ends and the DBC/1012. Each IFP is composed of a channel interface controller, a CPU, some memory and two Y-net interfaces – DBC/1012 internal bus interface (see later).

A minimum of two IFPs are connected to each mainframe for supporting 'fail-safe' – fault-tolerant – operations.

2 *Communication Processor (COP)*. The role of the COP is to manage the I/O communication between the workstations or PCs on a LAN with the DBC/1012. Each COP incorporates a LAN interface controller, a CPU, some memory and two Y-net interfaces. At least one COP is required per network. The COP network interface supports various communication protocols, including TCP/IP, ISO/OSI, XNS and SNA.

3 *Access Modules Processor (AMP)*. The AMPs execute relational database primitives (join, project and select), access the appropriate discs and prepare results during a user query. An AMP is connected to up to 4 Disc Storage Units (DSUs), see later. When database tuples (or records) are stored, they are horizontally distributed across all DSUs in the system – forming buckets of data. Under this arrangement, each AMP/DSU pair can operate on its associated DSU simultaneously with the others. For improved performance, an optional 2M-byte non-volatile disc cache can be added to the basic AMP configuration.

4 *Disc Storage Unit (DSU)*. The DSUs are standard large volume Winchester discs. Each contains buckets of relational database tuples and also certain system work files, e.g. spooling information. Optionally, part of the DSU can be designated as a *critical data region*. Data in these regions may be intentionally or automatically duplicated in order to prevent accidental information losses.

5 *Ynet*. The Ynet [30] – a patented design of Teradata Corporation – is the heart of the DBC/1012. It is an intelligent interconnection bus which connects the IFPs, COPs and AMPs. A Ynet interface node incorporates logic to perform hardware sort/select operations on data as they pass through. The sort/select capability is used to support relational database operations (e.g. sort-merge joins). Two Ynets are connected to each IFP, COP and AMP. Each Ynet is fully independent: it has separate circuits with separate power supplies. Normally, both Ynets share the load; however, if one of them is inoperative, the other will take up the full load.

The processor modules – IFP, COP and AMP – have a similar hardware architecture which consists of a CPU, a controller, some memory and two Ynet interfaces constructed from four printed circuit boards. The difference between the three modules lies in the interface controller. The IFP, COP and AMP have respectively a controller for a channel interface, a network interface and a disc interface. There are three models of processor module: model 1 which is the earliest version (ca. 1983) incorporates a 8086 CPU and a 8087 numerical processor unit (NPU); model 2 incorporates a 80286 CPU and a 80287 NPU; and the latest model 3 incorporates a 80386 CPU and a 80387 NPU. (CPUs and NPUs in all three models are Intel processors). The three models can be mixed within a DBC/1012 system; thus reducing the cost of system upgrade. A DBC/1012 system may be configured with from 3 to 1024 processor modules.

To connect a computer (mainframe or workstation), the computer is required to run the proprietary Teradata Directory Program (TDP, see fig. 4). The TDP manages the channel activity and services user requests. A user query is passed to the TDP on the host and is dispatched to the DBC/1012. The IFP receives the query and translates it to relational database worksteps. The worksteps are broadcast to the appropriate AMPs via the Ynet. Each AMP executes the worksteps with its associated DSUs. The AMPs function in parallel. The result is transmitted back to the TFP via the Ynet and subsequently returned to the host via the TDP. During their journey to the TFP, the Ynet interface node may perform hardware select/sort, thus merging the results from all AMPs into one master solution set.

At the user-interface level, the DBC/SQL query language is needed. A user can issue DBC/SQL statements to the DBC/1012 in three ways: interactively using the ITEQ (Interactive TEradata Query) facility; as embedded DBC/SQL instructions in application programs; or in batch mode through the BTEQ (Batch TEradata Query) facility.

Select and project operations are straightforward and simply require the specific select/project attributes to be hashed and distributed to the appropriate AMP/DSU pairs. Joins can be performed by different algorithms: *nested-loop*, *hashed-join* and *sort-merge* algorithms depending on the join attributes. For instance, if none of the join attributes of the 2 joining relations is a primary index, either the nested-loop or the sort-merge algorithm will be used – if the latter algorithm is used, the joining tuples must be sorted. On the other hand, if one of the joining attributes is a primary index (unique or non-unique), the hashed-join algorithm will be adopted. Moreover, for any database operation, ordered results can be achieved by utilising the Ynet's select/sort functionality.

2.4 ShareBase Server/8000

The Servers /300, /700 and /8000 are back-end database machines developed by ShareBase (formerly known as Britton-Lee). The philosophy of the Server mechanism is based on the Share database system architecture. Server/8000 is the most recent product from ShareBase marketed in April 1989 [22]. The other machines Server/300 and Server/700 were originally marketed by Britton-Lee and were known as Intelligent Database Machines (IDMs). The architecture of the IDM500 (now known as Server/700) is reported in [31].

The Shared Database System Architecture is equivalent to the Teradata's Shared Information Architecture. Both architectures are based on the notion of a database server containing some centralised information being shared by multiple heterogeneous client computers. Different client computers are supported, e.g. SUN and Apollo workstations. Fig. 5 shows the Shared Database System architecture based on Server/8000. Server/8000 consists of the following functional units implemented at board level:

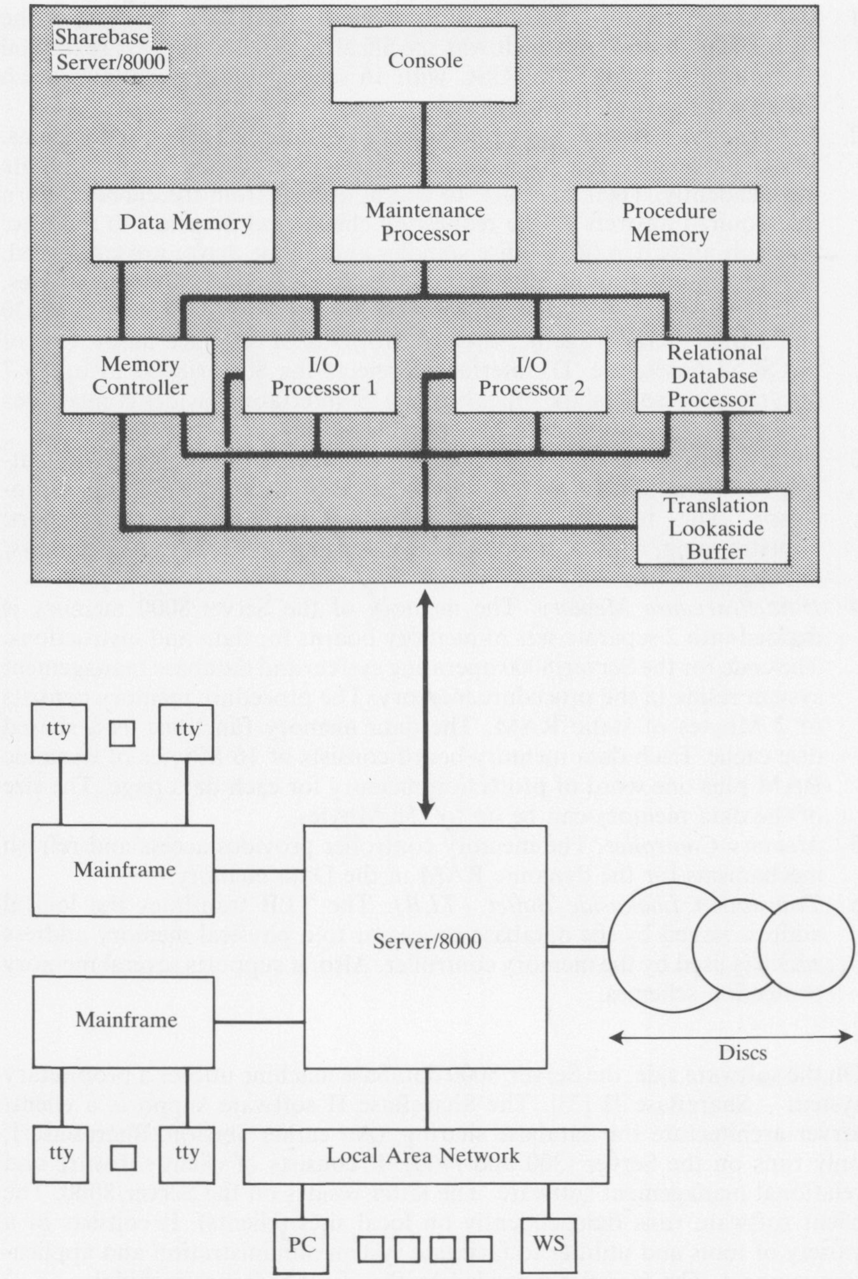


Fig. 5 The ShareBase's Shared Database Architecture based on the Server/8000

1 *Database Processor*. The database processor (RDBP) is the heart of the Server/8000 hardware which was specifically designed for fast relational operations. It is an ECL RISC with 16 sets of register-windows (each window consists of 16 registers).
2 *I/O Processor System*. Server/8000 has 2 or more I/O processor systems. These processor systems have their own local memory and operate independently. Their roles are: to accept queries from the clients, return the required answers to the requesting clients and interface to the disc/tape sub-units. Up to 104 disc spindles and 4 tape drives are supported. The maximum storage capacity of the Server/8000 is 104 Giga-bytes. Each I/O processor system consists of 3 processors: 1 Motorola 68020 and 2 Intel 8032s. Together they control 2 SCSI interface buses. One of the SCSI buses, the 'D' interface connects the Server/8000 to up to 7 disc/tape controllers; the other bus, the 'S' interface provides connections to the Ethernet and the RS232 controllers.
3 *Maintenance Processor*. The Maintenance Processor is designed for unattended operations. Its architecture is based on an Intel 80286 microprocessor. The role of the maintenance processor is to support: bootstrapping, console handling, error logging and hardware diagnosis/debugging.
4 *Data/Procedure Memory*. The memory of the Server/8000 memory is divided into 2 separate sets of memory boards for data and instructions. The code for the Server/8000 operating system and database management system reside in the procedure memory. The procedure memory consists of 2 Mbytes of static RAM. The data memory functions as a shared disc cache. Each data memory board consists of 16 Mbytes of dynamic RAM plus one word of protection memory for each data page. The size of the data memory can be up to 256 Mbytes.
5 *Memory Controller*. The memory controller provides access and refresh mechanisms for the dynamic RAM in the Data memory.
6 *Translation Lookaside Buffer (TLB)*. The TLB translates the logical address issued by the database processor to a physical memory address which is used by the memory controller. Also, it supports several memory protection schemes.

On the software side, the Server/8000 database machine utilises a proprietary system – ShareBase II [23]. The ShareBase II software supports a client/server architecture for database sharing. (An earlier version, ShareBase I, only runs on the Server /300 and /700). It consists of client software and relational management software. The latter resides on the Server/8000. The client software runs independently on local sites (clients). It consists of a variety of tools and utilities to facilitate system administration and application support. The facilities provided by the client software include[1]:

[1]A summary of the ShareBase II facilities is given in Chapter 2 of [23].

1 *Query Facility*. This parses query language statements in the form of SQL and IDL (Intelligent Query Language, an extension of QUEL from Britton-Lee) and sends them to Server/8000 machine. It also receives resulting data from the server and displays it in the desired format.
2 *Application Facility*. This provides a software environment for developing system and application programs. It consists of a run time library (IDMLIB for C, Fortran or Cobol programming) and a number of precompilers.
3 *Share Tools*. This consists of a set of programmer tools developed by other vendors (e.g. FREEFORM – a portable, screen based query generator for non-SQL users, etc.)
4 *Development Administration Tools*. These provide a set of system commands (e.g. *idmcopy* transfers formatted data between a client and Server/8000) for administrating databases.
5 *ShareCom*. This is the network software which allows ShareBase clients to communicate with the server. ShareBase II supports the following communication options: RS232 serial communication, Ethernet/XNS, Ethernet/TCR and Ethernet/DECnet.

The ShareBase II software on the Server/8000 (the server software) is a relational database management system which also provides backup/restore, security and concurrency control facilities. Backup/restore is achieved by journalling (logging) together with mirrored disc support. The latter allows the Server/8000 to continue to operate in the event of disc failure. Security allows users to hide sensitive data. This can be performed at different levels: database, table and column.

3 Current States of the Commercial Machines

Although research on special purpose database computers for handling large information systems has been pursued very actively since the beginning of the 70s, only a few machines have been converted to commercial products from their laboratory prototypes. Among them, the ICL CAFS, Hitachi IDP, Teradata DBC/1012 and ShareBase Server/8000 are the best known examples.

ICL and Hitachi designed CAFS and IDP, respectively, as dedicated processing units to integrate with their mainframe computers. Therefore, the markets of these two database machines are quite narrow; they are mainly localised to their respective countries, U.K. and Japan, where ICL and Hitachi computers are most widely used. For example, in England ICL CAFS are employed in many government offices (such as the Inland Revenue). The other three database computers support open system principles. They were designed to integrate with different host platforms, including various mainframes, minis and workstations. The growing importance of networking (both LAN and WAN) enabling inter-connection of different computers forming heterogeneous computer systems favours open system database machines.

At present, a large portion of the world's market for database machines is occupied by the Teradata DBC/1012 and the ShareBase Server(s). Moreover, the 'open system' strategy adopted by the machines makes them popular with database users who want to upgrade and improve the performance of their existing database systems. Approximately 800 Server/300 and Server/700 database computers have been installed; and the Teradata DBC/1012 has about 100 installations [11]. Together they occupy at least 80% of the world database computer market. The Server/300 and Server/700 are targeted at small- and medium-sized database users. They are cheaper than the DBC/1012 and handle databases with up to 1 Giga-byte of data. On the other hand the DBC/1012 is designed for large database users; it is more expensive and caters for databases with capacities up to 1 Terabyte (10^{12}). The Server/8000 introduced in mid 1989 is the ShareBase solution to large databases. The database capacity of the machine approaches that of the DBC/1012; databases handled by the Server/8000 can contain up to 104 Gbytes. In the meantime the small- and medium-sized database markets of Server/300 and Server/700 are being challenged by many software alternatives. These include the systems from Sybase, Informix, Oracle, Sequent, Pyramid and Ingres which are cost effective software database engines based on a client/server architecture.

3.1 Factors Affecting Acceptance of a Database Machine

The level of market acceptance of database systems shows that specialised hardware machines are not widely used by database users. It is always argued that the cost/effectiveness of a specialised database machine is insignificant because of the rapid advances in hardware/software technology (e.g. the introduction of high performance general purpose processors and sophisticated software database engines). In general, a specialised database machine can only be considered as more effective than software database systems if it can offer a one order of magnitude performance improvement over the latter. Compared with their host computers, a number of existing commercial database machines (including the ones described in this paper) do satisfy this performance requirement.

The argument of advances in hardware/software technology is one-sided. The size and complexity of database systems do not remain static; they grow along with software and hardware technology. There is a limit to the ability of general purpose processors to cope with large complex databases. Commercial database management systems are implemented on top of general purpose operating systems. Due to the different operational requirements of the two systems [26], this piggyback approach is very inefficient. Its performance may be acceptable for small- or medium-sized systems, but it is intolerable for large databases. Special purpose database machines (e.g. the DBC/1012 and Server/8000) have their own management systems which are tailored to utilise the machine resources efficiently. For this reason a specialised database machine is suitable for large database applications.

Choosing between a hardware database machine and a software database engine for a given database system depends heavily on the size of the application that the system is designed to handle. Influenced by the advance of hardware/software technology, the capacity which software engines can handle is steadily increasing. At present, hardware database machines, e.g. the Server/8000 and DBC/1012, are designed to deal with very large databases containing over 10^9 (giga) bytes of information. Handling databases of such a large size can only be efficient with specialised hardware. However, in the near future, the capacity of a software engine will also approach the giga-byte range. Therefore, database machine designers must provide some features to keep up with the progress of the software engines. The strategy is to design a database machine with a scalable architecture so that the machine can cope with future system expansion. Effectively, scalability extends the "life cycle" of a database machine. This feature is highlighted in the architectures of the DBC/1012 and Server/8000 database machines.

