COMMUNICATIONS RESEARCH CENTRE

DEPARTMENT OF COMMUNICATIONS

OTTAWA - CANADA

TITLE: DISTRIBUTED DATA PROCESSING TECHNIQUES FOR VIDEOTEX INFORMATION SYSTEMS (FINAL REPORT)

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DEPARTMENT OF SUPPLY AND SERVICES
CONTRACT NO. : 0SU82-00119
FILE NO. : 24SU.36001-2-0894

DOC SCIENTIFIC AUTHORITY: Dr. M. Sablatash

CLASSIFICATION: unclassified

DATE: MAY 1983

INTRODUCTION AND EXECUTIVE SUMMARY

Objectives and Results

As stated in the contract, our research has two objectives :

(1) To find analytical and software engineering methods for investigating the following four distributed data processing problems which are direct applications to videotex systems: videotex file allocation, client (users and information providers) assignment, user interfaces with external databases and encryption-based security.

(2) To provide extensive bibliographies as reference resources for those distributed data processing problems which can be applied to videotex systems but whose developements are unrelated to videotex technology.

Our research began with a search over the relevant literature for analytical and software engineering approaches for solving these problems. For Objective (2), i.e., for those applications not directly relevant to videotex technologies, such as distributed database design, encryption-based network security, etc., we find that most of them have already established a good analytical foundation. Software engineering methods have also been used for the study of database query languages.

As for Objective (1), i.e., for those problems directly relevant to videotex technologies, such as functional properties of videotex networks, allocation of videotex files, assignment of users to videotex information centres, etc., we have found only a few using an analytic or software engineering approach. The relevant literature is overwhelmingly dominated by reports about marketing, social, psychological, developmental and field-trial studies of these systems. With very few exceptions, the contents of most of these reports are descriptive, failing to provide approaches for analysis and directions for analytic design. For example, a majority of the articles concerning videotex networks focus primarily on just hardware descriptions of these systems in an uncoordinated or casual manner. It is as if these networks are all different. Functional descriptions of their components are often incomplete, if not totally ignored. However, it is our belief that many design problems of videotex systems can be based on their functional or analytical specifications without explicitly referring to their hardware components.

In order to establish a foundation for our analytical study of a videotex system, we propose a network model for describing the functional relationship of its subsystems and for comparing their operational differences and similarities. The model is first applied to functionally classify many of the existing videotex systems. Several of them, though being quite different from a hardware point of view, are found to be functionally similar. Another major application of the model is that, by looking at these systems through the model, several analytical optimization methods available in the literature are found to be applicable for solving the problems of file allocation, user assignment, and information provider assignment for these systems.

Our research results are reported in two parts. The five chapters of Part I and the appendices present those results which we think are new, either in modelling or in experimentations. Part II includes five extensive bibliographies, providing a vast information resource of the well-developed analytical or software engineering techniques for distributed data processing.

PART I

Chapter I	Functional classification of videotex networks.
Chapter II	Allocation of files in videotex networks.
Chapter III	Assignment of users and information providers to the information servers.
Chapter IV	Issues of database interfaces.
Chapter V	Issues of data encryption.

PART II

Bibliography I	Distributed query processing.

Bibliography II Data, process and processor allocation.

Bibliography III Concurrency control for distributed databases.

Bibliography IV Data encryption.

Bibliography V Human factors methodology for database query languages.

Chapter I sets the foundation for our analytical investigation. Chapters II to V investigate those problems specified in the contract. A brief summary of these chapters follows.

Chapter I first presents a model for describing: (i) the functional interrelationship of the four subsystems of a videotex system, namely the subsystems of users, meta-service providers, information servers and information providers; and (ii) the functional architecture interconnecting the components of the information server subsystem. Based on this model, the major existing videotex networks are then classified into 5 types. Several of them, though being quite different from a hardware point of view, are found to be of the same type.

In an actual videotex system, information files are often duplicated at several geographical sites. For the purpose of deciding the locations of these files, Chapter II first classifies the 5 types of videotex networks mentioned in Chapter I into three groups. For Group I, allocation of the files is predetermined by the nature of the problem. Two analytical methods are presented for allocating the information files for videotex networks in the last two groups. These methods make use of the algorithms for the assignment and knapsack problems in mathematical programming. Some simulation results are included.

In a videotex system, the information retrievers (IR) provide the information retrieval services to the users and the information update servers (IUS) provide the information creation or modification services to the information providers (IP). In Chapter III, we consider the problems of how to assign the users to the IR's and the IP's to the IUS's in such a way that these services will be provided at a minimum cost. Minimization models based primarily on mathematical programming are proposed. Suggestions for simplifying the computational processes are also included.

Chapter IV studies the important problem of interface between an external database and a videotex system user. We first point out several issues of this problem which are specific to the videotex environment. One of these issues is the design of query languages utilized by users for accessing the databases. We classify query languages into 4 groups according to their complexities. Then we show how query languages may be 'executed' at a 'pure' videotex terminal by using two examples: a relational algebra of a relational database and DL/I of IBM's Information Management

System. Lastly, we briefly review some of the behavioural research works on query languages. Many references are listed in Bibliography V.

One of the methods often used in cryptanalysis is for the intruders to detect a trace of functional dependence between the plaintext and the cyphertext (for a fixed key) or between the key and the cyphertext (for a fixed plaintext). Breaking a cryptosystem may become much easier if such a dependence relationship is found. Videotex data, especially Telidon data which include publicly known opcode formats of the Picture Description Instructions, are sensitive to this kind of attacks. In Chapter V and Appendix C, we report the Chi-square test method for investigating this general problem. Experiments are run for the DES (NBS's Data Encryption Standard Algorithm).

The bibliographies of Part II are mainly for those system designers who want to pursue seriously the many distributed data processing concepts and methods available. Though we think most of the major works in these areas have been included, no claim is made of their being exhaustive.

Guideline for the Scope of Our Research

Videotex systems originated as low-cost interactive utility systems purely for the purpose of information retrieval. From a user's point of view, they are characterized by their very simple interactive page-oriented file searching techniques which are primarily based on tree-path traversal and menu-lookup. On the system side, videotex systems are frequently associated with the recent developments of videotex technologies, such as Telidon's Picture Description Instructions, Prestel's alpha-mosaic code for data representation, video terminals, videotex networks, etc.

For easy reference later, we refer to the above two characteristics as:

1. Videotex file-searching techniques (at user interface level).
2. Videotex data presentation technology.

Recently, research and field trials on videotex systems have evolved into integrated information management systems which offer, in addition to videotex information, a variety of other services, such as electronic mail, voice communications, telesoftware, etc. However, in order to claim to be a videotex system, they have to include (not exclusively) the above two characteristics as the essential factors in affecting their user interface and system design.

The above two characteristics have been used as the main guideline for determining the scope of our research. In general, we are seeking analytical or software engineering methods for solving 'pure' videotex problems, i.e., those problems directly involved with at least one of these two characteristics. Our results are collected in Part I. We do not look into, for example, a general electronic mail system. The design of such systems has very little to do with videotex technology, except perhaps at the level of user interface with a videotex system.

However, as required by the contract, we also provide in Part II of this report extensive references for some of the more general distributed data processing problems. These problems include many applications to videotex systems, though not necessarily having the above two characteristics of videotex technology.

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PART II

PART I

Chapter I

FUNCTIONAL CLASSIFICATION OF VIDEOTEX NETWORKS

1.1 INTRODUCTION

As pointed out in the Introduction and Executive Summary, there does not exist a logical foundation for analytical or functional studies of videotex systems. In this chapter, we provide such a foundation by proposing an abstract network model. This model describes the interrelationships of the different functional subsystems of a videotex network without referring to their hardware constituents. Section 1.2 describes the different subsystems of a videotex network. Section 1.3 describes the two parts of the proposed videotex network model. Part 1 is a functional architecture interconnecting the four subsystems of a videotex network. Part 2 is a functional architecture interconnecting the components of the central subsystem, namely the information server subsystem. Lastly, based on this model, the major (existing or proposed) videotex networks are classified into 5 types.

1.2 VIDEOTEX SUBSYSTEMS

Functionally, a videotex system can be considered as being composed of four subsystems, namely the subsystems of users (US), meta-service providers (MPS), information servers (ISS) and information providers (IPS). (See Figure 1.1)

A user (U), equipped with either a dumb videotex terminal or an intelligent terminal possessing videotex capabilities, requests services ranging from simple information retrieval to more sophisticated information management, such as electronic mail, voice communications, file transfer, etc.