Other factors which influence the use of specialised database machines are the software and hardware connectivities. "Most changes to existing database systems are evolutionary rather than revolutionary" (chapter 9 of [28]). Users would be less reluctant to adopt database machines if the effort in porting their existing databases to the machines were simple (software connectivity). The success of a database machine will depend on how easily it can be integrated into existing systems (hardware connectivity). Since systems based on networked heterogeneous computers are becoming widely accepted, a database machine must be designed with an 'open system' interface allowing it to connect to different computer models.

Reliability is also an important design factor. It can be very costly to abort or disrupt a database application when a small part of the database machine becomes inoperative. A practical database machine, therefore, must be designed to handle this sort of situation reliably. This is achieved by incorporating a redundant subsystem which can be activated and replace the faulty parts of the machine when it goes down. Furthermore, reliability in storage is also very important. Provision of backup storage facilities (e.g. mirrored discs) to prevent accidental loss of information is crucial.

Summarising, due to the increasing size and complexity of database systems, there is undoubtedly a need for specialised database machines. However, because of the challenge from their software counterparts, hardware database machines are only used in large database systems. They are targeted only at high end users for cost/performance reasons. To achieve widespread acceptance in the database community, the following factors must be carefully considered when designing a database machine:

- Software connectivity – how easy is it to port an existing database system to the database machine?
- Hardware connectivity – how easy is it to connect the database machine to existing hardware?

- Scalability – how easy can the database machine cope with future expansion, in both size and complexity?
- Reliability – how tolerant is the machine to faults and errors?

4 'Emerging' Machines

4.1 Grace

The Grace machine [10, 16] is a relational database computer for the Japanese Fifth Generation Computer System (FGCS) produced by the University of Tokyo. The target of the FGCS research programme is to develop a complete (hardware, firmware and software) knowledge information processing environment [20]. The overall architecture of the FGCS consists of a network of standalone personal inference machines (such as the Personal Sequential Inference Machine, PSI, or the Parallel Inference Machine, PIM), knowledge base machines (KBM) and relational database machines (RDBM). Grace is one of the RDBM candidates.

Join is the most time consuming and complex database primitive. By speeding up the join operation, the overall performance of a database system can be enhanced. The Grace machine was designed based on this philosophy. The architecture of the Grace machine, shown in fig. 6, consists of 4 different types of functional modules connected together by two ring networks, the processing and the staging rings:

1 The *P-module* (Processing module) is responsible for the execution of database operations. Internally, it consists of a custom VLSI sorter (SO), a tuple manipulation unit (TMU), a hash unit (HU) and an interface unit (IU) connected in tandem; these units are controlled by a control unit (CU). The SO, TMU, HU and IU are connected in tandem and operate in a pipeline fashion. The dedicated VLSI SO supports real time linear sorting at the disc transfer rate.
2 The *M-module* (Memory module) consists of some memory used as a working space for holding tuples of the relations involved in an operation. Such tuples may be derived from permanent base relations on the Disk modules; or they may be intermediate results in a complex query derived from the P modules.
3 The *D-module* (Disc module) consists of discs for permanent storage of relations. A Filtering Unit (FU) is attached to the discs for selective retrieval of disc resident tuples. A Hashing Unit (HU) connected to the output of the FU, applies hardware hashing to the selected tuples. The selected tuples are deposited in the appropriate M modules according to the hash values.
4 The *C-module* (Control module) coordinates the other 3 modules so that the overall system works efficiently.

During query processing, a query is decomposed into a number of database operations. The execution of the database operations is grouped into tasks.

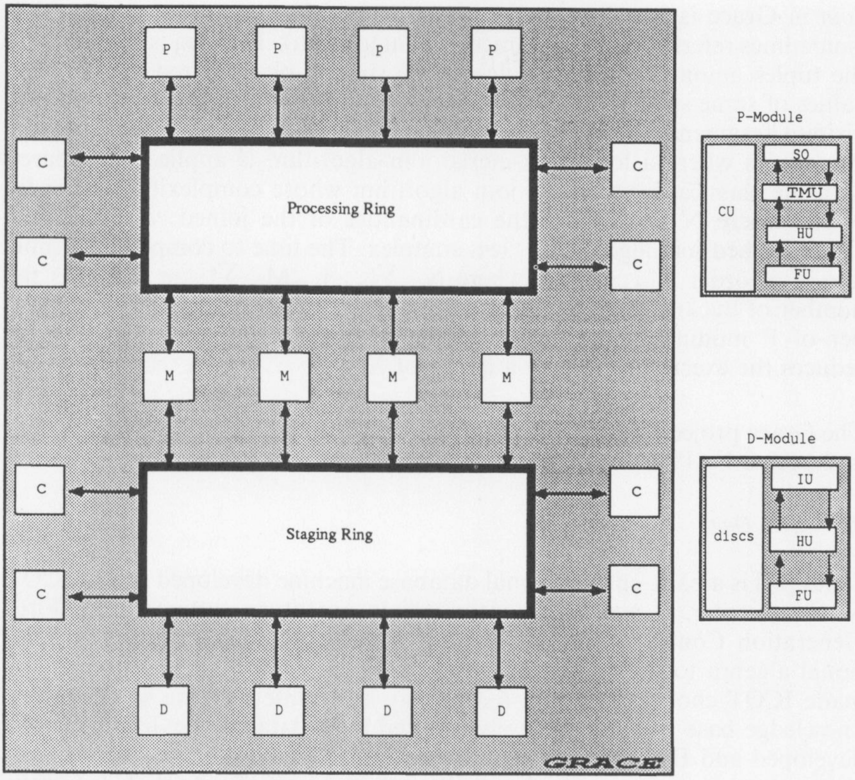


Fig. 6 The overall architecture of the Grace machine

These tasks are loaded into the P-modules. The required tuples are read from the M modules in the form of data streams – stream oriented processing. The task then operates on the tuples as the data streams along. This concept is rather different from the design principles of other database machines, e.g. Gamma, which distribute the database functions to where the data is stored rather than streaming the data to the functions. The number of functional modules involved in an operation depends on the nature of the query, the sizes of the relations and the parallelism required.

In practice, query execution proceeds in two phases: In the staging phase, the relations necessary for the first operation in the query are staged from the D to M modules. By invoking the hardware filter at the D module, only the relevant tuples are retrieved. This reduces the network traffic tremendously. Once the tuples are staged, the system goes into the processing phase. The P modules read the staged tuples from the M modules and perform the desired database operations upon the tuples simultaneously in a pipeline fashion.

Join in Grace is based on a distributed hybrid hash/sort-merge algorithm (sometimes referred to as the Grace hash algorithm). The idea is to distribute the tuples among the M modules at the staging phase based on the hash values of some specified attributes. Tuples in M modules are organised into disjoint fragments (or buckets). These buckets of data are streamed to the P modules where a local sort-merge join algorithm is applied. Compared with the classical nested loop join algorithm whose complexity is of order N*M (where N and M are the cardinalities of the joined relations), the Grace hashed-join algorithm is less complex. The time to complete the same join is of order $\sum_{i=1}^{s} n_i \times m_i$ where $N = \sum_{i=1}^{s} n_i$, $M = \sum_{i=1}^{s} m_i$ and s is the number of buckets. Moreover, distributing the join operations into X number of P modules which each module executes in parallel, theoretically reduces the execution time by a factor of X.

The Grace project is progressing rapidly and a fully functional Grace system is expected by 1992 – the end of the FGCS research programme.

4.2 ICOT Delta

Delta [24] is a back-end relational database machine developed by the ICOT research center. It acts as an intermediate prototype system in the Fifth Generation Computer System Project (FGCS). The close affinity of relational algebra to logic programming, the basis of the FGCS software, has made ICOT choose relational technology as an intermediate solution to a knowledge base system. A loosely coupled logic database environment was developed and Delta functions as the external database server. The overall system is based on multiple, dedicated Personal Sequential Inference Machines (PSIs) which support the logic programming paradigm – in Prolog. The PSIs are connected to Delta via a local area network (LAN). Delta maintains sets of Prolog facts which are shared by the PSIs.

In practice, users make queries in Prolog format on the PSIs and subsequently they are converted into query plans. These plans contain Delta commands which drive the Delta database machine. The plans are packaged into data packets and are sent to the Delta via the LAN. When the query data packets are received, the Delta machine extracts the Delta commands from them. The commands are interpreted and finally executed. Database operations are executed using a merge/sort algorithm in hardware. Resulting data, if any, is returned to the appropriate PSIs in the form of data packets via the LAN.

The global architecture of the Delta database machine is shown in fig. 7. Delta consists of 5 major processing units:

1 The *Interface Processor (IP)* provides an interface to the external systems (such as the PSIs via the LAN) and acts as a second means of communication between the other processing units.

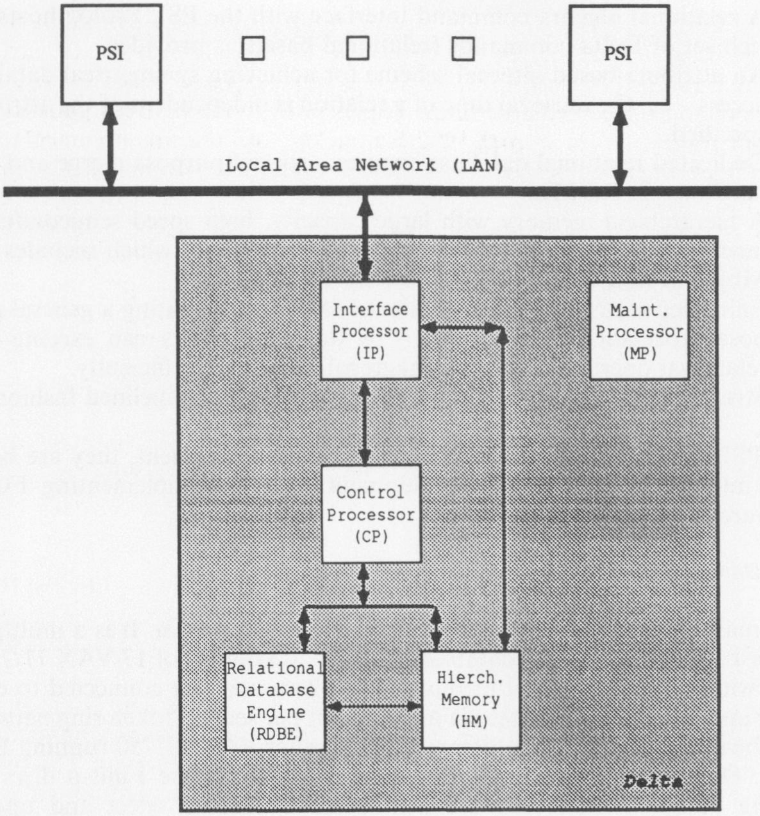


Fig. 7 Architecture of Delta/PSI Computer System

2 The *Control Processor (CP)* coordinates the operations of all the other units.
3 The *Relational Database Engine (RDBE)* contains several pieces of dedicated hardware that support database operations [21]. The execution of database algebra is achieved by a hardware pipeline merge/sort algorithm.
4 The *Hierarchical Memory (HM)* provides functions for storing, accessing, clustering and maintaining disc resident relations.
5 The *Maintenance Processor (MP)* controls the initiation and termination of the Delta system. It also monitors the states of the system and performs system configuration management.

The architecture of Delta has certain salient features specially designed to support database applications. They include:

- A distributed function multiprocessor configuration – IP, CP, RDBE and MP are independent special purpose processors running in parallel.

- A relational algebra command interface with the PSI, Prolog hosts – a rich set of Delta commands (relational based) is provided.
- An attribute-based internal scheme for achieving symmetrical database access – i.e. the retrieval time of a relation is independent of the attribute specified.
- Dedicated relational database engines – special purpose merge and sort hardware in RDBE.
- A hierarchical memory with large capacity, high speed semiconductor memory units – the total memory size is 20 Gbyte which includes 128 Mbyte of non-volatile semiconductor disc.
- Enhanced statistics collection functions by incorporating a general purpose processor in the RDBE – by doing so, Delta can execute non relational operations, such as aggregate functions, efficiently.
- Stream processing in which data is processed in a pipelined fashion.

The PSI computer systems are well established. At present, they are being used intensively as software development tools for implementing FGCS software.

4.3 Gamma

Gamma [9] was developed at the University of Wisconsin. It is a multiprocessor back-end relational database machine. It consists of 17 VAX 11/750s; each with 2 Mbyte of local memory. The processors are connected to each other and to a host computer via an 80 M-bit per second token ring network as shown in fig. 8. The host computer is another VAX 11/750 running BSD Unix. Only 8 processors have disc storage – 333 Mbyte Fujitsu discs for storing database files; they are also used to execute select and update database primitives. One of the 9 disc-less processors is allocated for query scheduling and global deadlock detection. The other 8 disc-less processors are used to execute join, projection and aggregate operations.

Relations in Gamma are horizontally partitioned across all disc storage in the system. By specifying the storage format using the Gamma query language *gdl* – an extension of QUEL – users can distribute the tuples of a relation in 4 different ways – round-robin, hashed, range partitioned by key attribute and range partitioned with uniform distribution.

Round-robin is the default strategy. When a relation is distributed using this strategy, each disc takes it in turn to store a tuple. If the hashed strategy is selected, a randomising function is applied to the key attribute of each tuple to select the storage unit. The key attribute is specified in the *gdl* partition command. In the third strategy the user specifies a range of key values at each site. Finally, if the user does not have enough information on the relation to identify key ranges, the fourth strategy may be used. Under this method, if a relation is not already loaded, it is initially loaded in a round-robin fashion. Once the relation is loaded, it is sorted (using a parallel merge sort) on the partitioning attribute. The relation is then re-

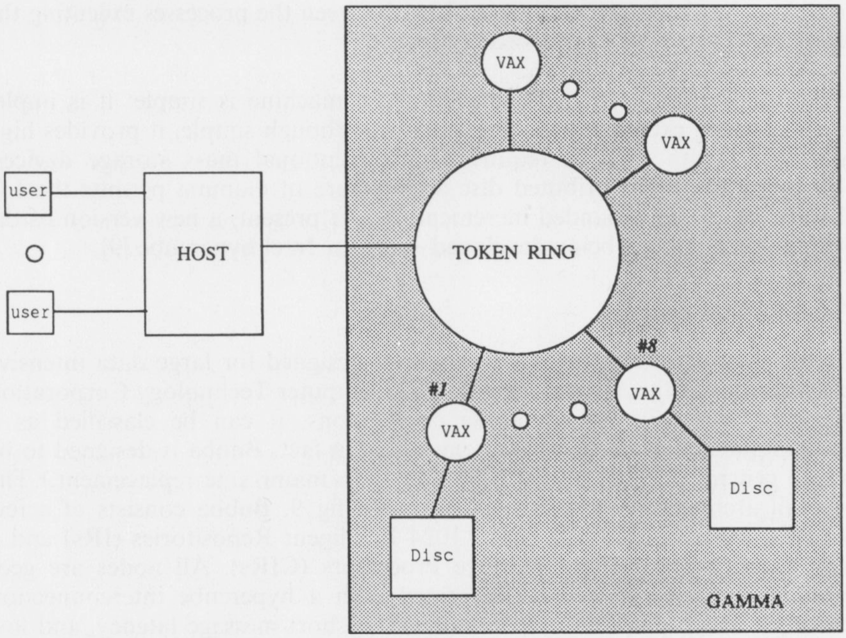


Fig. 8 Architecture of the Gamma database Machine

distributed in a fashion that attempts to equalise the number of tuples at each site. Finally the maximum key value at each site is sent to the host processor.

For query execution, Gamma adopts traditional techniques for query parsing, optimisation and code generation. The optimisation process is somewhat simplified as Gamma only employs hash-based algorithms for joins and other complex operations. Queries are compiled into a tree of operators. At execution time, each operator is executed by one or more operator processes at each participating site. After being parsed and compiled, the query is sent by the host software to an idle scheduler process through a dispatcher process. The dispatcher process, by controlling the number of active schedulers, implements a simple load control mechanism based on information about the degree of CPU and memory utilisation at each processor. The scheduler process, in turn, activates operator processes at each query processor selected to execute the operator. The result of a query is either returned to the user through the ad-hoc query interface or through the embedded query interface to the program from which the query was initiated.