A meta-service provider (MP) provides such services as teleconferencing, banking, etc. In general, these services are offered primarily to non-videotex users. Serving the videotex users is only their secondary role. They require special interfaces in order to communicate with the videotex users. A particular kind of meta-service provider, sometimes called third-party (TPD) or external databases in the literature, is worth special mention. These databases are organized according to a special data model (e.g., hierarchical, relational, etc.) and are usually stored in non-videotex formats. We shall return to this topic in Chapter IV.

An information server (IS) takes care of such tasks as usage accounting, statistics, and logging, information storage, retrieval and update, and meta-service switching. Depending on the implementation, an IS may perform only some of these tasks and an information server subsystem may include several types of IS´s. For example, in Britain´s Prestel System (TROU80), an update centre (UPC) performs only the information update service while an information retrieval centre (IRC) takes care of the other tasks.

An information provider (IP), as implied by its name, is responsible for creating the information. The information will be coded and stored in videotex formats in an information server for subsequent retrieval or update. Note that, in some real videotex systems, the tasks of data creation and update are often combined in a computing centre.

Note that the above scheme of classifying subsystems is functional. In actual implementation, a computer may be involved in several of these functional subsystems.

1.3 VIDEOTEX FUNCTIONAL NETWORKS

In this section, we propose a network model for describing: (1) the functional interconnection of the four subsystems mentioned in Section 1.2; and (2) the functional architecture of the information server subsystem (ISS). The model serves at least two purposes:

(i) As a basis for functional description and classification of videotex networks. In the literature, videotex networks are described uncoordinately, usually with more emphasis on their individual physical characteristics. No attempt is made to compare their functional similarities or differences or to provide a direction for their systematic investigation. We believe that many design issues can be pursued simply through their functional descriptions. Based on our model, we have been able to functionally classify the major existing or proposed videotex networks into five types. Several of these physically different systems are found to be functionally similar.

(ii) As a basis for analytical investigation of the many distributed data processing problems, such as file transfer protocol or electronic mail protocols for videotex services, etc. In particular, based on this model, this report considers the following problems for a videotex system : the allocation of files (Chapter II) and the assignment of users and information providers to information servers (Chapter III).

The model includes a description of the functional architecture of the information server subsystem. A description of the other three subsystems (US, IPS and MPS) is not included in the model because of two reasons:

(a) The model is concerned primarily with the overall functioning of a videotex system and not with the design of the individual subsystems.

(b) In a videotex network, the information server subsystem acts as the central communications controller. The other three subsystems do not communicate directly with one another. They communicate through the information server subsystem.

1.3.1 A Network Model

Our model consists of two parts. Part 1 (Figure 1.1) is a functional network architecture which describes the functional relationships among the four aforementioned subsystems, i.e., users, meta-service providers, information servers and information providers. Part 2 is a functional subnetwork architecture which describes the interconnection among the components of the information server subsystem (Section 1.3.2).

The functional network (Figure 1.1) can be realized by linking the different units of the four subsystems by means of various public or private communications networks, such as telephone networks, packet switching networks, CATV cable networks, local area networks, etc. Figure 1.2 shows an example of such a realization, in which information provider IP is connected to the information servers IS , IS and IS through an X.25 packet switching network.

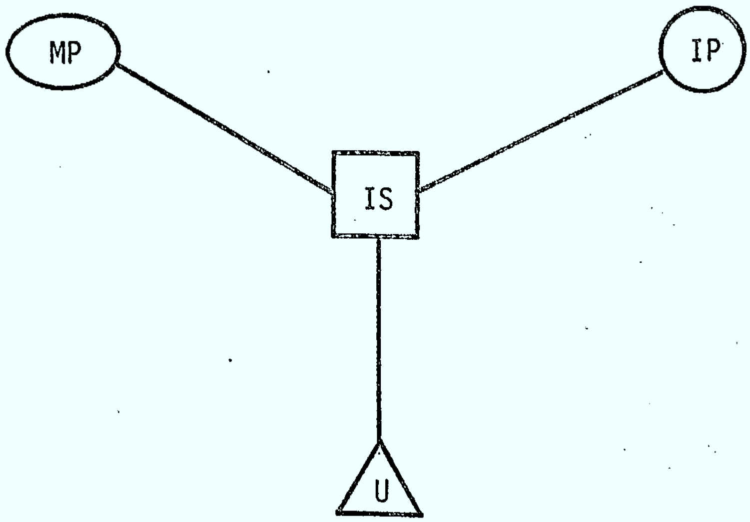


Figure 1.1 Functional network of a videotex system (IP: information provider; IS: information server; MP: meta-service provider; and U: user).

It is not within the scope of this contract to consider the design problems of these communications networks. (Readers interested in these problems can refer to (BOCH80, MANN82, WOOL79)). Instead, we are interested in those problems which can be described entirely in terms of the functional interconnection of these subsystems. Thus, we shall ignore the underlying communications networks hereafter. Figure 1.2, for instance, will then become Figure 1.3 .

Note that, as illustrated in Figure 1.3, we can assume that the units within each of the user, information provider and meta-service provider subsystems do not communicate directly among themselves or across their subsystem boundaries. This follows simply from the functional concept that communication between two such units is always through an information server.

1.3.2 Functional network architectures of the information server subsystem

In this subsection, we first describe a general functional network architecture which connects the components of the information server subsystem among themselves and with outside units. We then present several typical cases of this architecture.

General functional network architecture

In a videotex network, the information server subsystem (ISS) acts as the central communications controller. In

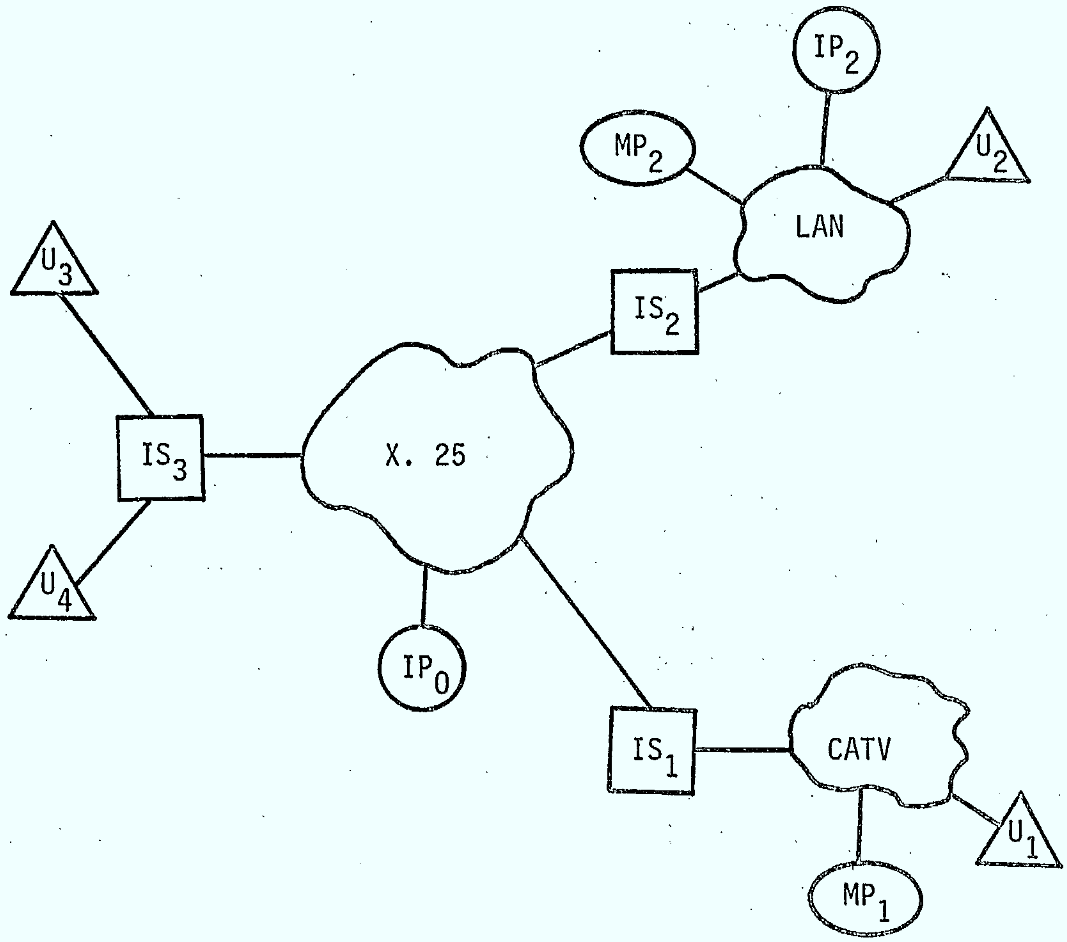


Figure 1.2 Realization of a videotex system by communications networks.