Gamma exploits dataflow query processing techniques. Each operator in a query tree is executed by one or more processes. These processes are assigned to a disc and/or disc-less processor by the scheduler process. Except for 3 control messages – 2 at the beginning of the operator and 1 when the operator has been executed, data flows between the processes executing the query and needs no centralised control.

The architecture of the Gamma database machine is simple: it is implemented using existing hardware systems. Although simple, it provides high disc bandwidth without requiring unconventional mass storage devices. Furthermore, the distributed disc architecture of Gamma permits the I/O bandwidth to be expanded incrementally. At present, a new version of the Gamma machine is being developed using an Intel hypercube [9].

4.4 Bubba

Bubba is a parallel distributed computer designed for large data intensive applications at the Microelectronic and Computer Technology Corporation (MCC, USA) [7]. For database applications, it can be classified as a standalone dedicated database computer. (In fact, Bubba is designed to be more general purpose and will be used as a mainframe replacement.) The overall architecture of Bubba is shown in fig. 9. Bubba consists of a few Interface Processors (IPs), up to 1024 Intelligent Repositories (IRs) and a few Checkpoint-and-log Interface Processors (CIRs). All nodes are geographically close. They are integrated with a hypercube interconnection network which provides ample bandwidth, short message latency, and low error rates.

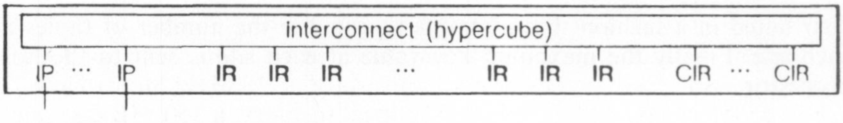


Fig. 9 Overall architecture of Bubba

An IR contains a fragment of the database (see later). During a transaction, it executes the required database operations on its database fragments. It consists of a disc with controller, a communication processor, a hypercube link and a main processor; these components share a local memory. An IP receives transaction programs and executes requests from one or more hosts and initiates processes which coordinate transaction execution. A CIR performs checkpointing and logging for recovery, frequently in parallel while the IR and the IP are in action.

A database is stored distributedly in several IRs. A transaction is executed in multiple IRs. The objective is to bring the program to where the data fragments "live". Transaction execution follows a dataflow strategy: a node begins execution of a database operator as soon as enough of the required data is available. Results are sent back to the nodes responsible for executing the subsequent operator. Parallelism in a transaction is determined by: the degree of data distribution – how many IRs are used to store a fragment of a data set; and the granularity of pipelining between operators.

The number of IRs participating in a transaction varies between applications. Some applications may be serviced by a few IRs, whereas others may require the service of a few tens. On an IR, execution is based on the workspace model: updates of a transaction are stored temporarily in a private workspace. The changes become permanent at commit time and are migrated to disc in the background. A global validation step is required as part of the protocol. The storage manager on each IR gives effect to the concept of *extents*: a sequence of blocks physically close to each other.

A user transaction program in Bubba is expressed in FAD [14]. FAD provides an object oriented programming model. It provides user defined atomic types, tuples and sets and a set of operators for object manipulation which is a superset of the relational algebra operators (i.e. FAD is relational complete.) Moreover, FAD provides a number of control operators such as *while-do* and *if-then-else*. This makes FAD more general purpose than a conventional relational language (e.g. SQL). A FAD program is translated to PFAD (parallel FAD). PFAD is the target interface to Bubba. It is FAD with communication primitives and a parallel model of execution. PFAD is expressed in the form of dataflow graphs. Each node of a PFAD graph represents a database operation on a data fragment and the arcs represent the data dependency between fragments. The arcs also show the transmission path for partial results from one set of IRs to another. In practice, nodes of a PFAD dataflow graph are converted to threads and are loaded into the corresponding IRs. A dataflow execution strategy is adopted, as explained above.

At present, a Bubba prototype is implemented on a 40 processor Flex/32 multiprocessor. Each processor node consists of an 18 MHz Motorola 68020 CPU, 68851 MMU 68881 FPU, 6 MB local memory, a 150 MB disc and a ESDI[2] disc controller. A simulation of the hypercube interconnection network is constructed using 9 MB of common memory. This memory is partitioned into buffers and each of the processing nodes is assigned a dedicated buffer pool. The nodes only access this pool for messages. 32 of the 40 processors are used as IRs. The remaining 8 are used for experiment and system controls.

5 Trends of Database Machine Architecture

5.1 A Multiprocessor System

For cost/performance reasons, database machines are mainly designed for large database applications. To handle large applications efficiently, multiprocessor architectures are used. The most important goal in the design of multiprocessor database machines is to exploit parallelism as much as possible with a minimum of control and communication overheads.

[2]Enhanced Small Disc Interface.

A multiprocessor database machine may be comprised of multiple identical general purpose processing elements (e.g. Gamma); or it may be a heterogeneous system implemented with different types of processing elements (e.g. Delta). The former architecture is more practical and widely used (e.g. Teradata DBC/1012). Compared to a heterogeneous system, a multiprocessor machine with identical processing elements is more robust and is easier to maintain. Scalability is another advantage of this architecture – speed and storage performance of a machine may be increased by simply introducing additional processing elements.

5.2 'Data Declustering' and 'Shared-Nothing' Architecture

In conventional database systems, a large centralised disc system is used to contain the database files. Such a configuration gives rise to inefficient database performance due to the disc I/O bottleneck. To relieve this predicament, the trend in database machine design is to adopt the technique of 'data declustering'. Using this technique, a base relation is divided into fragments, based on either a horizontal (row-wise) or vertical (column-wise) partitioning scheme. The fragments are distributed and stored in several processors – referred to as the 'home' processors. During execution of a query, database operations need only be directed to the appropriate 'home' processors. This technique is known as function distribution (i.e. sending functions to data rather than data to functions as in normal database systems). Function distribution has the effect of sharing the load of the disc I/O between multiple 'home' processors. The 'home' processors may be active simultaneously, performing parallel database operations. In the context of database systems, the multiprocessor architecture with distributed data (or distributed memory) is often referred to as the 'shared-nothing' architecture. This architecture is preferred over the 'shared-memory' and 'shared-disc' architectures for multiuser database applications. It provides higher availability, reliability and scalability [27].

There are many possible ways to decluster data. They are based on 4 main data placement strategies (see also the section on Gamma): (1) round-robin, (2) hashed, (3) range partitioned by key attributes and (4) range partition with uniform distribution. Strategies (2)–(4) have the advantage of reducing the search space. To achieve that, a set of keys needs to be specified for a relation at creation time. This is not a requirement for the round-robin strategy. Strategy (1) performs better for non-keyed searches. Therefore, for knowledge base applications which requires symmetrical information access (c.f. Delta), the round-robin strategy is preferred. An ideal database machine supports all 4 strategies. At run time, depending on the current working relation, a specific strategy is selected. This is, in fact, the case in Gamma.

It is interesting to note that simple database applications, such as debit/credit, favour a large 'degree of declustering'. This is because there is little inter-process communication in debit/credit applications. On the other hand, for complex decision support applications, a low 'degree of declustering' is preferred [25].

5.3 Reduced Process and Communication Overheads

Two major technical difficulties arise from database 'declustering'. The first one is load balancing. Unevenly distributed data can create hotspots which in turn may affect system performance. Part of the responsibility of the database operating system is to ensure that the machine is efficiently balanced. The second difficulty is the 'degree of declustering' [25]. Database operations are executed on 'home' processors; therefore, the number of 'home' processors involved can affect system performance. In practice, the number of processors can only be increased up to a certain point. Beyond this point, an adverse effect takes place. This classical diminishing return behaviour is caused by an *inter-process overhead* due to a high rate of message passing between separate processes and an *intra-process overhead* caused by overheads in process coordination (such as process startup, switching and synchronisation).

To reduce the effect of message passing, a well designed communication protocol and a fast communication system are required. The latter can be achieved with a high bandwidth, low latency network coupled with a high speed network interface unit on each processing node. This feature is exhibited by the Teradata DBC/1012 with its Y-net communication links.

Overheads for process coordination can be reduced by introducing 'light-weight' processing mechanisms on each processing element. The coordination of 'light-weight' processes (threads) are faster than normal processes because less work needs to be done by the kernel. The kernel needs to maintain fewer resources. Resources such as the process table, the lock table, ... etc, are shared by all threads of the same task. These resources could be kept in a common area and need not be stored/restored during context switches. The coordination of threads, therefore, is less CPU- and memory-intensive. Database transactions are divided into sets of 'light-weight' processes. They are executed in different processors on a 'shared-nothing' database machine in parallel. Moreover, on each processor, multiple 'light-weight' processes may be executed concurrently.

5.4 Database Operations in Parallel

Join is the most complex and time consuming database operation. It can be executed efficiently on a multiprocessor system in parallel. There are 3 basic multiprocessor join algorithms: the nested loop, sort-merge and hashed join algorithms. The nested loop algorithm is the simplest. Its execution time is inversely proportional to the number of participating processors. It works best when the number of processors is high. Furthermore, since each tuple is compared with every tuple, the nested join algorithm easily supports non-equijoin.

The sort-merge join algorithm is more complex and performs better as the operand relations become large. It is implemented in most Japanese machines using specialised sort/merge hardware (e.g. ICOT Delta). For a certain configuration, the addition of new processors causes very little improvement in performance with this algorithm. This is due to the high overhead caused by inter-processor communications and message passing. However the sort-merge algorithm has the merit of utilising another useful operator, namely sorting.

The hashed join algorithm is better when the number of matching tuples in the larger relation is small. In that case, the use of bit arrays (as proposed in the ICL CAFS [3] and implemented in Gamma) avoids many useless accesses to the hashed file. For a given configuration, each of the algorithms can excel, according to the characteristics of the operand and result relations. Since the join operation is very important in relational systems, the trend is to support all the algorithms and at run time, choose the best one by estimating the required execution cost. This strategy is adopted by Grace.

Aggregate functions, which are simple integer arithmetic, are performed by the CPUs on the relevant processing elements. The CPUs are general purpose microprocessors with extra hardware functionality for the support of distributed database operations (e.g. fast context switching).

Selections and updates are performed directly on the relevant 'home' processors. To coordinate multiple accesses, a concurrency control mechanism is provided by the operating system on each 'home' processor. There are several strategies for concurrency control [5]. By far the simplest is the *two-phase commit locking scheme*. Various locking granularities are possible. Depending on the applications, a database can be locked at the database, relation, page or tuple level. Furthermore, a separate dedicated coprocessor could be embedded on each processing element for concurrency control. This could save the associated main processor from being interrupted when a locked relation is requested by other transactions; thus the main processor could concentrate mainly on data operations.

5.5 Dataflow Execution

During a transaction, more than one database operation is usually involved. At the compilation phase, a transaction is translated into an execution program in the form of a dataflow graph, where nodes correspond to operations and arcs correspond to dependencies between operations. The code for the operations is distributed to the relevant 'home' processing elements. On a processing node, an operation exists as a 'light-weight' process (or 'thread'). The simplest way to run a transaction is to pre-activate the 'threads' on all 'home' process elements at the start of the transaction. However, not all 'homes' can do useful work at the same time. This is because the start of some operations may depend on the results of others. Therefore, although all 'threads' are activated, some 'threads' are simply waiting for results from their predecessors. These waiting 'threads' are harmful and prevent their corresponding processing elements from running other tasks.

One way to enable waiting 'threads' to perform useful work is to use a dataflow execution strategy [8]. This strategy is adopted by many existing machines, e.g. Gamma. Dataflow execution is based on the notion of dynamic activation [2]. Operation 'threads' for a transaction are only activated when the results of their predecessors arrive. Efficient execution of dynamic activation requires fast 'thread' switching. When a message containing the result arrives at a processing element, the processing element must be able to bind this message to the appropriate 'thread' rapidly.

5.6 A Specialised Database Operating System

Implementation of a DBMS on top of a general purpose operating system is inefficient. The inefficiency of this approach is shown in the experiments conducted by Hagmann et al. [12]. The only advantage of this approach is portability – a database management system can be integrated with an existing system easily. Therefore, it is adopted by many commercial vendors for developing software database engines (e.g. Ingres from Relational Technology Inc.). These engines are only suitable for medium-sized system. Hardware database machines are built to handle large databases. Their operating systems must be specially designed to support the unconventional architecture of the machines and the low-level data management. A standalone database operating system is complex. To design an efficient database operating system, requires careful consideration of the following areas [26]:

- Buffer management (e.g. buffer allocation in a join operation).
- File management (e.g. data placement, concurrency control).
- Process management (e.g. multithreading supports).
- Process scheduling (e.g. dynamic 'thread' activation).
- Process communication (e.g. message passing between threads).
- Query optimisation (e.g. decide the fastest route for a query).

At the implementation level, a database machine must provide hardware features to support its database operating system.

6 Conclusion

This paper reviews the state-of-the-art architecture of 'now' (commercial) and 'emerging' (research) database machines. The architectural features of these machines will influence the design of future database machines. Two important aspects of database machine design have been discussed:

- From a practical point of view, integration of the machine with existing systems must be simple (software/hardware connectivity); the machine must be able to cope with an expanding work load (scalability); it must have good recovery mechanisms to tolerate system faults and errors (reliability); and it must provide a means to handle confidential information (security). These are vital factors which will influence the acceptance of the machine and must be taken into account when designing a database computer.

- At the architectural level, various desirable features are identified. They include: the 'shared-nothing' multiprocessor architecture to exploit data parallelism; database 'declustering', high-speed message passing protocols, multithreading (or 'light-weight' processes) and the dataflow execution mechanism for parallel operations; and also a specialised database operating system is essential for efficient system management.

The design factors and the architectural trends discussed in this paper may be used as a set of guidelines for designing future database machines.

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Computer Simulation for the Efficient Development of Silicon Technologies

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Abstract

The very high cost of the capital equipment required for the manufacture of modern integrated circuits makes it important that development time for each generation of techology is reduced as far as possible. Computer simulation is now used to assist in this development and STL has been involved in Alvey and ESPRIT collaborative programmes to advance such methods.

Modelling is applied to two classes of problem: the processing steps which lead to the diffusion of dopant within the silicon and the growth of surface oxides, and the electrical performance of the device. Both give rise to coupled sets of non-linear partial differential equations which can be solved by adapting numerical techniques widely used in other engineering fields such as the finite element method. For solution of the problem on two-dimensional sections through the devices this results in large sets of algebraic equations [4,000–12,000] which have required the development of efficient sparse matrix techniques for their solution. To obtain the required accuracy care has to be taken in the choice of the mesh and the representation of the equations on the mesh in order to have an accurate and stable solution.

These modelling techniques have been extensively used by STC to help technology developments. Current applications include the development of bipolar technology for Gbit optical fibre repeater use and the development of CMOS technologies at 1 and 0.7 μm.

1 Introduction

The rapid advance of silicon technology has enabled the vast growth of computation power now available to society. This rapid advance of computer technology has in turn been used in the development of the silicon technology. An efficient silicon IC production line is now producing components using expensive computer controlled manufacturing equipment and managing the production flow with computer based scheduling. Only with these techniques can sufficient control be achieved to ensure the reliable operation of circuits with hundreds of thousands of transistors with dimensions close to 1 micron.

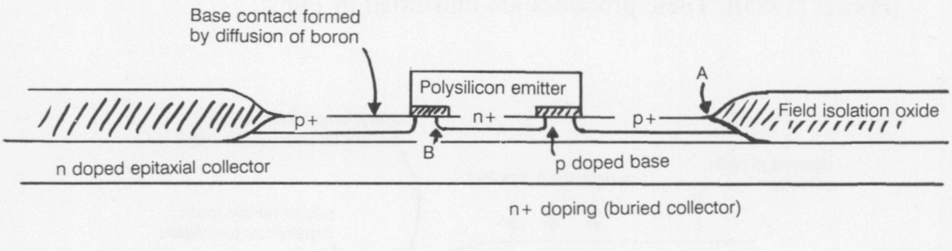
The nett effect is that modern IC manufacturing is capital intensive. It is therefore imperative that the time to develop the technology is reduced to ensure that the large capital investment is turned into production use quickly. To assist in this, computer modelling techniques are now widely used throughout the world, and at STL we have been involved in helping advance these techniques through collaborations in the Alvey and ESPRIT programmes. These modelling techniques embed the technologist's knowledge, previously stored on graphs [e.g. oxide thickness v growing time in furnace] into numerical code which enables the details of the features which control the minimum size of each transistor to be investigated. Thus the techniques form a primitive knowledge-based system combined with a powerful simulation capability to answer "what if" questions and thereby enable the next generation technology to be developed more rapidly.

In this article it is intended that the computation of problems encountered when building these tools will be discussed. The reader interested in the development of the physical modelling, which forms the knowledge base for the simulation is referred to Selberherr (1984), Engl (1986).

2 The Physical Problems of Process and Device Simulation

When developing a silicon technology, two distinct types of simulation tool are used.

Firstly, we wish to understand how the manufacturing process controls the surface topology and the distribution of dopant atoms in the device. Figure 1 illustrates the cross-section of a bipolar device. If we wish to make smaller



A: diffusion at local oxide edge

B: diffusion at n+ emitter edge.

Fig. 1 Cross-section of silicon bipolar device devices it is necessary to reduce the sideways diffusion of the features such as local oxide edge [A in Fig. 1] or the n+ emitter doping region [B in Fig 1]. The steps in the manufacturing process which control these features are the ion implantation procedure which introduces the doping atoms, and the high temperature anneals which subsequently diffuse them. The simulation of these steps is therefore the key part of process simulation.

Secondly, given the device structure, we wish to understand how the device will perform electrically. How fast will it switch? How much current can the transistor supply? What voltage can be applied before the device breaks down? The device simulation stage therefore requires the solution of the equations which control the distribution of potential and flow of currents within the device.

Computationally, the greatest challenge for process simulation is the diffusion process which controls the motion of dopant in the silicon during the anneals and the rate at which oxygen from the ambient gas during the anneal reaches the surface to react with the silicon to form silicon dioxide. These processes can be represented by Fick's equation,

$$\partial c/\partial t = \mathrm{div}\ (D\ \mathrm{grad}(c))$$

where c represents the local concentration of oxidising species or dopant, whilst D, the appropriate diffusivity, is now known to be a complex function of concentration of all of the diffusing species. Thus the model equations are non-linear, coupled partial differential equations with a specified distribution at the start of the anneal. To further complicate the model, the oxidant will only diffuse within a surface oxide layer. When it reaches the silicon it will react to create more oxide, thus changing the location of the interface, the geometry of the oxide and possibly introducing stress into the oxide [Poncet (1985)]. These processes are illustrated in Fig. 2.

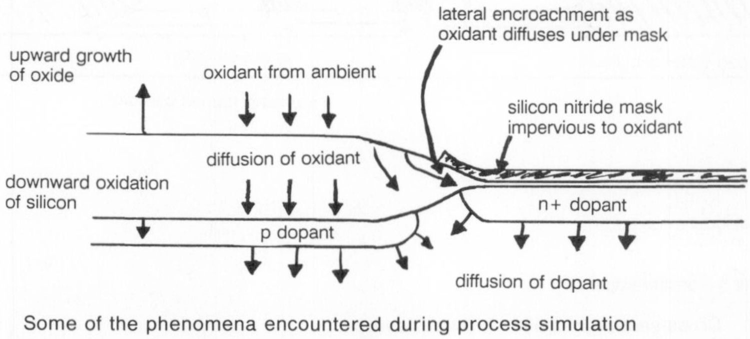


Fig. 2 Some of the phenomena encountered during process simulation

In the device simulator, the distribution of potential is determined by Poisson's equation and the potentials applied at the contacts to the device. Thus

$$\mathrm{div}\,(\mathrm{grad}(\Psi)) = -\varepsilon\varepsilon_o q[p - n + N_d - N_a]$$

where Ψ is the internal electrostatic potential,
$\varepsilon\varepsilon_o$ is the local dielectric constant
p,n are the local hole and electron densities
N_d, N_a are the local density of donor and acceptor impurities
q is the electronic charge.

The current flow within the device simulator is controlled by the equation for continuity of carrier density, and the equation which represents hole flow due to both drift and diffusion.

$$\partial p/\partial t = -{}^1/_q\ \mathrm{div}(J_p) + G$$

$$J_p = -q\mu[p\ \mathrm{grad}(\Psi) + {}^{kT}/_q\ \mathrm{grad}(p)]$$

where J_p is the local hole current density [a similar expression can be derived for electrons]
μ is the local hole mobility
k is Boltzmann's constant
T is the absolute carrier temperature
G represents electron-hole generation or recombination.

These mechanisms are illustrated in Fig. 3.

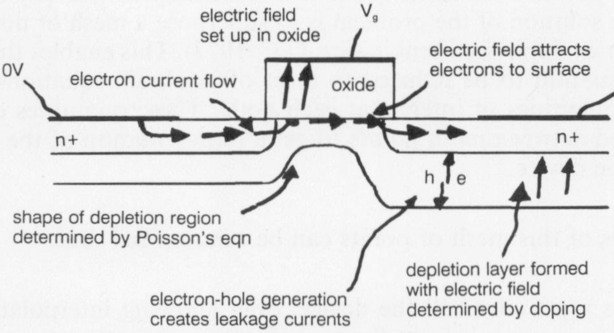


Fig. 3 Some of the phenomena encountered in device simulation

Thus for device simulation the problem can be expressed as a coupled set of equations which are non-linear since the mobility and generation are functions of the carrier concentration and potential [Selberherr (1984)]. Thus the equations for both process and device simulation are very similar in form.

One of the most important features of the equations for silicon technology modelling is that they represent conservation of a physical quantity. In the case of the process models that quantity is the diffusing species; the equations for current flow conserve current and carrier density whilst the Poisson equation conserves charge. These conservation properties are physically important. We expect the current that flows into one terminal of a device to flow out of the others under steady-state conditions, and it is therefore important that they are preserved by the solution techniques used.

The similarity of the equations means that comparable techniques can be used for both process and device simulation. In practice, the computation techniques to solve the process problem have developed less rapidly; this, I believe is due to the fact that there is still a great effort required in developing the physical models for diffusivity whilst the physical models for device simulation are better understood. There has been a push towards improving computational aspects. This push has resulted in the recent development of simulation tools capable of modelling a three-dimensional device (rather than two-dimensional sections through it) in a tolerable time on a minicomputer. Much of the following discussion on computational aspects will therefore be centred on device simulation in which we have been active at STL in the developments in the Alvey device modelling project (VLSI/034) and in the collaborative development of a three-dimensional device simulator in ESPRIT project 962.

3 Mesh Generation

In common with many other engineering problems which can be expressed in the form of partial differential equations, the most practical way to obtain a quantitative solution of the problem is to superpose a mesh of nodes over the device (for example see Zienkiewicz, O.C. 1977). This enables the partial differential equation to be reduced to a set of algebraic equations for the value of the quantities of interest at each node. These quantities can then be interpolated between mesh points to get a representation of the solution throughout the device.

The properties of this mesh of points can be summarised thus:

1 The points must cover all the device, even allowing interpolation into corners that may result from the manufacturing process.
2 The points must be sufficiently close together to allow accurate interpolation; this is especially true where a quantity is varying rapidly.
3 Too many points will lead to slow computation of the solution.
4 The points must be connected topologically in a way that ensures a stable and accurate solution.

Figure 4 illustrates two types of mesh used for simulation.

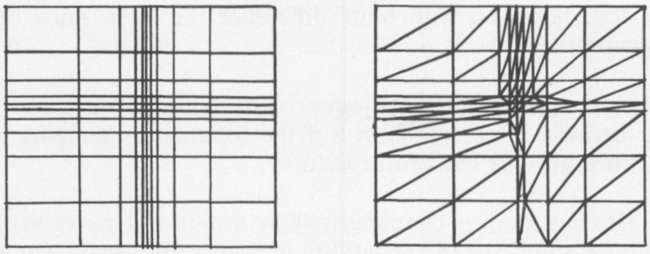


Fig. 4 Types of mesh employed by semiconductor simulators

The 'finite difference' mesh is characterised by mesh lines that pass directly from one side of the device to the other. This type of mesh is extremely easy to construct. If the device is not rectangular it is possible to find a mathematical transformation that maps the device onto a rectangle and construct the mesh on the transformed domain. If the mathematical transformation can be achieved with a conformal mapping (Penumalli B.R. (1983)) then the equation set is not overly complicated by the mapping. This technique is often used for the solution of diffusion of dopant under an oxide where the interface is smooth (as in Fig. 2). An example of such a mesh is shown in Fig. 5).

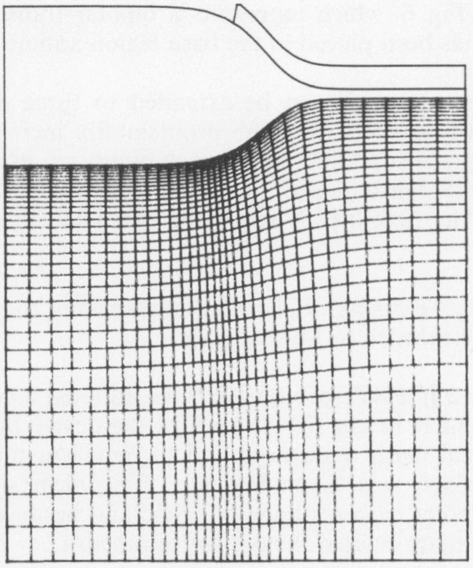


Fig. 5 Conformally transformed mesh in silicon under a selectively oxidised surface

To meet the second requirement of adequate mesh density, the only recourse is to insert more mesh lines. With a finite difference mesh this can be wasteful as the extra mesh density is often only needed at one place in the device, say at the top; however, with finite difference the mesh must be inserted from top to bottom.

The rectangular geometry of the mesh provides a stable numerical 'discretisation' and because of the regularity of the topology, managing data on a finite difference mesh is straightforward.

The finite element mesh is characterised by a union of polygons which fill the device. For simplicity and generality, triangles are usually chosen in two dimensions. This allows any general boundary to be represented by a piecewise linear approximation. With this type of mesh, any domain can be represented without a transformation and mesh points can be added locally if extra refinement is needed.

At first sight this appears to be the ideal choice for all meshes. However, managing the data on a finite element mesh is not so straightforward and generating the mesh is very difficult. To exploit the mesh fully requires considerable user intervention to select the areas where mesh refinement is required. Furthermore, the requirement that the mesh topology gives rise to an accurate and stable solution can be shown to require meshes that contain no (or at least very few) obtuse angled triangles. Despite these problems, finite element meshes are frequently used, though the most successful variants are those that build their mesh from a rectangular grid such as that shown in Fig. 6, which represents a bipolar transistor where extra mesh refinement has been placed in the base region and at the pn junctions.

The finite difference method can be extended to three dimensions fairly simply, but it must be noted that the problem size increases rapidly. For two-dimensional problems 2,000–4,000 mesh points are usually required for a typical finite difference mesh. In three dimensions this increases to 50,000–100,000. The inability to refine the mesh locally is now a severe disadvantage.

To implement a finite element mesh in three dimensions, the logical extension would be to use tetrahedra to fill the space.

In the collaborative ESPRIT project (962) we adopted a compromise position where rectangular bricks fill the bulk of the device but tetrahedra are used to enable local mesh refinement and to represent the boundary geometry. This approach was taken because of problem size [it takes five tetrahedra to represent each rectangular brick] and because of the slowness of calculating geometry-related factors for tetrahedra.

So far the comments on mesh generation are based on the concept of a fixed 'a priori' mesh. This relies heavily on it being possible to identify a mesh which is accurate enough and based on the user's 'feel' of how the problem will turn out. Inevitably, to ensure the mesh being accurate enough, extra mesh points are included, leading to longer simulation times. In

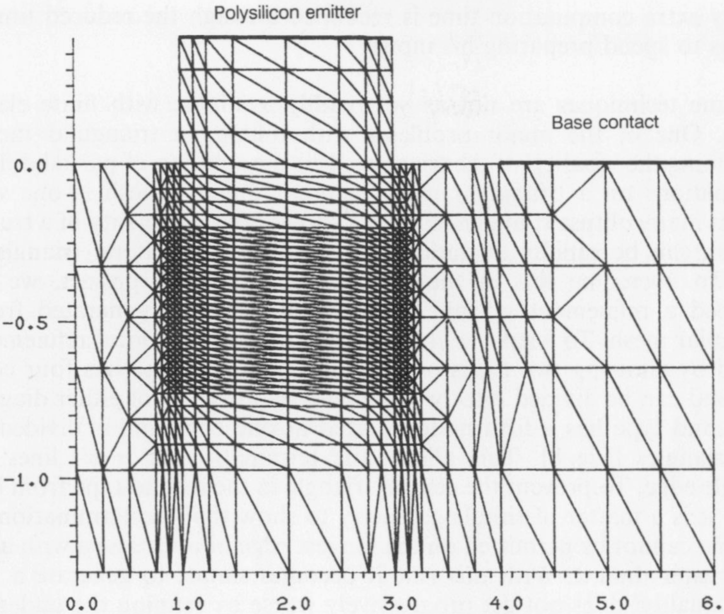


Fig. 6 Finite element mesh representation of a polysilicon emitter bipolar transistor

addition, as the simulation progresses, the domains which require a fine mesh to resolve the variable of interest move through the device. This situation is encountered when dopant is being diffused into the silicon from the surface and the dopant depth increases monotonically as the diffusion time increases.

Current simulation still relies on a cautious, fixed mesh and hence longer simulation times. Within the Alvey process modelling project [VLSI/066] the moving finite element method [Miller K 1981] which is used to simulate shock fronts, was investigated for this problem. In the moving finite element method the mesh topology is kept fixed but the nodes are allowed to move with the diffusing species. Limited success was obtained, but the difficulty of choosing the topology of the initial mesh so that it could move successfully with the advancing profile meant that the method could never be used with great confidence.

The second approach to automating the mesh is to add nodes wherever the interpolation is inaccurate according to some criterion which can be determined by the software. This approach can be implemented very easily in a finite difference mesh if a suitable criterion for error can be defined. MINIMOS [Selberherr 1979] is probably the most widely used device simulation program available and it automatically inserts lines wherever the potential is changing rapidly. Thus the user need never get involved with the mesh and any extra computation time is recouped through the reduced time the user has to spend preparing his input.

The same techniques are not as yet readily available with finite element meshes. One of the major problems with refining a triangular mesh is maintaining the 'quality' of the triangles. For the solution of partial differential equations on a triangular mesh, a poor 'quality' mesh is one which contains many obtuse triangles. Figure 7 shows how the quality of a triangular mesh can be rapidly degraded by refining an equilateral triangle just twice. To overcome this in the collaborative ESPRIT project, we have developed a refinement scheme built around triangles generated from a rectangular mesh. To keep the finite element advantages, local refinement is enabled by allowing two types of rectangle. The first type has four corner nodes and can be divided into two triangles by insertion of either diagonal. The second type has a fifth node inserted at one edge and is divided into three triangles [Fig. 8]. This allows the termination of mesh lines at a rectangle edge. To prevent the central triangle in the second type from being obtuse, it is a matter of simple geometry to show that the termination of a mesh line cannot be permitted on the longest edge of a rectangle with aspect ratio greater than 2. With this rule it becomes simple to generate a mesh whose 'quality' does not get progressively worse by refining the underlying rectangular structure. The mesh shown in Fig. 9 captures a p-n junction by an automatic refinement procedure based on this rectangular structure. This concept is now being extended to cover three-dimensional simulation domains where it is very important to have an automatically adapted mesh as it is impossible to view a three-dimensional mesh to judge its adequacy.