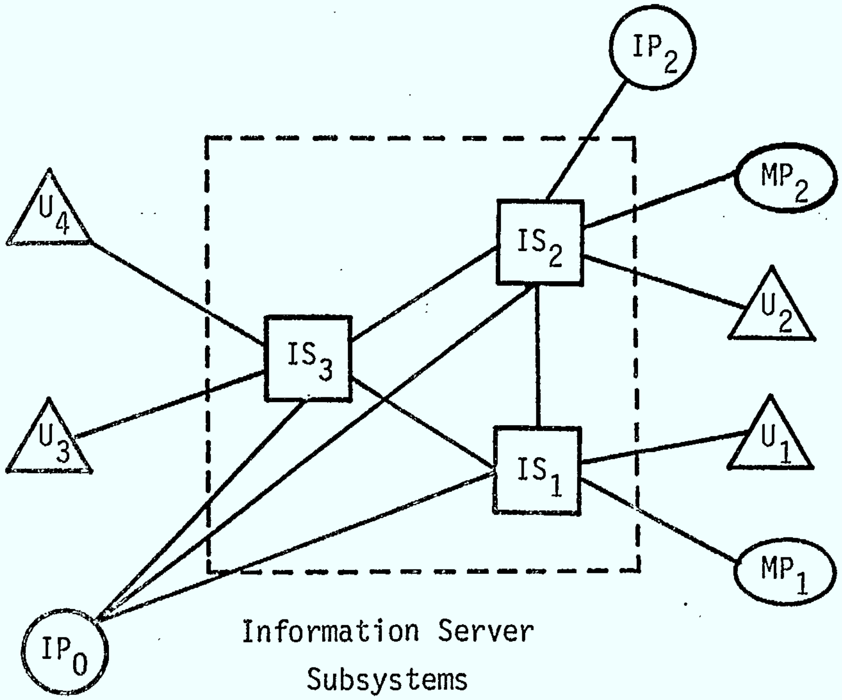


Figure 1.3 Functional network description for the interconnection of Figure 1.2.

order to interface with the three other subsystems, the components of ISS can be conceived as being clustered into three groups, namely the group of information retrievers (IR), the group of information update servers (IUS) and the group of meta-service switchers (MSS). Their functions, as shown in Figure 1.4 (a detailed version of Figure 1.1), are described below.

An information retriever (IR) interfaces with the users. It stores the videotex data and takes care of usage accounting, logging and statistics. It takes care of local data retrieval requests. It also passes control to an MSS for local or remote meta-service requests or remote data retrieval requests.

An information update server (IUS) receives data from an information provider (IP) for update. If the IUS and IP do not reside in the same computer, this can be done either off-line or on-line and either in an interactive mode (for news, stockmarket information, etc.) or in a batch mode (for more static information). If the data are already organized and coded in a videotex format, they are passed without any change onto the relevant information retrievers (IR) for storage. Otherwise, they have to be organized and coded in a suitable videotex format first.

A meta-service switcher (MSS) switches users' remote data retrieval requests or (local or remote) meta-service requests between IR's and meta-service providers (MP).

<u>Typical architectures</u>

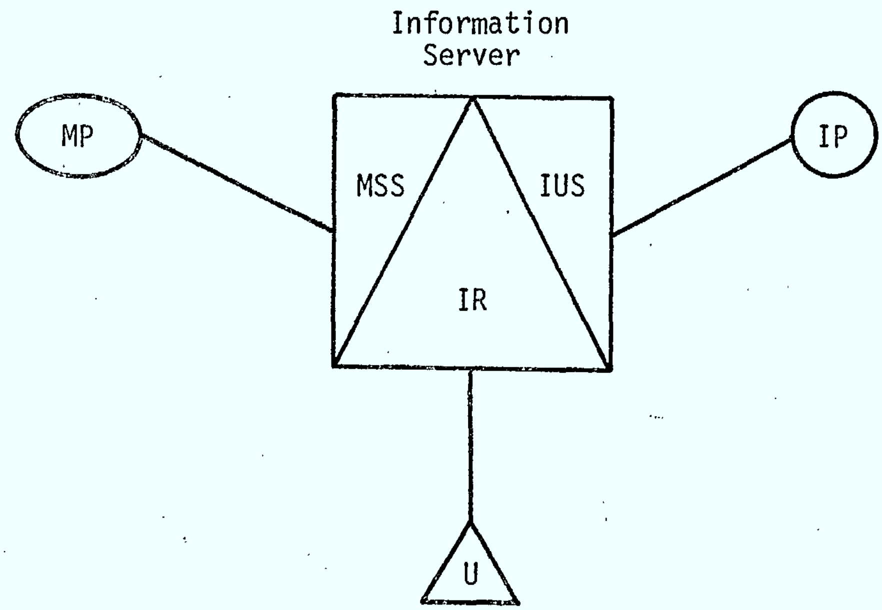


Figure 1.4 Interface components of an information server (IR: information retriever; IUS: information update server; and MSS: meta-service switcher).

The general architecture of the information server subsystem described above includes many special cases. In the following, we describe specifically a few typical ones. They represent the architectures of many well-known existing and proposed videotex networks. They also serve as the base for classifying these networks functionally. The classification scheme depends on such properties as how the components of ISS are functionally interconnected, whether all the IR's have a copy of the master database, how many IR's whose data will be updated by each IUS, etc. Solutions to two distributed data processing problems based on this classification scheme will be described in Chapters II and III, respectively.

The following notation will be used.

Notation

IP - information provider

IR - information retriever

ISS - information server subsystem

IUS - information update server

U - user

(m,n,k) - An ISS belongs to Class (m,n,k) if it has m IUS's and n IR's, and each IUS is responsible for updating the stored data of k of the IR's. If k is not known or irrelevant to the problem under consideration, it may be replaced by "?".

Type 1 For a videotex network of this type (Figure 1.5), its ISS belongs to Class (1,1,1). It has a single

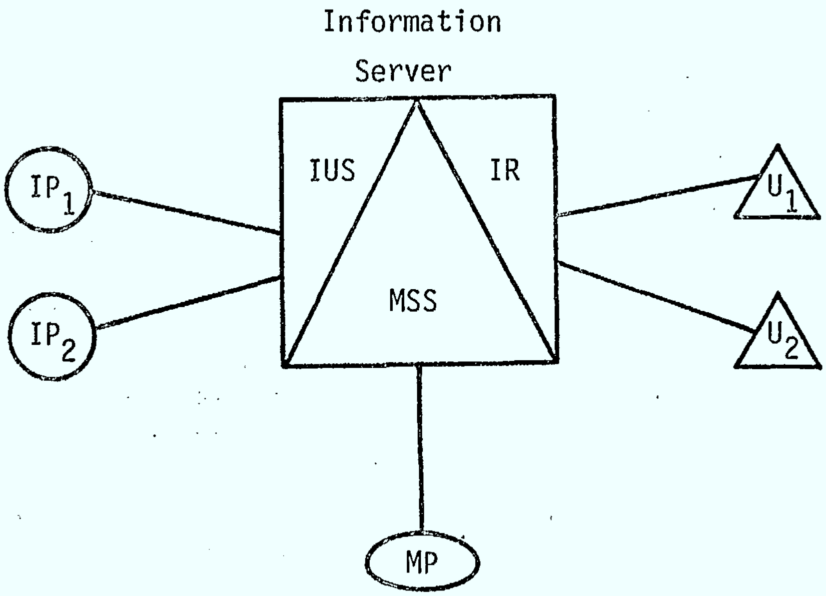


Figure 1.5 Type 1 videotex networks.

information centre which provides both information retrieval and update services to all the users and IP's.

This is the most common type of videotex networks. It includes many of the small videotex systems designed for the public or closed user groups and also many of the large-scale systems at their early stage of development.

Example 1.1 The first stage of Bell Canada's Vista System (BNR79, WILS80) consists of a single host which provides all the information providers with update service and all the users with retrieval service. (See Figure A.1 in Appendix A.)