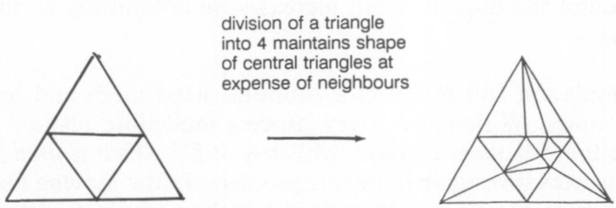


Fig. 7 Degradation of triangle 'quality' through refinement

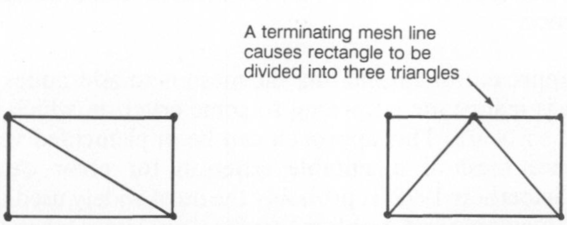


Fig. 8 Two types of rectangle used to build an adaptive finite element mesh

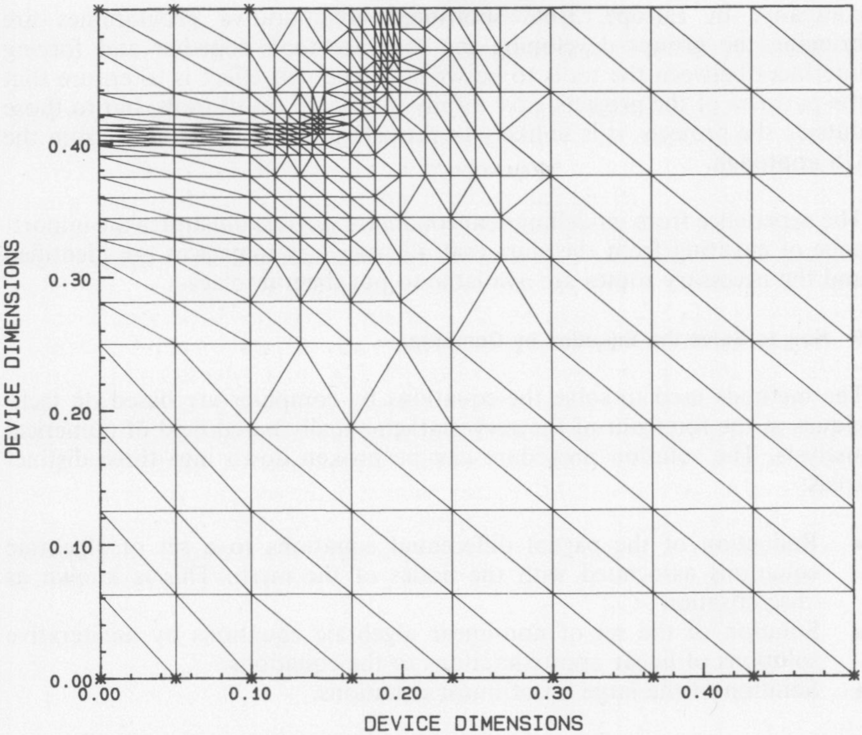


Fig. 9 Depletion region around a p-n junction captured by an automatically adapted grid

4 Interfacing

Historically, process and device simulators have been independently developed. This poses the user with the problem of providing an interface which enables data describing the device geometry and the doping to be passed from the process simulator into the device simulator or for results from either simulator to be displayed graphically in a consistent form with a single set of commands. Furthermore the native input language to control the simulator can be very different from one code to the next. Within the semiconductor simulator field there is no defined standard nor has any one piece of software gained such a dominant position that it provides a 'de facto' standard. Practically, most large companies have developed some form of interface software for the tools they use. At STL we have developed a central interface programme which enables data to be taken from one code, displayed and/or converted to the input format of a second code.

Two other interfacing solutions are emerging. In the United States, simulation software is sold by small software companies (eg. TMA) who have taken University developed software, polished it and provided interfaces. These interfaces, however, lock the user into software provided by that company. In Europe, EEC sponsored collaborative programmes are bringing the groups developing the software tools together and forcing interfaces between the tools to be written. The nett effect is to ensure that the partners of the projects have a fully interfaced set of tools; but to those outside the projects, it is unlikely to provide tools any differently from the US approach.

The experience from modelling semiconductor devices illustrates the importance of ensuring from the start that all necessary interfaces are identified and the necessary routes are available to put them in place.

5 How to Solve the Equation by Computer

The methods used to solve the equations by computer are based on techniques at the forefront of the very mathematically based field of numerical analysis. The solution procedure can be broken down into three distinct areas:

- Reduction of the partial differential equations to a set of algebraic equations associated with the nodes of the mesh. This is known as 'discretisation'.
- Solution of the set of non-linear algebraic equations by an iterative solutions of linear approximations to the equations.
- Solution of the large set of linear equations.

Whilst it is inappropriate to follow these topics through in detail in this article, further information is presented in the appendix and details can be followed up in the references. In this section I wish just to present some of the key directions pursued in developments in which STL has been involved.

The 'discretisation' of the semiconductor problem is strongly based on the requirement to conserve key physical quantities. For example, once an impurity has been introduced into a silicon wafer by ion implantation, subsequent heat treatment will redistribute the impurity but not change the total quantity unless some diffuses to a surface from which it can escape. This conservation is achieved by ensuring that the 'discretisation' approximates the physical fluxes which flow from node to node thus ensuring that any flux which leaves one node will be transferred to its neighbours.

The set of algebraic equations which result from the 'discretisation' of the semiconductor problems is always non-linear. This is at its most severe when trying to simulate the current flow within a device, as the local carrier density is a rapidly varying (exponential) function of the potential. This should come as no surprise, as it is this rapid dependence of carrier density on potential that enables semiconductor devices to make such good switches and amplifiers. The solution of such a set of non-linear equations is achieved by a traditional iteration technique originally due to Newton where an initial guess is improved by looking at the slope of the non-linear function at the current guess. This technique works well for the semiconductor problem but developments have been made to:

- improve the initial guess based on our understanding of the problem.
- allow us to compensate for some of the known curvature about our current guess as we try to improve it.
- give us improved criteria to state when the iteration procedure can be terminated.

The effective solution of the non-linear equations relies on having an efficient linear solver to calculate the update that needs to be applied to improve the current guess. However, since a typical problem has 4,500 – 12,000 equations, the linear solver must perform well on large problem sets. A special feature of linear equations that are generated from partial differential equations is that they are 'sparse' i.e. each equation involves only a few variables, those at the neighbouring nodes. The combination of sparse storage schemes and efficient modern linear algebra techniques based on iterative methods have been demonstrated in our projects to represent a significant step forward in performance for large problems. This advantage comes because the time to find a solution increases less rapidly with problem size than conventional techniques. On a symmetric test problem the time taken was given by:

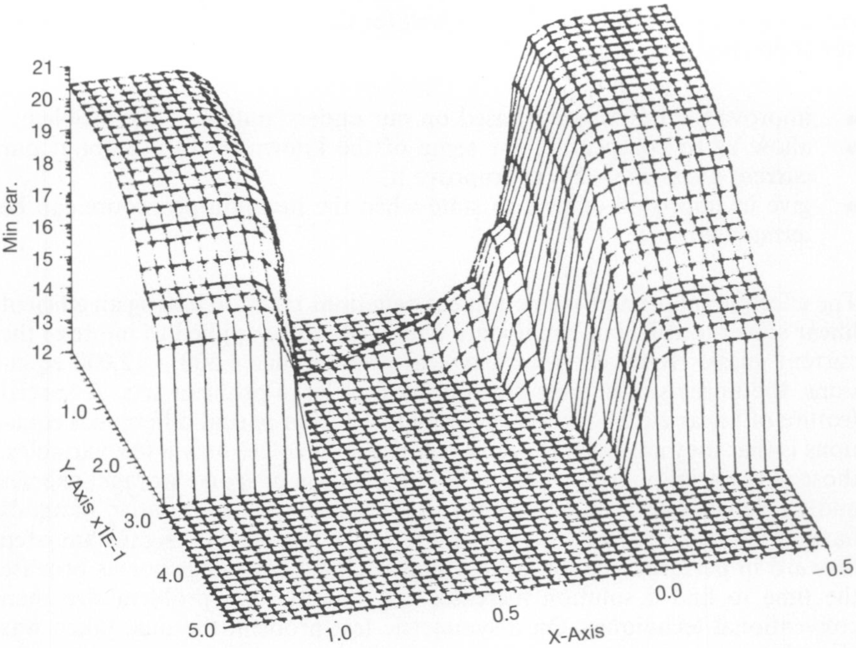
$$[(\text{no.of unknowns})/1000]^{1.3} \text{ seconds on a VAX 8650.}$$

6 An Example

At STL the modelling techniques have recently been applied to the development of a 1 μm CMOS technology at STC Components. One of the important design issues in CMOS technology is the engineering of the pMOS device doping to ensure that, even when the maximum bias is applied to the drain terminal, if the gate is turned off no significant leakage current flows.

The initial process flow drawn up with the process engineers was simulated and the hole density within the device is shown in fig. 10a. The two regions of high hole concentration either side of the device are the source and drain contacts and the ridge of holes connecting them represent a leakage path beneath the surface of the device. This conduction beneath the surface is known as punchthrough and by inspection of the doping profiles in the device it was simple to identify that this was caused by excessive diffusion of a surface boron layer during the critical gate oxidation step. It is worth emphasising the point that without simulation there would be no way that the position of the leakage path could be identified by measurement.

In this case the punchthrough is not severe, but we took the opportunity to move the process away from a latent problem by exploring the different



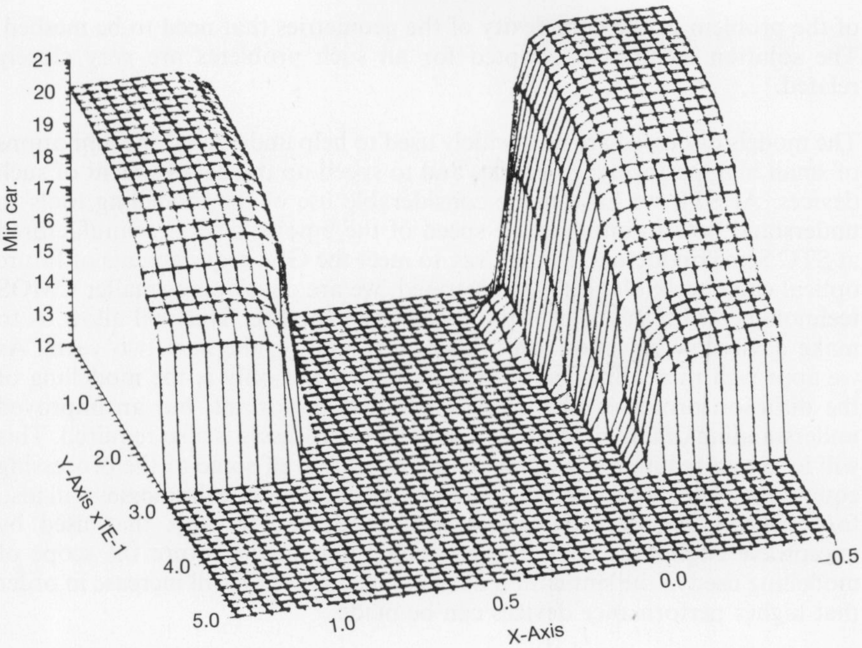
a/ original process showing start of leakage path

Fig. 10 Distribution of holes in a 0.8 μm p-MOS device with −5V on the drain but the gate turned off

process options which would influence the profile using a one-dimensional process simulator where run times take a few minutes on a microVAX. The process was reconfigured with the surface boron layer being created after the gate oxidation. The hole concentration within the device no longer displays the ridge from source to drain, indicating that the modifications were successful. The two-dimensional simulations required up to two hours of CPU time on a VAX station but the results are obtained sufficiently rapidly that a particular process option can be investigated by an engineer using simulation tools in about one week.

At STL, about 3 man-months of simuation work have been used to provide a process flow which we predict will provide n- and p-channel devices of close to target threshold voltages [+0.8V, −0.8V respectively]. The devices will not show punchthrough behaviour and the isolation between devices will resist breakdown at maximum supply rating.

Even with well planned experimental work, to reach this stage would take 3 or 4 batches of silicon and at least 6 months after the necessary equipment has been installed. Thus modelling provides a significant saving after allowing for the modest computational costs and the cost of maintaining and developing the software. The latter costs are reduced by purchasing the



b/ final process adjusted to suppress leakage.

Fig. 10

basic programs from companies which provide maintainance, and by developing software within collaborative projects as this allows sharing of costs with other industrial users.

The simulations of the 1 μm CMOS process have not yet been proven, the first silicon is still in processing. Nevertheless the modelling tools have been proven on earlier technologies to give confidence in the accuracy of the simulators used. In particular, considerable experience has been obtained in simulation of the key MOS parameters of threshold voltage where the simulated value has been typically within 100 mV of the measured value. Considerable effort has also been put into accurate models for the mobility within the silicon, and above threshold the current can be predicted to better than 20%. This accuracy is sufficient to give confidence in the performance the first devices will have and we are expecting only one minor iteration to bring us to our target process.

7 Final Comments

I have given an overview of the general mathematical models we use to simulate semiconductor processes and devices, and the techniques we use to solve the equations. The mathematical models are similar to those used in other fields, such as cooling of circuit boards, or flow of oil from an oil reservoir. Numerically, the distinction between the problems is often better made not so much by the model equations as by the resulting non-linearity of the problem or the complexity of the geometries that need to be meshed. The solution techniques adopted for all such problems are very closely related.

The models discussed are now widely used to help understand the limitations of small high performance devices and to speed up the development of such devices. At STL we have made considerable use of the modelling tools to understand how to improve the speed of the bipolar devices manufactured at STC Semiconductors, Foots Cray to meet the Gbit requirements of future optical cable technologies. As illustrated, we are developing smaller CMOS technologies with the help of the modelling expertise. This will allow us to make devices with feature sizes down to 0.7 μm in the next two years. As we approach these dimensions, it is clear that not only is the modelling of the diffusion processes and device operation important, but an improved understanding of film deposition and etching processes is also required. This will lead to a requirement to model the operation of some of the processing equipment. The move towards higher speeds in silicon technologies will also force silicon engineers to extend their modelling towards that used by microwave engineers. Thus it is envisaged that in the future the scope of modelling used in the simulation of silicon technologies will increase in order that higher performance devices can be made.

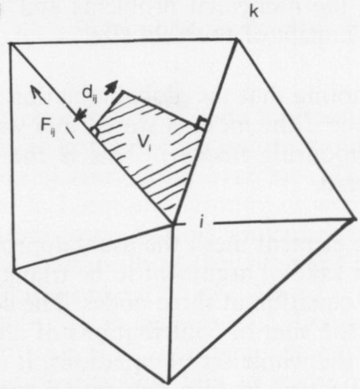
8 Appendix

'Discretisation'

Semiconductor device simulation poses some particularly tough problems for the numerical analyst trying to convert the partial differential equations into a finite set of equations. Both the process and the device simulation processes require the ability to cope with a very large change in the key variable. For example, the doping in the emitter of a bipolar transistor will change by two or three orders of magnitude close to the base junction, whilst the electron concentration can change by more than ten orders of magnitude at the same place. This constraint has prevented the adoption of the sophisticated 'discretisation' techniques that have been developed e.g. higher order finite elements. In fact, the same principles are used for 'discretisation' of the equations whether on a finite element or finite difference mesh.

The underlying concern is to ensure that a consistent picture for conservation is established. Thus the discretisation will maintain the conservation of current, dopant, etc. This is achieved by building up a flux balance equation at each node, as illustrated in Fig. 11. At each node (i) a box is drawn around that node that encloses all the area which is closer to node i than to any other node. The edges of this box are the perpendicular bisectors of the lines ij joining i to its nearest neighbours j. Now the form of the equations which represent the physics of the processes involved is,

$$\operatorname{div} \underline{F} = A$$



FOR each triangle with node i DO

set up $\sum_{m=j}^{k} d_{im} F_{im} = V_i A_i$

ENDDO

Fig. 11 The box scheme to assemble div(F) = A

To form the discrete set of equations we wish to approximate this equation using only the values of the variables at the nodes of the mesh. In the discrete form of the equations we actually solve a weaker form of this, since we cannot ensure that this equation is true everywhere in space [in a finite mesh]. We insist that

$$\int_{\text{box i}} \operatorname{div}(\underline{F})\, dV = \int_{\text{box i}} A dV$$

Thus we are ensuring that this equation is solved in the average sense on each box. The left hand side can simply be transformed using the divergence theorem:

$$\int_{\text{box edge}} \underline{F}\, d\underline{\Gamma} = \int_{\text{box i}} A dV$$

To be able to use this equation we have to make further approximation since neither A nor F is known throughout space. A at node i is assumed to be a good approximation to the average over the whole box whilst $\underline{F}\, d\underline{\Gamma}$ is approximated by flux along the line ij [which can be calculated from the variable at nodes i and j] and the width of the edge d_{ij}. Thus we can write the equation as,

$$\sum_{j} d_{ij}\, F_{ij} = V_i A_i$$

Thus at each node i the problem will be represented by one equation for each variable. Each of these equations is (in general) non-linear and involves the variables at node i and its immediate neighbours j only. This defines the topology of the numercial problems and I shall return to this when considering the impact of problem size.