Type 2 For a videotex network of this type (Figure 1.6), its ISS belongs to Class (m,m,1). Conceptually, it consists of m non-overlapping Type 1 subnetworks. Each subnetwork has a computing centre which functions as the information server subsystem (ISS) and has only one IR, one IUS and one MSS. Each IUS serves only the IR belonging to the same subnetwork. The MSS switches requests for data or meta-services to other subnetworks. Every file has only one copy within the entire network. According to the allocation policy of the files and users, we can

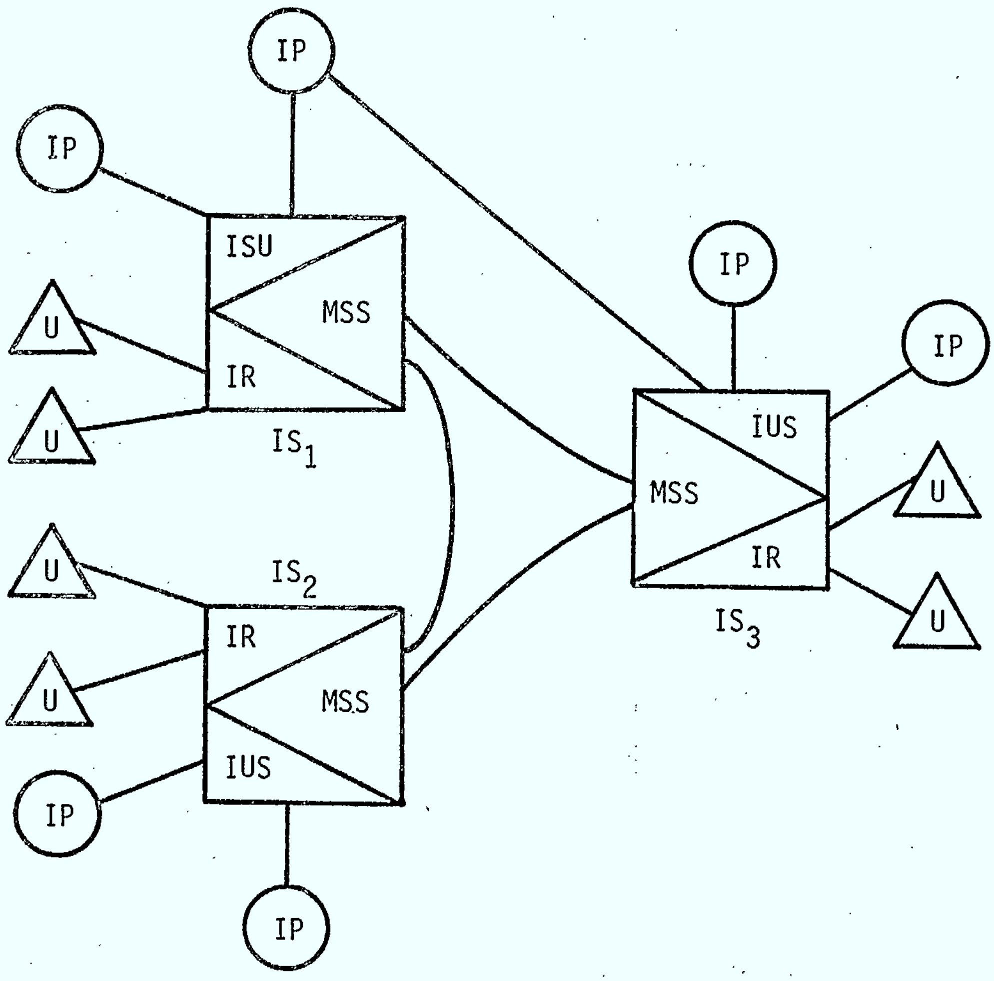


Figure 1.6 Type 2 videotex networks (compare with Figure 1.3).

distinguish between two cases of this type of networks:

Type 2.1 : A videotex network is of Type 2.1 if it belongs to Type 2 and if its files cannot be reallocated and the users cannot be reassigned from one subnetwork to another.

The subnetworks of this type want to exchange information and/or meta-services while maintaining their autonomy for control over their users and IP´s.

Example 1.2 A typical example of a videotex network of this type is the current iNET (FARR82). At the present time, TransCanada Telephone System´s (TCTS) Computer Communications Group (CCG) is responsible for a one-year field trial on this national network. iNET interconnects (not permanantly) the information centres of a number of Telidon-based videotex systems, such as Teleguide (by the Government of Ontario and Informart), Vista (by Bell Canada), NBTel (by New Brunswich Telephone), B.C.Tel (by British Columbia´s Telephone), etc. These videotex systems maintain their individual administrative autonomy but exchange data and services through DATAPAC or telephone networks.

Type 2.2 : A videotex network is of Type 2.2 if it is of Type 2 and if each of its files either has duplicates at all sites or has no duplication at all. The files can be reallocated and the users can be reassigned from one subnetwork to another.

The subnetworks of this type, probably all belonging to the same owner, can exchange the files they store and the users they service.

Example 1.3 During the current field trial, Germany's Bildschirmtext System (GRIE82), has two information servers (called BTX centres), one located at Berlin and another at Dusseldorf. These two BTX are independent as far as their users and information providers are concerned, but they share some of the meta-services and their files can be related from one BTX to another. (See Figure A.2 in Appendix A)

Type 3 In a videotex network of this type (Figure 1.7), its ISS belongs to Class (1,n,n). That is, the ISS has only one IUS and an arbitrary number of IR's. The number of MSS's is irrelevant. The IUS is connected to all the IR's and serves all the IP's. We distinguish between two cases of this type.

Type 3.1 A videotex network is of Type 3.1 if it is of Type 3 and each of its IR's contains a copy of the master database (i.e., data are fully duplicated at all IR's).

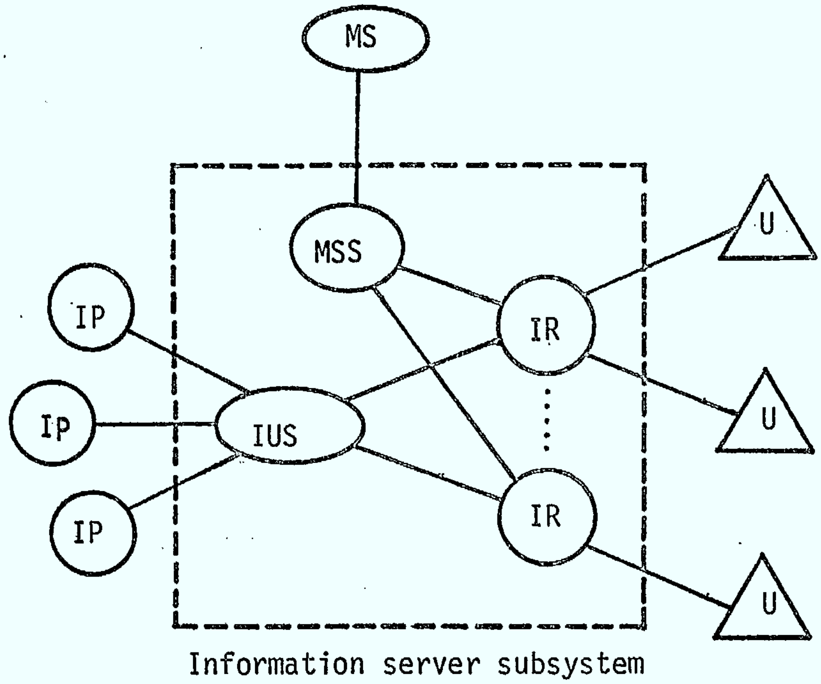


Figure 1.7 Type 3 Videotex Networks.

Example 1.4 The early stage of Britain's Prestel System (WOOL80) belongs to this type. A single update centre (UPC) was located at London. All data were updated there before being transferred to and stored at the information retrieval centres (IRC) located at London, Central Scotland, N.W. England and Birmingham. For the convenience of information management, every data frame is duplicated at all the IRC's. (See Figure A.3 in Appendix A.)

Type 3.2 A videotex network is of Type 3.2 if it is of Type 3 and only one of its IR's contains the master database, while all the other IR's contain only a portion of the whole database.

Example 1.5 At its current stage, France's Antiope System (MART79) belongs to this type. Its single information update centre (IUC) is connected to all IP's and serves all the information retrieval centre (IRC). However, unlike the Prestel System, only the IR located at the same site as the IUC contains the master database. The other IRC's contain only local information. (See Figure A.4 in Appendix A.)