It is worth noting that the global equation for each node can be set up one node at a time if the mesh is stored in a way that gives easy access to each of the neighbouring nodes j. This is the standard approach for a finite difference mesh.

With a finite element mesh the usual approach is to note that each element [assumed for sake of argument to be triangular] will have a contribution to make to the equation at three nodes. The complete equation at any node is made up of the sum of contributions of all elements containing that node. To generate the whole set of equations, it is simply necessary to pass from element to element in turn generating each element's contribution to all three nodes and adding these contributions into the relevant model equation. Thus the flexibility of the finite element method is obtained, since we only need to consider discretising the equation on an individual element basis. This latter point can also be shown to be true even if there is a change in material as we pass from element to element, and so the discretisation is completely decoupled from the geometry.

A final comment is related to the calculation of the flux passing from node i to node j. The discretisation method will work well provided this flux is not rapidly varying from element to element. Scharfetter and Gummel (1969) exploited this fact when they demonstrated that it was possible to make a sensible discretisation of the device equation even in the presence of a rapidly varying electron or hole density. This occurs in a forward-biased p-n diode, for example, where there can be a very rapid change in carrier density as we pass through the depletion region, yet the current flow is almost constant. Thus, when calculating the current flowing from i to j from

$$J_p = -q\,\mu\,[p \text{ grad } (\Psi) + \left(\frac{kT}{q}\right) \text{grad } (p)]$$

it is not adequate to use linear difference to approximate grad(p) but a variation of p should be assumed between the nodes that keeps J_p constant. This leads to a current flowing between nodes i and j.

$$J_{ij} = \frac{q + [\Psi]_i^j [p.\exp(q\Psi/nT)]_i^{j*}}{L_{ij}[\exp(q\Psi/kT)]_i^j}$$

- where $[f]_i^j = f_j - f_i$

The extra complexity of this equation is essential because of the accuracy and stability it brings to the solution of the device equations. This approach has been adopted in all device simulators in use today, which demonstrates the power of the technique.

The Non-linear Iteration Procedure

The iteration procedures commonly used in the device simulators are illustrated in Fig. 12. The fully-coupled method, or Newton method, solves all the equations together ($F(u)=0$) and uses the derivative of these equations with respect to the variables (u) to guide the update procedure. Schematically this can be obtained by truncating a Taylor series; thus it is required that:

$$F(\mathrm{u}+\delta u) \approx F(u)+\partial F/\partial u\ \delta u=0$$

hence $\delta u=-[\partial F/\partial u]^{-1}F(u)$

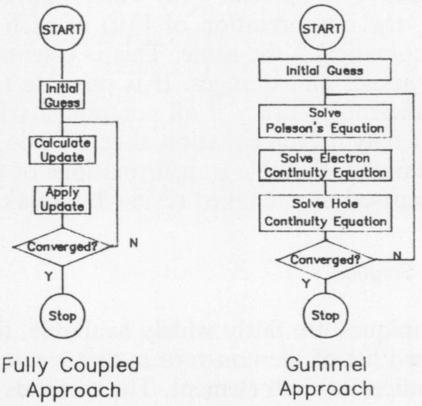


Fig. 12 Iterative schemes employed by device simulators

Note that as there are n equations to be solved (three for each mesh point) and n variables, $\partial F/\partial u$ is an n by n matrix. For problems of ≈ 1600 mesh points solving the above is expensive. The fully coupled process requires a good initial guess from which to converge, but once the updates in potential are less than 25 mV, rapid (quadratic) convergence is guaranteed and machine accuracy can be achieved in a further four iterations.

The alternative procedure is due to Gummel (1964). In this procedure the equations are solved sequentially. However, this ignores coupling between the equations, so the procedure is repeated until convergence. Because this procedure does not generate such a large matrix to invert, it is more economical per iteration than the Newton procedure. Moreover it converges better from a poor initial guess. However, it does not display quadratic convergence at the end of the iteration and is therefore more difficult to terminate.

The demands of problem size mean that the sequential or Gummel procedure is usually preferred for device simulation. However, many simulators mix the Gummel procedure and the fully-coupled procedure, exploiting the greater economy of the Gummel procedure to provide a good initial guess, and then obtaining rapid convergence by switching to the fully-coupled scheme.

It should be noted that considerable care has to be put into the conditions for terminating these iterative procedures. Two points need to be considered when defining the truncation. Firstly, the same absolute accuracy is not always required at every point in the device. For example, where the carrier density is 10^{20} cm^{-3} a figure of 10^{18} cm^{-3} is accurate, but this would be completely inadequate where the carrier density is only 10^{16} cm^{-3}.

Secondly, it is attractive to monitor F(u) which approaches zero near the solution. However, the interpretation of F(u) at each node and for each equation is not automatically the same. This is essentially the problem of trying to compare apples and oranges. It is possible to say the equations are solved with sufficient accuracy if all components F(u) are less than a given tolerance, but only if each equation at each node is suitably weighted to give a fair comparison. Suitable transformations of the equations which achieve this are discussed in a detailed review by Polak (1987).

The Linear Equation Solution

Sparse storage techniques are fairly widely available, the general principle is to store an ordered list of the non-zero matrix elements and a list of the row and column indices of each element. The methods for storing the row and column indices are a trade-off between storage space and ease in performing matrix arithmetic with the resulting matrix. The technique we have adopted in the three-dimension simulator is based on the work of Fichtner in Engl (1986). It has the advantage that it is suitable for use where there are several equations to be solved at each node of a mesh. In this case the sparse structure represents only the mesh topology. However, each element stored is no longer a scalar but is a small block matrix ($m \times m$) where m is the number of equations to be solved at each node. This has the added advantage that the sparsity pattern does not vary as the number of variables at a node increases. It is also mathematically straightforward to perform all matrix operations using these submatrices by simply replacing all scalar operations with their equivalent matrix operations.

To solve the matrix equations, the conventional techniques used for small matrices such as LU decomposition [Wilkinson (1965)] are not available as they introduce extra non-zero elements into the matrix. Iterative techniques provide a means of solving large families of equations without having to introduce extra non-zero elements. To illustrate the iterative technique consider the equation.

$$Ax = b.$$

If we have an approximation to the solution x_n. We can define a residual

$$r_n = b - Ax_n$$

If we can define a simple operation A^{-1} which approximates to the inverse of the matrix A we can write

$$x_{n+1} - x_n \simeq A^{-1} r_n$$

and here we can calculate r_{n+1} etc. until we have an adequate solution. The success of this method relies on the suitable choice of A^{-1} so that it gives a rapid convergence and is economical to calculate with the sparse matrix structure. When the matrix is symmetric, positive definite and an m-matrix [Polak, 1988] the technique of ICCG [incomplete Cholesky conjugate gradient] due to Meijerink [1977] proves a very reliable and robust scheme. However, in general our problem is not symmetric and there has never been as clear a choice for asymmetric matrices as there is for symmetric matrices. We have adopted the CGS [conjugate gradients squared] technique of Markham [1983] and applied an incomplete LU decomposition to precondition the problem. This has given reliable results.

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The use of Ward and Mellor Structured Methodology for the Design of a Complex Real Time System

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Abstract

The real time system described provides the soft functionality for the Node Support Computer of the SX Node which was described in the previous issue of the Journal. The designers' aims for the project – known internally as ISA for Initialisation and Support Application – were to produce a real time system of improved quality and at the same time to increase their own productivity. These objectives were achieved by using the Ward and Mellor Structured Methodology supported by the proprietary design capture tool Excelerator.

The background of ISA is recounted and the reasons for choosing the methodology and how it was introduced into the project are explained. The analysis and design phases of the project are then described, emphasising the Ward and Mellor features employed and the use of Excelerator. Finally some broad conclusions are drawn from the success achieved through the use of both methodology and tool.

1 Background

In 1987 the project was faced with the challenge of producing a complex Real Time System. Statistical evidence from the previous project (OSA) [Saxon 1986] demonstrated an imbalance with regard to the various principal Lifecycle Model phases. Insufficient time had been spent on the analysis and design phases which had resulted in significantly longer times for the coding and testing phases. Research [Macro and Buxton 1987] emphasised the importance of the analysis and design phases in reducing timescales and bug count. It also highlighted the previous lack of sufficient effort on these phases.

It was therefore felt that emphasis on the analysis and design phases would offer major improvements in product quality, a reduction in overall time-scales and a reduction in the bug density of the product delivered to

Integration. The selection of an appropriate methodology and support tool is discussed later but their introduction added additional complexity with respect both to staff training and to tuning the methodology to the specific problem domain of the product.

This paper shows *how* the chosen methodology was introduced and subsequently used in the analysis and design of this complex real time system. It does not describe either the methodology itself or the design support tool which was used by the project, though a summary of the methodology is included.

1.1 The product

The product, ISA, is the Initialisation and Support Application which is resident in the Node Support Processor (NSX) of an SX Node (SX being the large Mainframe first marketed by ICL in 1990).

The main ISA functions are –

- Control of Initial Program Load (IPL).
- Error Management of Fatal Node Hardware Failure (Photo).
- Error Management of Fatal Node Software Failure (Dump).
- Support of In-Line Recovered Node Failure.
- Support of Remote Diagnostic Access to the Node (VISA).
- Support of Ancillary Units ie. power and coolant control systems, cabinet displays and switches.
- Support of Operational Node software ie. provision of Software Watchdog and Non-Volatile Store.

ISA is the evolutionary sucessor to a set of three applications which provided similar functions for earlier versions of Series 39 Nodes. It is based on and is structurally very similar to one of these applications, OSA (Operational Support Application) which was a Multi Task application. A Multi Task solution offers one effective means of partitioning functionality especially in a real time situation involving multiple sources of events and process concurrency.

The final product is approximately 17,500 lines of code and has cost nearly 30 man years of efforts from High Level Analysis and Design through to Customer Release. It is written in PLM86 and the processor within the Node Support Computer is an Intel 80286.

1.2 Need to improve

There was a low perceived value attached to Support Processors which paradoxically had been complex and costly to produce as bespoke hardware and software solutions. There was a view that by moving aspects of the functionality into node software and Picode (microcode) and by making the node hardware self initialising and self diagnosing, the Support Processor could be designed out.

These views dominated early SX system design and the production of an evolutionary product in the Support Processor area was not considered to be the way forward. Despite this, as early SX System Design progressed major gaps were found in the traditional Support Processor areas of IPL, Error Management and Remote Diagnostic Access. It was then decided that an evolutionary product was needed despite the fact that some functionality had been successfully moved into node software and Picode and the node hardware had been designed with ease of initialisation and diagnosability as design constraints.

A requirement on the ISA Project was to improve productivity and delivered product quality from that achieved with the earlier equivalent products. To meet this requirement decisions were made to put increased emphasis on the analysis and design phases, to introduce a design methodology and to introduce design support tools. The choice of methodology and tools is considered in Section 2.

1.3 Common house style

Within OSA there had been successful use of a "house style" for design and implementation (eg documentation standards, code style and standards). This had enabled easy movement of staff within the project and had enhanced the effectiveness of design reviews and desk checking of code.

A similar approach was adopted for ISA covering design, implementation and the selection of the appropriate parts of the chosen methodology.

2 Adoption of new methodology

There is no alternative to the use of a methodology. A choice can however be made between an explicit formal methodology and an implicit Traditional and Common Sense (TACS) methodology. A major problem with TACS is the individual person's interpretation of "common sense". Common sense is paradoxically not common (ie shared) at all and therefore TACS relies to a large extent on experience and personal intuition.

Many organisations have endeavoured to develop their own methodologies, building upon their present tools and techniques', however as stated in [Maddison 1983], "A complete methodology specification may be impossibly long to write and teach, and to cover every possible real situation would waste developers' time during training".

It therefore seemed sensible that the ISA Project should consider the adoption of an established and proven methodology. There is no formal method to compare design methodologies. Certain non-rigorous classifications exist, but essentially a methodology is optimised for a particular problem domain. The choice of a methodology and its introduction are discussed below.

2.1 Choice of methodology

ISA is an example of a Real Time System (RTS), and displays the following typical characteristics.

a) Sensors which continually report the state of the various components of the system and its environment.
b) Functionality to allow the system to react to changes in the environment (eg. sense a breakdown and implement a corrective action).
c) Concurrent processing of multiple inputs/outputs etc.
d) Being aware of and responding to events.

A list of prime objectives was drawn up to serve as input to the selection of a specific methodology. This list was also used later as a basis for the evaluation of the software development process.

2.1.1 Prime objectives

1 The methodology must be graphic in nature. Pictorial representation has been proved to be more easily understood and meaningful.
2 The graphical system must be 'rich' enough to convey the design, easy to understand and use as few symbols as possible.
3 The chosen methodology must run on a design capture tool, the heart of which must be a data dictionary. Any attempt to use a structured technique without a data dictionary at its heart is likely to be unsuccessful.
4 The methodology must be applicable to the analysis and design of a RTS. It must provide for the modelling of events, parallel processing etc.
5 The methodology must distinguish the "Essential" features of a system (ie. the characteristics it would have if implemented with perfect technology) from its "Incarnation" (ie. eventual implementation).
6 The methodology must be expandable with problem size and through different levels of abstraction.
7 The methodology must provide the ability to perceive the system as a whole, and allow for partitioning of functionality.
8 The methodology must provide a range of complementary viewpoints of the design (ie. for a RTS – Control, Process and Data).

A study by the ISA Project and the Development Route team resulted in the choice of the Ward and Mellor methodology [Ward and Mellor 1985], using the design capture tool Excelerator RTS [Index Technology Excelerator Series 1989].

The Ward and Mellor methodology is based on the SADT (Systems Analysis and Design Technique) developed and marketed by Ed Yourden [Yourden and Constantine 1979] and Tom de Marco [De Marco 1978]. The Ward and Mellor methodology extends the traditional Data Flow diagram with the introduction of Control Transformations and Control Flows. Control Transformations are an essential aspect of RTS analysis and design and allow for a state view of the system in the form of State Transition Diagrams. Control Flows allow for the signalling of events both within (temporal) or external to the System.

Excelerator RTS is a RTS analysis and design support tool which incorporates graphics facilities, a data dictionary, analysis reports and a documentation production facility. It is particularly suited for use with the Ward and Mellor methodology and supports the full range of graphs required.

This combination of Ward and Mellor/Excelerator fulfilled all the above objectives, as did several other possibilities. The combination also however offered certain advantages which are listed below.

2.1.2 Advantages of the adoption of Ward and Mellor/Excelerator

1 Excelerator RTS was the most widely used design capture tool, and the Ward and Mellor methodology had been adopted by many major industries.
2 As Excelerator ran on IBM PC compatibles, an ICL DRS M60/80 network could be used.
3 There were well established "User Group" and "Hot Line" facilities, together with a range of specialised training courses.
4 The assessment of the design quality (at reviews and elsewhere) was greatly facilitated. This was as a direct result of applying the more formal criteria of:
   - *Cohesion* – How well the components fit together.
   - *Coupling* – Inter-module dependency & extent to which the effects of change need to be considered.
   - *Information Hiding* – The extent to which design decisions are concealed from "view".

These criteria can be divided further, as specified in [Page-Jones 1988]. Yourden has also attempted to assign weightings to the various sub-levels [Bergland and Gordon 1981] which is useful in that it highlights the more important aspects of the above criteria.

2.2 Methodology introduction to project

The emphasis was on the creation of an "Awareness of Design and the Design Process" rather than the teaching of specific design skills.

The limitations of our perceptions can be traced beyond the flow chart to the Von-Neuman architecture. This architecture, performing a sequence of operations, one at a time, on elemental data items "acted as a powerful symbol and conditioned our perceptions" [Page-Jones 1988]. People nurtured in traditional DP environments tend to see a problem in terms of sequences and operations to be performed. An attempt was made in the project to break this "Von-Neuman mind-set" and to emphasise an "Outside In" rather than a "Top Down" design approach.