Type 4 In a videotex network of this type (Figure 1.8), its ISS is of Class (m,n,n). The ISS has several IUS's, each of which is connected to a disjoint subset or

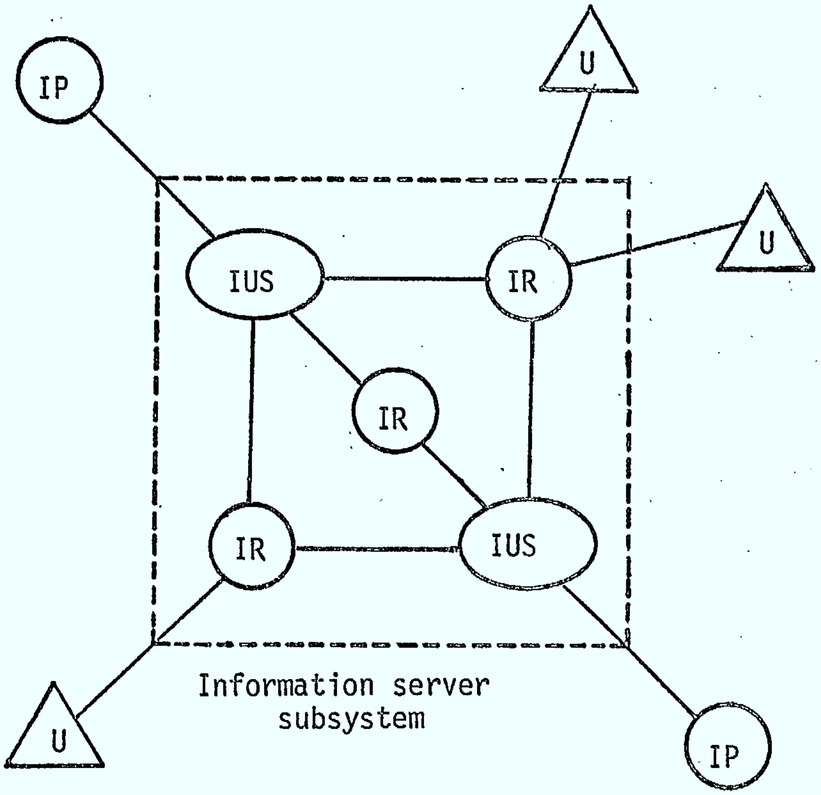


Figure 1.8 Type 4 Videotex Networks.

IP's but serves all the IR's. Each IR contains a copy of the master database.

Example 1.6 Currently, Britain's Prestel System (TROU80) is experimenting an architecture which contains up to three update centres (UPC) and many information retrieval centres (IRC). Thus, each UPC updates information for a specified group of IP's and sends a copy of the updated data to all the IRC's. Thus, each IRC contains a copy of the master database. (See Figure A.5 in Appendix A).

Type 5 In a videotex network of this type (Figure 1.9), its ISS is of Class (m,m,n). There are usually several videotex information centres. Each centre consists of an IUS and an IR (and possibly an MSS). An IUS serves not only the IR located within the same centre, but also those remote IR's where data are duplicated.

Example 1.7 Germany's new Bildschirmtext System (GRIE82), scheduled for starting services in Autumn 1983, has several videotex information centres (called BTX). Only one of these BTX's contains the master database. The other BTX's contain only local information. A data frame is updated and stored locally and a copy will be transferred to the master

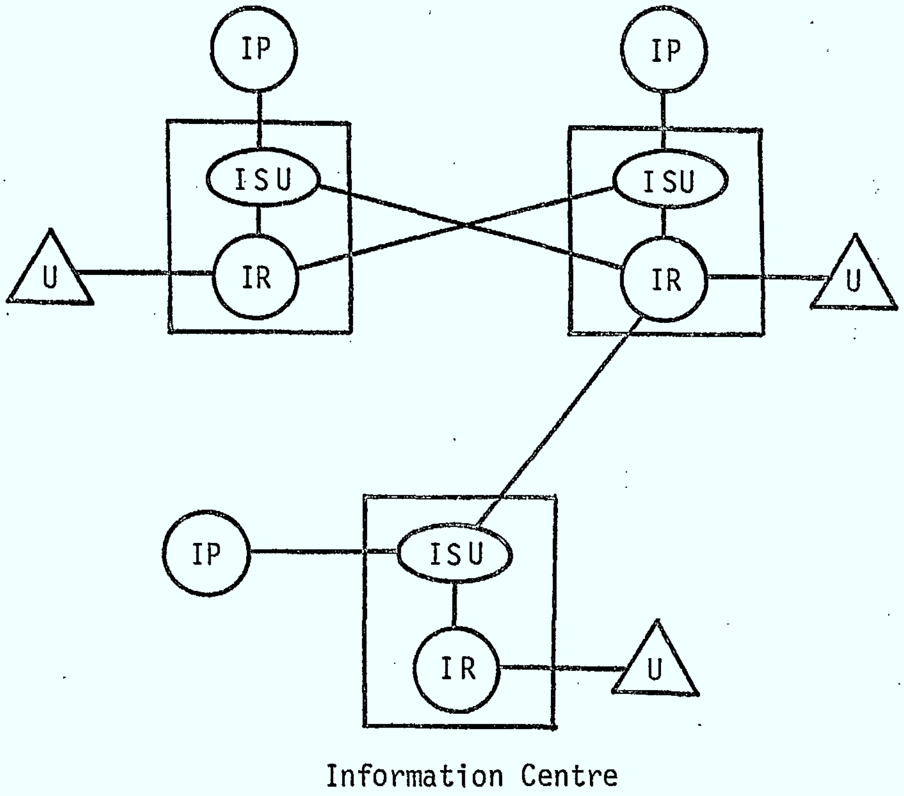


Figure 1.9 Type 5 videotex networks.

database. Other BTX´s having the same data frame will be informed and marked, but not updated immediately (for the purpose of reducing communications costs). Later, they will be physically updated from the master database when they are requested at these BTX´s. (See Figure A.6 in Appendix A.)

Chapter II

ALLOCATION OF FILES IN VIDEOTEX NETWORKS

2.1 INTRODUCTION

Normally, in a videotex system, multiple copies of each information file exist and are distributed in some ad hoc way to some (or possibly all) of the sites. In this chapter, we study the problem of how to allocate these files to the sites in a 'best' manner. Though the file allocation problem is often mentioned (BALL81, BOCH81, GECS82) as an important design issue for videotex systems, we do not know of any study of analytical methods for its solution in a videotex environment. It is not clear from the literature what criteria and methods the existing videotex systems use for allocating their files. In general, it appears to be done in a way that simply serves the convenience of administration or software design. In an analytical approach, the objective is to minimize a certain combination of communications, storage and processing costs. Though an analytical solution is usually not taken as the final solution in a design process, it often forms the initial step of an approximation procedure and provides insights into the problem which is often too complex to handle by intuition alone.

In the early stage of our search for analytical methods for these problems, one of the obstacles was the lack of a functional view of videotex systems. This led to the proposal of the network model of Chapter I. Through this model, we are now able to identify several analytical methods of solution, based mainly on mathematical programming and approximate solutions to the knapsack problem, to the file allocation problem for those types of videotex networks as classified in Chapter I. These methods will be described in the following sections.

2.2 ASSUMPTIONS AND COSTS FOR FILE ALLOCATION

In our study of the file allocation problem, we make the following general assumptions:

1. The geographical locations and network interconnection (both physical and functional) of the components of the videotex information subsystem, namely the information retrievers (IR), information update servers (IUS) and meta-service servers (MSS), are known.
2. The locations of the users are fixed and known.

3. For each file, its retrieval traffic (induced by the users) and update traffic (induced by the information providers and information update servers) can be estimated. These kinds of statistics are usually available at the information centres for billing or system analysis purposes. The communications cost for each file is therefore estimable.

4. The processing and storage capacities at each information retriever are known.

Additional assumptions may be needed for individual problems.

In order to estimate the total costs for communications, storage and processing, it is necessary to know who pays for these services. In general, this depends on the policies of the individual videotex network. The following example shows a typical case :

Example Payments by the users and information providers (IP) in the Prestel System (WOOL80) are as follows :

Users pay : i) to IRC for connection-time;

ii) to IP for frame accesses;

iii) to PO Telecommunications for telephone usage;

iv) to TV industry for adapted TV´s.

IP´s pay : i) to IRC for storage and connection-time; and

ii) to PO Telecommunications for telephone usage.