The limitations of currently used methods (flow charts, text) were explained to the Project and the benefits of the new methodology were emphasised. It was shown that flow charts were incapable of capturing a RTS (eg. no way of representing concurrent processing or the responding to events). Examples demonstrating the sequential nature of flow charts were used to show that they could only be used in a restricted environment. Textual representation of design was shown to be unsuitable for many reasons (eg. ambiguity, difficulty of detecting omissions). A "textual design is largely dependant on the grammatical ability of the designer".

The quality measures of Cohesion and Coupling were used to highlight the additional clarity gained by using the Ward and Mellor methodology. This more than any other factor proved to be most influential in achieving a general staff acceptance of the new methods.

Staff training consisted of the CTD2 (Core Technical Training) course, internal presentations and individual study of the methodology via application to ISA functionality. This required a substantial investment in time and energy and involved a large learning curve.

3 Ward and Mellor usage

ISA is a complex real time system. No information on the Ward and Mellor methodology (textbooks, worked examples, etc) could be found demonstrating its use for the modelling of such a system. The use of this methodology in the design of ISA therefore broke new ground and involved innovative uses of the methodology features.

3.1 ISA Analysis and Design History

The analysis and design phases of ISA followed the Ward and Mellor model hierarchy. Note however that the terms Logical and Physical are taken from [McMenamin and Palmer 1984] whilst in [Ward and Mellor 1985] the terms Essential and Implementation are used. The terms Logical and Physical were adopted by the project as they emphasised the lifecycle stages of *Logical Analysis* and *Physical Design*.

The modelling began with the construction of a High Level Logical (or Essential) Model. Although it was feasible to resist any work on the Physical

Model until completion of the Logical Model, the approach chosen involved the production of a High Level Physical (Implementation) Model at an earlier stage and the iteration between these Logical and Physical Models was found most useful (as it was throughout the analysis and design phases). Though shown as a separate phase on the diagram below, the Low Level Logical Model was in fact produced as part of Low Level Physical Design and a full understanding of the Low Level Logical Analysis phase has only been gained in retrospect. The Low Level Physical Model from which the implementation of ISA took place therefore also contained the Low Level Logical Model. Details of the analysis and design phases associated with these models can be found in Sections 3.2.1 – 3.2.4.

At specific stages in the analysis and design phases "Fagan" style reviews were held before proceeding to the next phase.

Though at times iteration back to the Logical Model lagged behind developments on the Physical Model this iteration was always carried out and the High Level Logical Model now represents a clear, implementation-free model of ISA.

The *ISA Analysis and Design History* is summarised in Fig. 3.1.

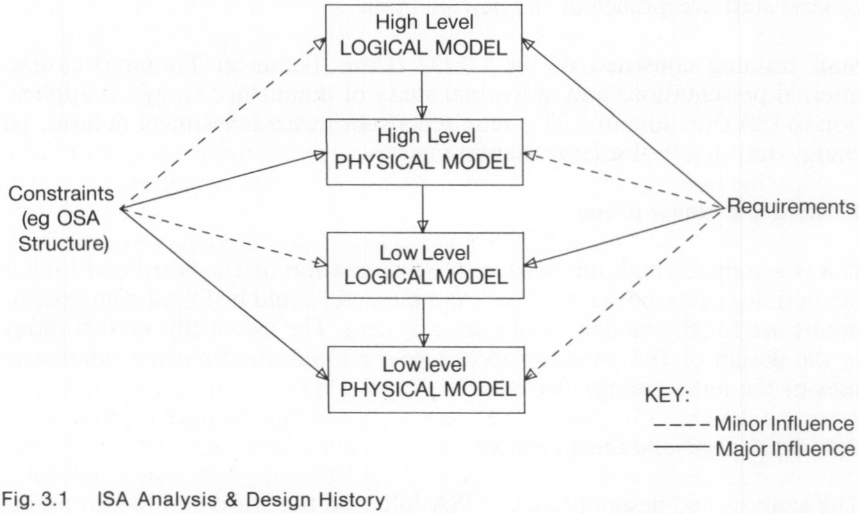

Fig. 3.1 ISA Analysis & Design History

As shown on the diagram above, though Ward and Mellor practice was followed, outside constraints influenced the analysis and design at an earlier stage than might have been expected and changing and additional requirements had to be accomodated throughout all the phases.

One major constraint was the requirement that for reasons of time and cost, the basic structure of OSA was to be carried forward to ISA.

3.2 Features used

Throughout the analysis and design phases the need to define and maintain separate, but complementary, Process, Control and Data views was kept in mind. The bulk of the design comprised Process decomposition with the Control aspects appearing only after some decomposition had taken place. Thus separate but interlinked Process and Control views were produced. A Data view was included in the High Level Logical Model but though in itself it was found useful it was not developed any further.

The ISA design phases are considered in the subsections below and the Ward and Mellor features that were employed in each are described. Problems encountered are also mentioned. A number of examples are included. These give a flavour of both how the features were used and of the complexity of ISA.

3.2.1 High level logical analysis The logical model that was constructed was an Essential Model as defined in [Ward and Mellor 1985] and consisted of two parts: a description of the environment in which the system operates, the *Environmental Model*, and a description of the required behaviour of the system, the *Behavioural Model*.

The Environmental Model comprised the *Context Diagram*, the top level Transformation Graph which showed the External Entities with which ISA communicates and the nature of these communications, together with the *Event List*. The *ISA Context Diagram* can be found in Fig. 3.2. An Event List is a list of all external events where an external event is defined, in [Ward and Mellor 1985], as "something arising in the System's environment at a specific point in time which requires a preplanned response".

In the Behavioural Model the ISA Process was decomposed using a set of *Transformation Graphs* (TRGs). The Control View of ISA appeared in this decomposition as in addition to Data Processes, Control Transformations were introduced. These were described by *State Transition Diagrams* (TRDs) which modelled the ISA States and Process Modes. Further detail was provided where necessary by *Matrix Graphs* (MTRs). The use of TRDs to show the possible ISA States and the allowable State changes together with MTRs to specify the detail of these State changes proved to be a powerful and accurate method of modelling the complex control necessary for ISA.

The Behavioural Model also contained the *Information Model.* This represented the major Data to be handled by ISA and comprised a single *Data Entity Relationship Diagram* (ERA).

3.2.2 High level physical design The High Level Physical Model was derived from the High Level Logical Model and in it the ISA functionality was incorporated into the basic structure derived from OSA and the component ISA Tasks were identified and defined. Note that where the term Task

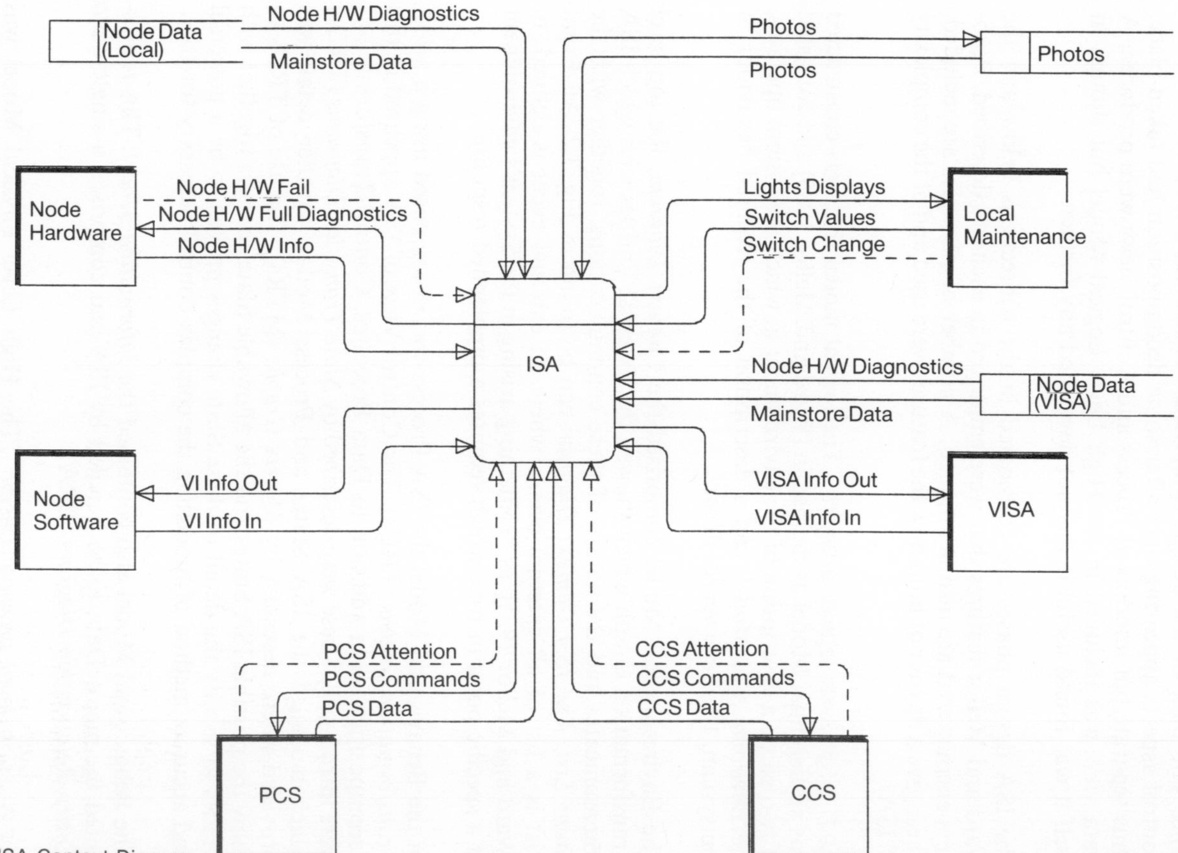

Fig. 3.2 ISA Context Diagram

is given a capital letter this refers to an *ISA* Task which should not be confused with the general use of the term in [Ward and Mellor 1985]. An ISA Task is defined as "a collection of related processes grouped together to form a convenient unit of implementation". These processes are generally associated with a particular external entity (eg PCS – Power Control System).

In phase one of High Level Physical Design the start point was the Context Diagram (TRG) and the ISA Process was then decomposed using a set of *Transformation Graphs* (TRGs) down to the level at which the component ISA Tasks were identified. As with the High Level Logical Model, Control Transformations which were introduced were described by *State Transition Diagrams* (TRDs) and further detail was provided where necessary by *Matrix Graphs* (MTRs). The Information Model from the Essential Model was not carried over and pursued.

In phase two of High Level Physical Design the Tasks were decomposed using *Transformation Graphs* (TRGs) and *State Transition Diagrams* (TRDs) until they reached the "elementary process" stage ie became sufficiently concise and compact that they would not benefit from any further decomposition. Figure 3.3 shows the TRG *1.3.1 Reset Task*.

The need for a standard approach to modelling Task inputs and outputs became evident as the High Level Physical Design progressed and a standard "Task Model" was produced. The lack of such an approach until late in the day gave rise to some unnecessary design differences between Tasks in both the High Level and the Low Level Physical Models.

The High Level Physical Model described above represents the final situation. Initially it was thought that the "primitive process" stage had been reached with the definition of the ISA Tasks which were then further described using Structure Diagrams and Structure Charts in the subsequent analysis and design phases (see below). This approach was fairly successful but ISA Tasks contained complex functionality which was not visible in Structure Diagrams and Structure Charts. Some issues were therefore not properly considered and the current rigorous design was only achieved after the second phase of High Level Physical Design had been completed and the "missing" levels of TRGs and TRDs produced.

In retrospect it is clear that the control side of ISA was allowed to become too complex, with an excess of states and substates. To an extent this was caused by confusion between process and state. At times it seemed that every process introduced had to have an associated state or substate! This uncomfortable situation was tackled in the final iteration back to the High Level Logical Model and a much simpler control view resulted. This is shown in Fig. 3.4, the TRD *0.1 Control ISA*.

3.2.3 Low level logical analysis Low Level Logical Analysis was in fact carried out as the first stage of Low Level Physical Design and the Low

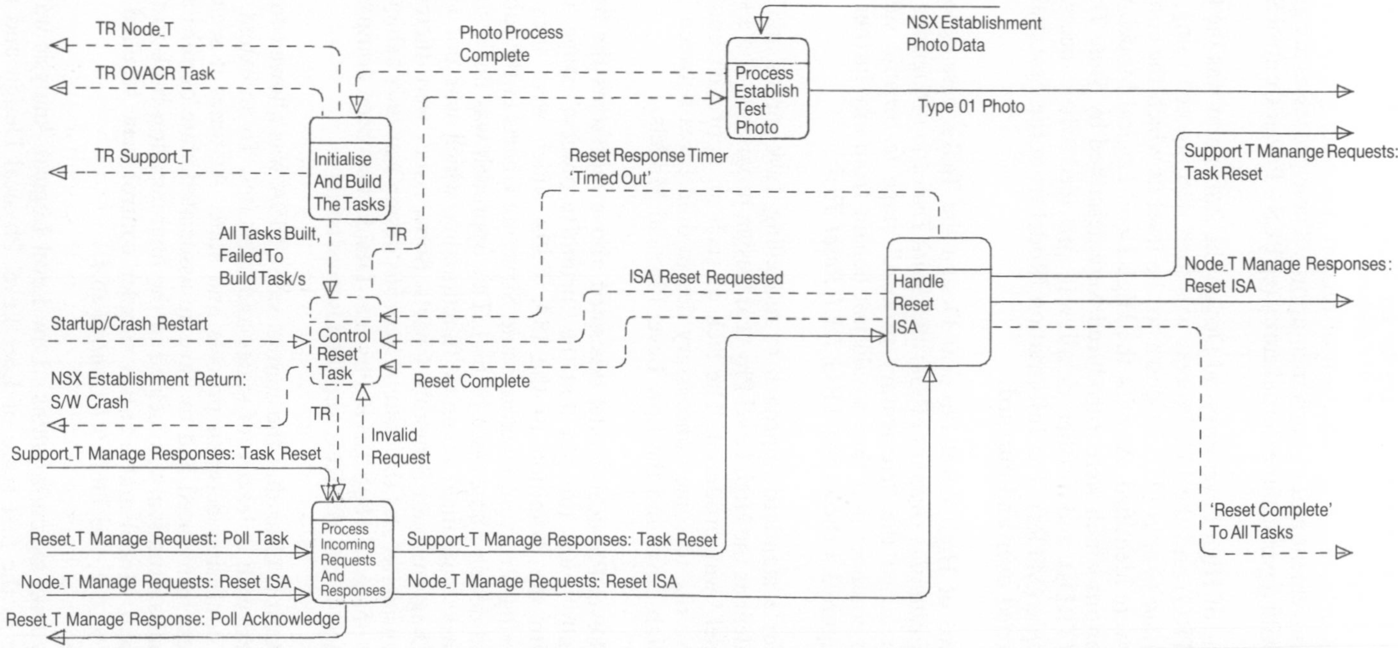

Fig. 3.3 1.3.1. Reset Task

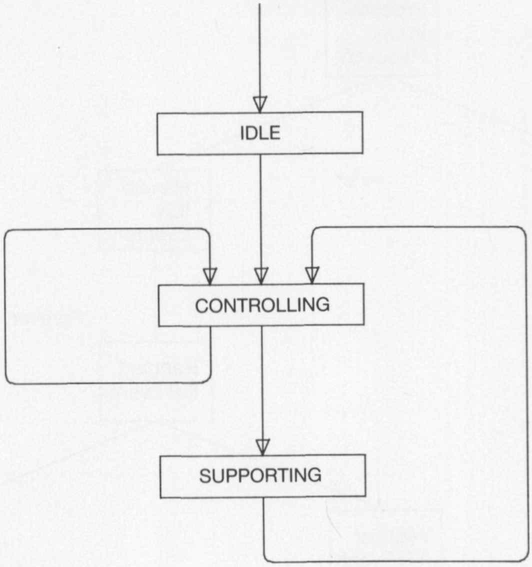

Fig. 3.4 0.1 Control ISA

Level Logical Model produced was therefore a component of the Low Level Physical Model! *Structure Diagrams* (STDs) were used to describe what the processes identified at the higher levels should do. An example STD, *ILR 01 Process in Line Recovery*, can be found in Fig. 3.5.

The use of STDs during Low Level Logical Analysis could be considered suspect as these diagrams are fundamentally procedural. There was therefore a risk that the model would describe *how* the process was to be implemented rather than *what* the process should do. Other methods (eg non-graphic, non-procedural specification using pre and post Conditions, decision trees) were considered but rejected as being unsuitable for the design of the complex low level ISA data processes. Another possibility here would be the use of State Transition Diagrams, and if a "State View" was considered beneficial these would be the ideal representation.

Despite the above reservations the adoption of STDs proved successful with their pictorial nature being a very useful attribute for this stage in the lifecycle. Any future use of STDs for Low Level Logical Analysis should concentrate on their selection and repetition features. However, as stated in [McMenamin and Palmer 1985], "if there is an essential order among the actions that make up an essential activity, you've got to have some way of stating it"!

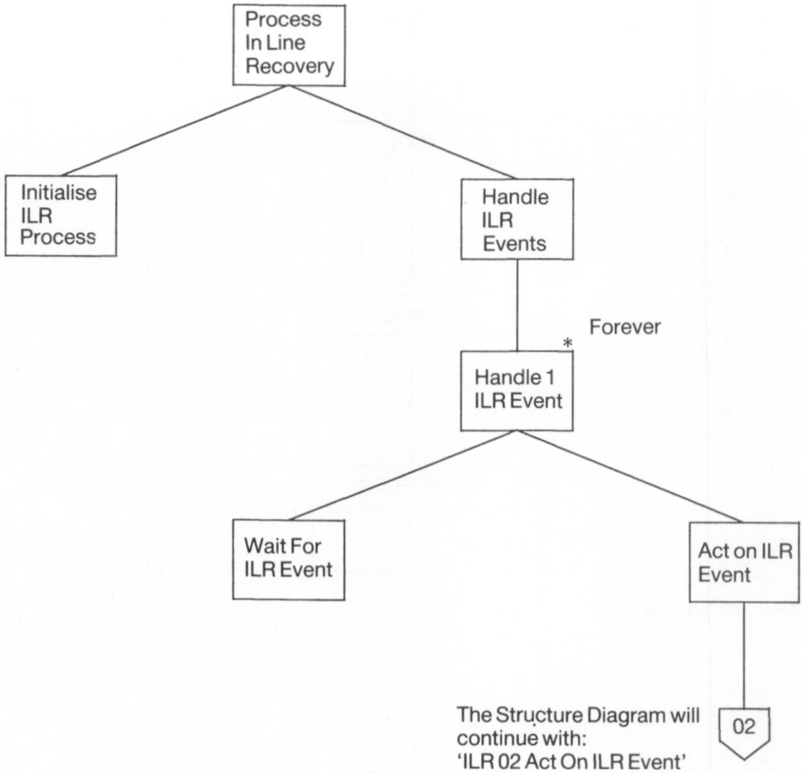

Fig. 3.5 ILR 01 Process In Line Recovery

It would not be accurate to describe the Low Level Logical Analysis of ISA as a separate phase though with hindsight its value is now apparent and greater emphasis would be placed on it in any future application of the Ward and Mellor methodology.

3.2.4 Low level physical design In the first phase of Low Level Physical Design the ISA Tasks were broken down into their component procedures and represented on *Structure Charts* (STCs). This phase used the (logical) process analysis described in the Structure Diagrams of the Low Level Logical Model to determine the physical procedure breakdown. Figure 3.6 shows the STC *ILR 01 ilr – start.*

The next phase, the procedural description phase, was the final design stage and represented the level immediately above the code. *Structured English* was used for this phase, this being a relaxed form of pseudo code with no precise syntax. Structured English was found to be formal and restricted enough to be unambiguous and its adoption involved only a very short learning curve.

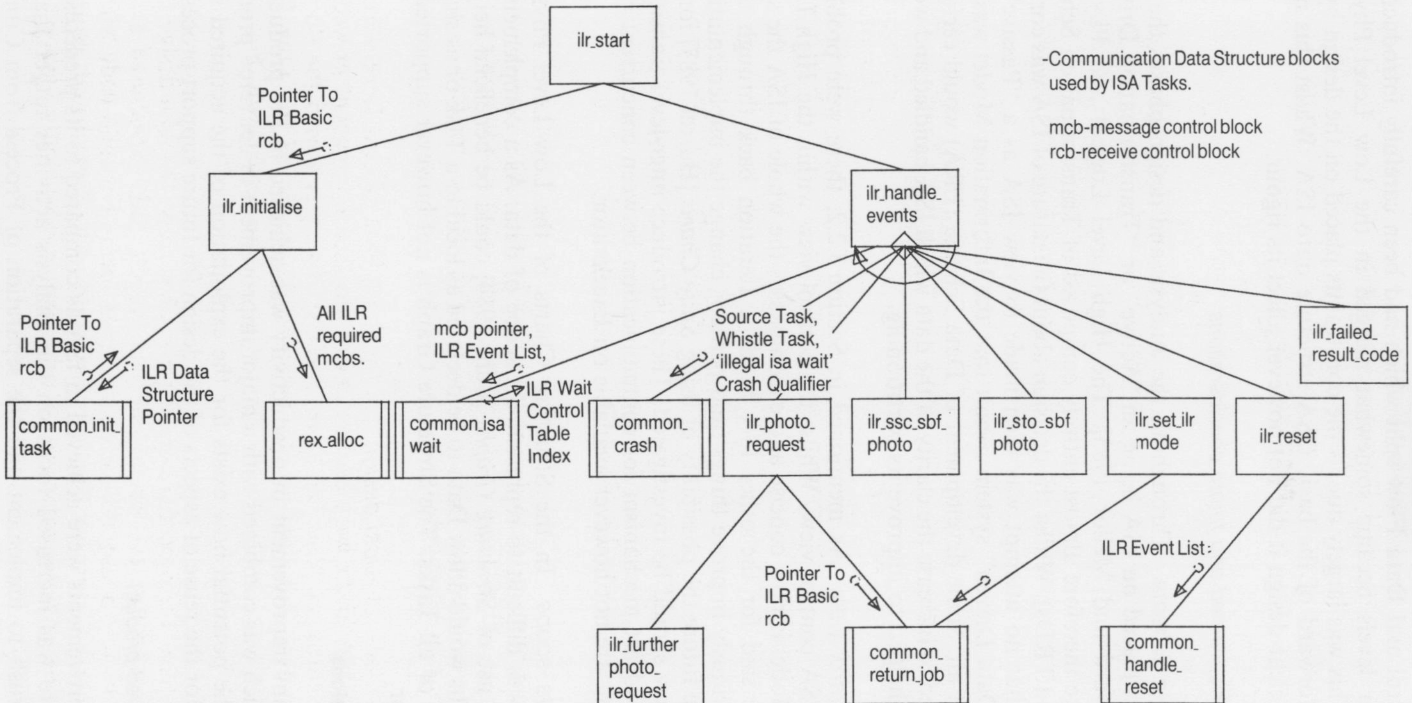

Fig. 3.6 ILR 01 ilr–start

The Control and Data Flow split which had been carefully introduced at the higher levels became somewhat merged in the Low Level Physical Design. This was largely due to the constraints placed on the design by the carrying forward of the basic OSA structure onto ISA. Whilst this made for a less clear design it did not however affect its rigour.

3.3 Lessons learned and future considerations

3.3.1 Data schema Throughout the analysis and design phases the emphasis was placed on ISA being an "Active" or "Transformation Driven" system [Ward and Mellor 1985]. The High Level Logical and Physical Models are therefore almost entirely composed of Transformation Schema (TRGs and TRDs). Whilst the decision about the nature of ISA was correct, the fact that no attempt was then made to view ISA as a "Passive" or "Stored Data Driven" system meant that the Information Model was not pursued at all. Some development of Data Schema (ERA) would certainly have helped to increase the clarity of the data which ISA handled and would also have helped to improve its partitioning.

3.3.2 Control view As mentioned in Section 3.2.2, there were problems with the ISA control view. Whilst the control view within the High Level Logical Model is now concise and encompasses the whole of ISA the same cannot be said for the other ISA Models. Iteration back through these would obviously improve things (and perhaps change the implementation!) but for the future the possibility of using *State Charts* [Harrel 1987] for the control view should be investigated. These introduce inter-level transitions and a broadcast mechanism for communication between concurrent components but are not however available on Excelerator.

3.3.3 Data scope In the Structure Charts of the Low Level Physical Model it was difficult to represent the scope of data. As a complement to STC's the use of *Structure Graphs* [Buhr 1984] could be beneficial here as these graphs would allow Data to be declared as local to a Task or as shared by several or all Tasks. The Structure Graph is not however supported by Excelerator.

4 Conclusions

A significant improvement in productivity was achieved in the production of ISA which was combined with a major improvement in delivered product quality. The potential now exists for the exploitation of the acquired staff skills and for the reuse of aspects of the design for future support processes.

4.1 Improved product

Major improvements were achieved in ISA as compared to its predecessor, OSA. There was increased focus on the analysis activities rather than a headlong rush to implement and the separation of Process from Control greatly improved design clarity. The development of an ISA "house style" (applicable to any methodology) made design and code reviews highly effective and promoted early bug removal. There were difficulties in introducing and evolving a new methodology at the same time as designing a complex system but these were successfully overcome.

The bug density in the product delivered to pre-release Integration staff was down by a factor of 5 which offered major reductions in integration costs and timescales. Relevant ISA statistical information can be found in [Murray 1990]. This shows that design faults had been largely eliminated from the coding and testing phases (only 3% of the bugs reported there were attributable to design errors as against 40% for OSA!) and that only 55 bugs remained in the product on delivery to Integration compared with 275 for OSA.

4.2 Advantages

There were many advantages in using the Ward and Mellor methodology and Excelerator. Staff were highly motivated by the opportunity to increase their skills and the product design was clear and unambiguous, so simplifying all subsequent development phases. As design documentation was generated by the design tool this greatly reduced the problems of document production and design maintenance. The application of professional methods to the design of ISA enabled it to be presented positively and went a long way to combat the poor Support Processor image mentioned in Section 1.2 (Background).

4.3 External documents

The methodology was used throughout the ISA project and designs were expressed using its representational options but it was also necessary to communicate externally in an appropriate and acceptable manner. For many of the key external documents and interface definitions the only sensible option was to use standard English text. Ward and Mellor representation could have been employed but external staff and customers might then have been irritated by the use of an unfamiliar method of representation and by an insensitive approach which implied a requirement on them to understand it.

4.4 Subsequent interest by others

Having gained experience in the introduction and use of the methodology and supporting tools, the project has been able to offer advice and consultancy to other groups with similar problems. The view that has been offered is that the choice of methodology is the first step after which suitable tools can be selected but that the methodology must be tuned to the specific problem domain to be addressed. The selection of Ward and Mellor was in response to the real time nature of ISA.

4.5 *Design reusability*

The methodology used has produced two complementary representations of the system (Essential and Implementation) both of which comprise separate Process, Control and Data views. These representations have been produced in a range of levels of design detail. Design fragments are thus available for reuse from either representation and with different levels of detail. This does not pre-suppose that an Evolutionary Support Processor or Process is inevitable on any future mainframe but it envisages that design reuse may in many cases be more subtle and innovative. The System Design of any new mainframe is likely to take note of past solutions and constraints while allowing scope for novel and revolutionary options.

With the future in mind work has already begun on the production of a range-independent model of the Support Process in the form of an *NMU Essential Model* (The NMU is the Node Management Unit, the logical unit responsible for management and support of the Node).

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Alan Fuller undertook academic training as a research chemist gaining a Doctorate in High Temperature Gas Phase Kinetics or "explosions" to the layman. Much of the analysis of the research was done using computers, which led to a career into the computer industry. After working for Oxford University in their Computing Laboratory on communications software for front end processing systems, he joined ICL in 1977.

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Don Murray joined ICL in 1973 having graduated from Dundee University with an Honours Degree in Physics. His induction period was spent working on 2900 Series test software and test operating systems and since 1975 he has worked as a manager and designer on Support Systems for ICL Mainframe Computers. This has involved the SCP (System Control Processor for S-Series) from 1975 to 1981, the NSC (Node Support Computer for

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He first worked for the Ontario Ministry of Housing developing a specific application for that Ministry before joining the Ontario Hydro Corporation in 1987 as a Systems Analyst. He joined ICL Network Applications (Paris) in 1989, where his role was to adapt the ICL/ISDN application to France Telecom specifications.

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Colin Taylor is Manager of Standards in ICL Systems Integration Division. He is a graduate of Manchester University, a Chartered Engineer, and a Fellow of the British Computer Society. He has held senior positions in the development of many of the major successful ICL product ranges from 1900 onwards, in systems design, architecture and development management roles. He was one of the originators of the VME architecture and was chairman of the companywide group that laid down the supervisor interfaces and architecture definitions. His team created and developed the DME and CME systems, and he was Technology Centre manager responsible for the architecture of the ME29 range. Since 1982 he has been particularly concerned with Open Systems, the world UNIX scene and ICL's UNIX technical strategy. He is a founder of X/Open, an Alternate Director on the Board of the X/Open Company, and the ICL manager on the X/Open Technical Management Group. He has recently also become responsible for Standards Strategy for the Division.

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Roger Whetton joined ICL in 1968 after gaining a BSc (Hons) in Chemical Engineering at University College London. He worked on 1900 and 2900 Series test software until 1980 and since then he has been involved with Support Systems for ICL Mainframe Computers. In this capacity he has worked on the design and implementation of NSC (Node Support Computer for L-Series) Firmware and latterly he has been responsible for the design of NSX (Node Support Computer for SX) Firmware which has employed Structured Design Techniques.

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Kam-Fai Wong received his B.Sc. and Ph.D. from the Department of Electrical Engineering of Edinburgh University in 1983 and 1987, respectively. For his Ph.D. thesis, he designed and developed a hardware garbage collector system for real-time AI applications. He joined the Computer Science Department of Heriot-Watt University in 1986 and worked as a research associate on the Prolog Database Machine Project. In 1988, he joined the System Software Engineering Department at Unisys, Livingston, Scotland. There he worked briefly for a year as a software engineer designing a real-time kernel. Since the end of 1989, he has been working for the European Computer-Industry Research Centre (ECRC) at Munich. He is a researcher in the Computer Architecture group at ECRC and is currently leading a small team investigating performance issues of parallel database systems.

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There is no fixed upper or lower limit, but a useful working range is 4000–6000 words; it may be difficult to accommodate a long paper in a particular issue. Authors should always keep brevity in mind but should not sacrifice necessary fullness of explanation to this

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All papers should have an Abstract of not more than 200 words, suitable for the various abstracting journals to use without alteration. The Editor will arrange for each Abstract to be translated into French and German, for publication together with the English original.

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Two copies of the manuscript, typed $1\frac{1}{2}/2$ spaced on one side only of A4 paper, with right and left margins of at least 2.5 cms, and the pages numbered in sequence, should be sent to the Editor. Particular care should be taken to ensure that mathematical symbols and expressions, and any special characters such as Greek letters, are clear. Any detailed mathematical treatment should be put in an Appendix so that only essential results need be referred to in the text.

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Line diagrams will if necessary be redrawn and professionally lettered for publication, so it is essential that they are clear. Axes of graphs should be labelled with the relevant variables and, where this is desirable, marked off with their values. All diagrams should have a caption and be numbered for reference in the text, and the text marked to show where each should be placed – e.g. "Figure 5 here". Authors should check that all diagrams are actually referred to in the text and that all diagrams referred to are supplied. Since diagrams are always separated from their text in the production process these should be presented each on a separate sheet and, most important, each sheet must carry the author's name and the title of the paper. The diagram captions and numbers should be listed on a separate sheet which also should give the author's name and the title of the paper.

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e.g. in the text: "... further details are given in [Henderson 1986]"

with the corresponding entry in the reference list:

HENDERSON, P. Functional Programming, Formal Specification and Rapid Prototyping. IEEE Trans. on Software Engineering 1986, SE-12, 2, 241–250.

Where there are more than two authors it is usual to give the text reference as "[X et al ...]".

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