2.3 ANALYTICAL METHODS FOR FILE ALLOCATION

In general, the method for allocating files in a videotex system depends on the functional architecture of the videotex network. Since there are many such architectures (as pointed out in Chapter I), it is quite impossible to find analytical solutions for all of them. In the following, as illustrations, we shall consider three groups of videotex networks. Each group includes several types of networks as classified in Chapter I. When combined together, these groups cover most of the major existing videotex systems.

Group I This group includes networks of Types 1, 2.1, 3.1, and 4.

Examples: Bell Canada's Vista (Example 1.1), Britain's Prestel Systems (Examples 1.4 & 1.6) and Canada's iNET (Example 1.2).

Characteristics and Solutions: For videotex networks of Type 1 or Type 3.1 or Type 4, every IR contains a copy of the master database (i.e., every file is duplicated at all IR's). Thus, no decision making about file allocation is necessary.

A videotex network of Type 2.1 is an interconnection of several Type 1 subnetworks. The whole network has only one copy of every file, which can be retrieved by users both inside and outside its subnetwork, but can only be updated by the IUS´s within its subnetwork. It is not allowed to reallocate the files from one subnetwork to another. In practice, for example, the subnetworks may belong to different owners and their interconnection into a single videotex network is solely for the purpose of exchanging data and meta-services. They maintain their autonomy over their own subscribers (users and IP´s). For this kind of networks, a file is always allocated to the IR belonging to its owner´s subnetwork.

Group II This group includes networks of Type 2.2.

Example: Germany´s current Bildschirmtext System (Example 1.3).

Characteristics: In this group, the files are assumed not to be duplicated and to be relocatable from one subnetwork to another. Those files having duplicates at all sites may be excluded from consideration for our file allocation problem. In practice, for instance, the files may all belong to the same owner and their allocation to a suitable site may decrease the system´s overall expenses.

Solution: We want to allocate the different files to the sites so as to minimize the total cost for communications, storage and processing. The problem can be formulated as a generalized assignment problem as follows.

Notation	Explanation
F_i , $i=1,2,\ldots,n$	The n different files to be allocated.
s_i	The size of F_i .
S_j , $j=1,2,\ldots,m$	Sites of computers, each containing an IR and an IUS .
b_j	Storage capacity of the computer at S_j .
c_{ij}	Communications and processing cost if F_i is located at S_j , due to the retrieval traffic induced by its users and the update traffic induced by its IP .
x_{ij}	$x_{ij} = \begin{cases} 1 & \text{if } F_i \text{ is allocated at } S_j \\ 0 & \text{otherwise.} \end{cases}$

Note that the constants s_i , b_j and c_{ij} are readily available or estimable. In particular, c_{ij} are usually recorded by the system for billing or system analysis purposes. Note also that when all computers charge the same rate for processing and storage, these costs may be ignored as they do not affect the total cost no matter where the files are stored.

The optimal locations of the n files can be obtained by solving the following assignment problem :

Minimize: $\sum_{j=1}^{m} \sum_{i=1}^{n} c_{ij} x_{ij}$

$$
\text{subject to} \begin{cases} \sum_{i=1}^{n} s_i x_{ij} < b_j & ,j=1,2,\dots,m \\ \sum_{j=1}^{m} x_{ij} = 1 & ,i=1,2,\dots,n \\ x_{ij} = 0 \text{ or } 1 & ,j=1,2\dots,m; \\ & j=1,2\dots,n. \end{cases} \quad (1)
$$

In fact, (1) is a special case of the generalized assignment problem where the constants s_{ij} are replaced by s_i. There exist at least two algorithms (DEMA71, SRIN73) for solving the special case (1). A branch and bound algorithm (ROSS75), based on the solution of a series of 0-1 knapsack problems for determining the bounds, has also been developed for medium-sized (up to 4000 binary variables) generalized assignment problems.

<u>GROUP III</u> This group includes videotex networks of Types 3.2 and 5.

<u>Examples:</u> France's Antiope System (Example 1.5) and Germany's proposed Bildschirmtext System (Example 1.7).

<u>Characteristics:</u> The architecture of a videotex network of this group is shown in Figure 2.1. The IR at site S_0 has a master database and the IR's at the other sites contain a portion of the database only.

For information retrieval, the files located at a local site S_j will be searched first. If the data are not found, the request will be switched to the central site S_0. Since S_0 contains the master database, no further switching is necessary (See Figure 2.1). Thus, retrieval traffic will be increased along S_0/S_j if a file is not stored at S_j.

For information update, we distinguish between two cases:

<u>Case a</u> (Figure 2.2a) This case includes networks of Type 3.2. All IP's are linked to S_0. Thus, a file can only be updated at S_0. A new copy of that file is then sent to those sites (e.g., S_1, S_3) which also store a copy of it.

<u>Case b</u> (Figure 2.2b) This case includes networks of Type 5. The IP's are attached to different sites. A file is updated at the site (e.g., S_1) associated with its IP. A new copy of that file is then transferred to S_0, from where the other sites (e.g., S_3) containing a copy of it will be updated later (e.g., when there is an actual retrieval request at S_3 for that file).

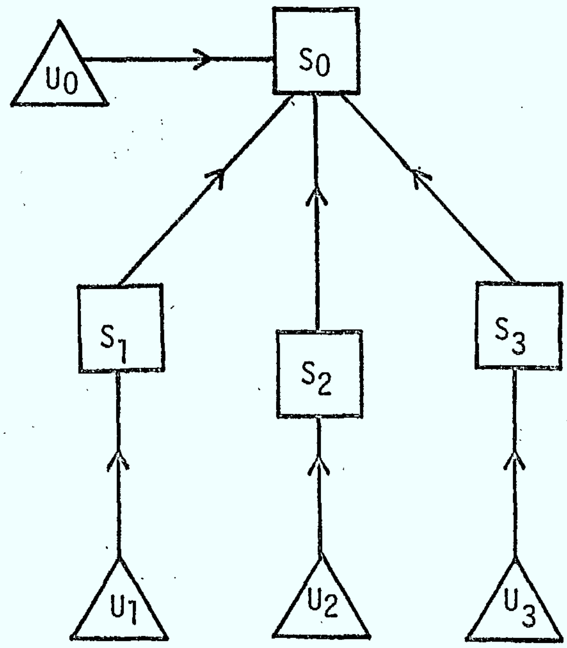


Figure 2.1 Direction of retrieval requests in Group III Networks.

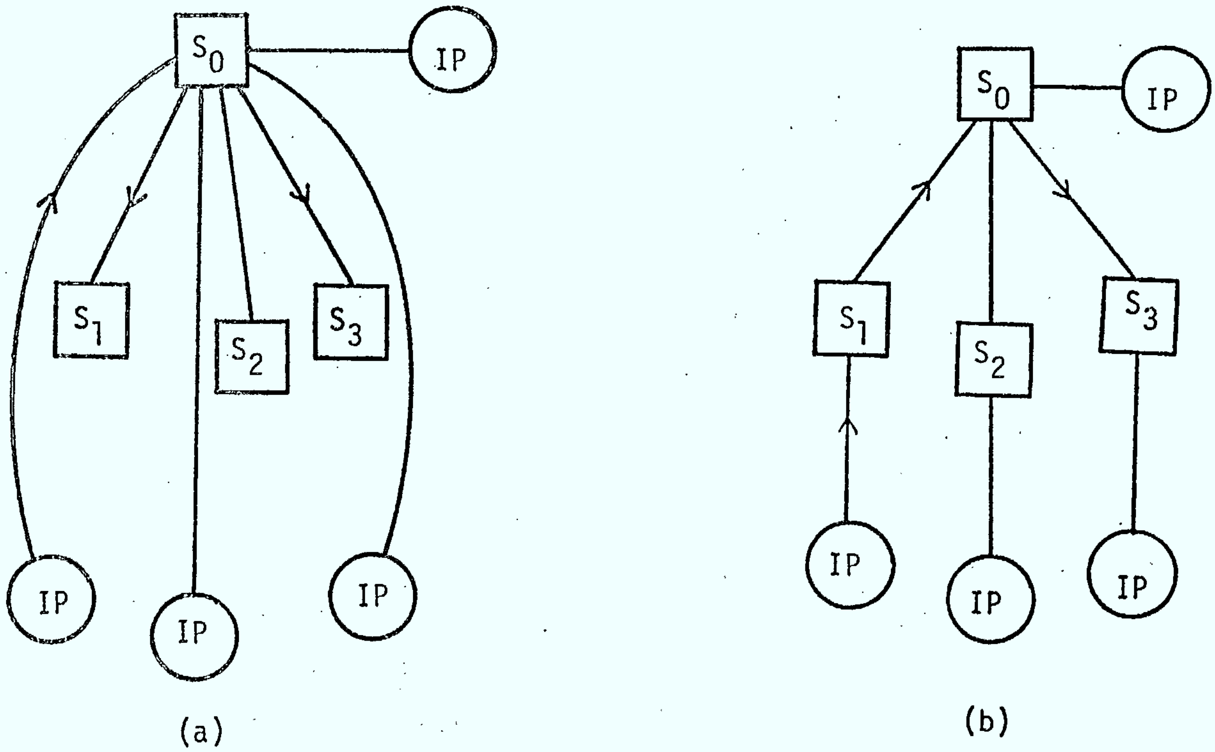


Figure 2.2 Direction of update requests in Group III Networks.

(a) All updates initiated at S_0 only.

(b) Update initiated at site S_1.

<u>Solution</u>: The file allocation problem for this group of videotex networks can be stated as follows:

"A set of videotex files F_i , i=1,2,...,n, is to be duplicated over the set of videotex information centres located at S_j , j=1,2,...,m. The main centre S_o will store all files and each regional centre S_j will store a subset of them. With the files being retrieved and updated in the way described above, we want to determine the subset of files to be stored at each of the regional centres so that the total storage and communication cost over the information server subsystem (ISS) will be minimal."

Note: For this problem, we are not concerned with the communication cost outside the ISS. For example, the cost of transmitting data from the IP's to the IUS's is not included in this formulation. It will, however, be studied in Chapter III.

This problem has been studied in a slightly more general context by Chang (CHAN75) for the case where the storage and communication costs are linear functions, and by Lam, et. al (LAMY80) for the case where these costs are step-functions. The main difference between their problem and ours lies in the file updating process rather than in the analytical method of solution. In their problem, update is usually reasonably dynamic and can be initialized by multiple users at various sites; whereas in our problem (essentially an information retrieval system), update of a file is usually less dynamic and is initialized by its IP at a specific site. As a result, statistics about update traffic can be collected more easily in our case.

In the following, as an illustration, we explain how to formulate Lam and Yu's problem in our context :

Analytic Formulation of File Allocation Problem for Group III Videotex Networks

We consider a distributed system consisting of a central computer located at site S_0 connected to a set of regional computers that are at sites $S_1, S_2, \ldots, S_m$. The overall system contains n files denoted by $F_1, F_2, \ldots, F_n$. A copy of each of these files is stored at the central computer S_0, while each regional computer S_j stores some subset of these files. The underlying problem is to determine which subset of files should be stored at each regional site. The solution is obtained in the context of minimizing storage costs and data traffic costs between S_0 and the regional sites. It is furthermore assumed that for each site S_j , the function $S=S(x)$ is known where $S(x)$ provides the cost of storing x units (bytes) of data at S_j and that the function $T=T(y)$ is known where $T(y)$ is the traffic cost of y units of data between site S_j and the central site S_0 .

We now examine the nature of the traffic between S_0 and site S_j . Two types of activity need to be separately considered.

a) Retrieval

Suppose a user connected to site S_j needs to retrieve data elements from file F_k . If this file is stored at S_j , then there is no traffic cost incurred. If, on the other hand, F_k is not stored at S_j then the request can only be serviced by accessing the copy of F_k which resides at S_0 and this results in a traffic cost on the S_0/S_j link. Clearly then, retrieval traffic costs are higher for those files not stored at S_j . (Note that there is no retrieval traffic on the S_0/S_j link due to a user at site S_i $(i \neq j)$ because a copy of all files exists at S_0 to which S_i is connected).

b) Update

Suppose a user at site S_j wishes to update data elements in file F_k . This necessarily (independent of whether or not a copy of F_k exists at S_j) results in traffic on the S_0/S_j link because S_0 contains a copy of F_k which must be updated. If a user at site S_i $(i \neq j)$ wishes to up-date F_k and a copy of F_k exists at S_j , then this also results in traffic on the S_0/S_j link. It therefore follows that update traffic is greater on the S_0/S_j link for those files that are stored at site S_j .

Thus, with respect to site S_j and file F_k , there are two traffic parameters u_k and v_k . The first characterizes the traffic on the S_0/S_j link if F_k is not stored at site S_j and the second characterizes the traffic if it is stored there. In addition, there is associated with F_k a third parameter, s_k, which is the storage space required to store F_k. This parameter is clearly not dependent on the remote site in question.

Let $d_k = 1$ if file F_k is not stored at site S_j and $d_k = 0$ if file F_k is stored at S_j, and let $D=(d_1, d_2, \ldots, d_n)$. The vector D therefore provides a characterization of which files are stored at site S_j. For any particular value of D the storage requirement at S_j is given by

$$x = x(D) = \sum_{i=1}^{n} s_i (1-d_i)$$

and the traffic on the S_0/S_j link is given by

$$y = y(D) = \sum_{i=1}^{n} \left[u_i d_i + v_i (1-d_i) \right]$$

Also

$$C = C(D) = S(x(D)) + T(y(D)) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

provides the total cost at site S_j of the file allocation characterized by D. The objective of our file allocation problem is then to choose D so as to minimize C.

A summary of the relevant notation is given below:

Notation	Explanation
S_0	Central computer site.
S_j, $j=1,2,\ldots,m$	Regional computer sites.
F_k, $k=1,2,\ldots,n$	Files to be allocated.
s_k, $k=1,2,\ldots,n$	Storage requirements (number of bytes) for file F_k.
u_k	Traffic on the S_0/S_k link if F_k is not stored at site S_j.
v_k	Traffic on the S_0/S_k link if F_k is stored at S_j.
$S(x)$	Cost of storing x units (bytes) of data at any site.
$T(y)$	Cost of y units of traffic between any two sites.
$D=(d_1,d_2,\ldots,d_n)$	Decision vector; $d_k = 1$ if file F_k is not stored at site S_j and $d_k = 0$ otherwise.
$C(D)=S(x(D))+T(y(D))$	Total cost of storing those files implicitly specified by D.

Equivalence to the Knapsack Problem

The knapsack problem in the mathematical programming literature has the following form: Let $a=(a_1,a_2,\ldots,a_n)$ and $b=(b_1,b_2,\ldots,b_n)$ be two given n-vectors of constants. Find the n-vector z which maximizes $\sum_{i=1}^{n} a_i z_i$ subject to the constraint that $\sum_{i=1}^{n} b_i z_i \leq M$ where, M is a given constant. Lam and Yu (LAMY80) have shown that, under certain assumptions about the functions S(x) and T(x) in equation (2), there is an equivalence between the file allocation problem and the knapsack problem. Specifically, if

i)

$$T(y) = \begin{cases} TM, & \text{if } y \leq \sum_{i=1}^{n} v_i + M \quad (M>0) \\ \infty & \text{otherwise} \end{cases}$$

ii) S(x) is monontonically increasing (i.e., $S(x_2) \geq S(x_1)$ for $x_2 > x_1$) and is finite for finite x, and

iii) D* is the solution to the associated file allocation problem,

then, z=D* is the solution to the knapsack problem associated with the coefficients $a_i = s_i$ and $b_i = u_i - v_i = h_i$ and vice-versa. (Note that the assumed form for T(y) implies that, if the traffic exceeds $\sum_{i=1}^{n} v_i + M$, then it cannot be handled; otherwise, the cost has a constant value of TM.)

The equivalence is established in the following way. First, observe that, for any D which yields a finite C(D), it must be true that $y(D) \leq \sum_{i=1}^{n} v_i + M$. Furthermore, C(D*) is finite because $C(D_0)$ is finite (where $D_0 = (0,0,\ldots 0)$) and by definition $C(D^*) \leq C(D_0)$. In other words

$$y(D^*) = \sum_{i=1}^{n} \left[u_i d_i^* + v_i (1-d_i^*) \right] = \sum_{i=1}^{n} h_i d_i^* + \sum_{i=1}^{n} v_i \leq \sum_{i=1}^{n} v_i + M$$

which in turn means that:

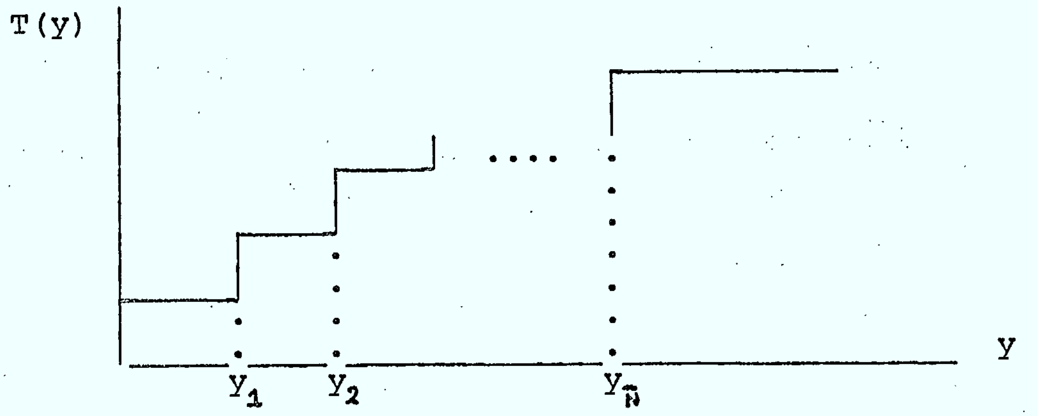
$$\sum_{i=1}^{n} h_i d_i^* \leq M$$

i.e., D* is a feasible solution to the knapsack problem in question.

Now, because T(y) is constant, the minimization of C implies the minimization of S(x(D)) in (2). But because S(x) is monotonically increasing and $x = x(D) = \sum_{i=1}^{n} s_i - \sum_{i=1}^{n} s_i \cdot d_i$ (where $\sum_{i=1}^{n} s_i$ is a constant), it follows that the minimization of S implies the maximization of $\sum_{i=1}^{n} s_i d_i$. Thus D* is the solution to the instance of the knapsack problem under consideration.

It is worth noting at this point that if, in equation (2), $h_k = u_k - v_k \leq 0$, then it means that, from a traffic point of view, there is as much (or more) cost in placing file F_k at site S_k as there is in not placing it there. Since its placement at S_k would typically introduce a storage cost as well, it follows that the best strategy is not to place F_k at S_j ; i.e., set $d_k = 1$. This observation makes it possible to reduce the dimensionality of the problem.

The above equivalence result can be utilized in the reasonably realistic context where both the storage cost function and the traffic cost function are step-functions. A typical form for T(y) is:



Here a discrete jump in traffic cost occurs when the traffic moves across each of the points in the finite set $y_1, y_2, \ldots, y_{\bar{N}}$. The solution to the file allocation problem in this framework can be obtained by solving a sequense of $\bar{N}$ knapsack problems. A description of the algorithmic procedure is given in Figure 2.3.

. For $k=1,2,...,n$, determine s_k, the storage required for file F_k.

. Let $N = \{1,2,...,n\}$.

. Repeat for $j=1,2,...,m$ (i.e., for each remote site)

. For $k=1,2,...,n$, determine values for u_k, the retrieval or update traffic on the S_0/S_j link, if file F_k is not stored at S_j.

. For $k=1,2,...,n$, determine values for v_k, the retrieval or update traffic on the S_0/S_j link, if file F_k is stored at S_j and let $z_1 = \sum_{i=1}^{n} v_i$.

. Determine the set I^* where

$$I^* = \{ i \in N: h_i = u_i - v_i \leq 0 \}$$

and let $\hat{I} = N - I^*$.

. Repeat for $\alpha = 1,2,...,\bar{N}$

. Solve the knapsack problem:

$$\max \left(\sum_{i \in \hat{I}} s_i d_i \right)$$

$$\text{subject to: } \sum_{i \in \hat{I}} h_i d_i \leq (Y_\alpha - z_1 - \sum_{i \in I^*} h_i).$$

. Denote the solution by D_α^*.

. Increment α.

. Find $\min \{ C(D_\alpha^*): \alpha = 1,2,...,\bar{N} \}$.

. Increment j

Figure 2.3 Solution Procedure for the File Allocation Problem for Group III Videotex Networks.

The procedure in Figure 2.3 is stated in terms of obtaining a true solution to each of the sequence of knapsack problems. While algorithms are available (Horowitz and Sahni), the problem is NP-hard. Approximate procedures, however, are available and can be used in a large network where computational costs may become prohibitive. Depending on the level of approximation selected such alternate procedures can have a high probability of providing a good match to the true solution.

As an illustration of the procedure in Figure 2.3, a representative numerical example has been treated.

Example We assume 6 sites (m=6) and 10 files (n=10). The storage cost function, S(z), is shown in Fig. 2.4 and the traffic cost function, T(y), is shown in Fig. 2.5. The storage requirements for each of the files are summarized in Fig. 2.6(a) and the u/v vectors for each of the sites are given in Fig. 2.6(b). The results obtained from the program based on the procedure of Fig. 2.3 are given in Fig. 2.7.

Listings of the various Fortran subprograms which were used in the computation are attached in Appendix B.

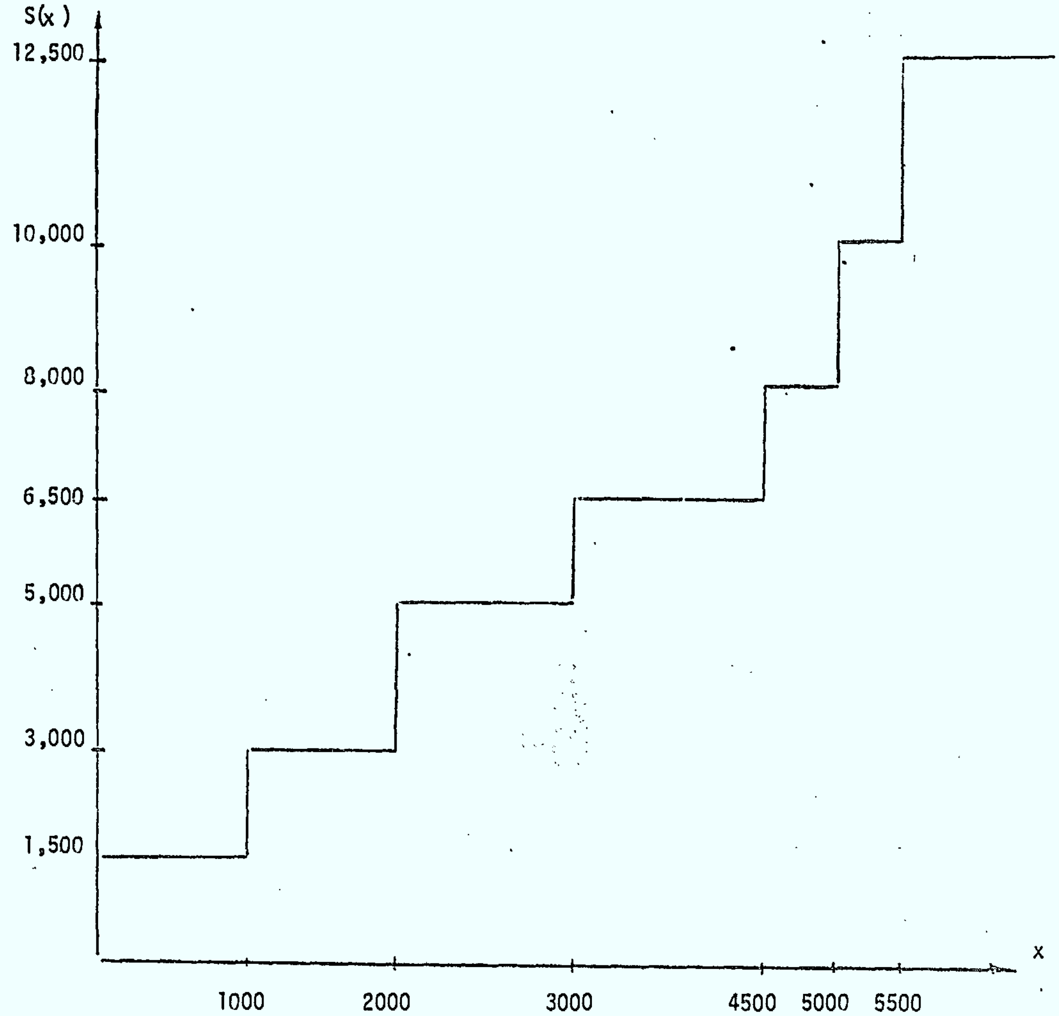


Figure 2.4

Storage Cost Function for the Example Problem

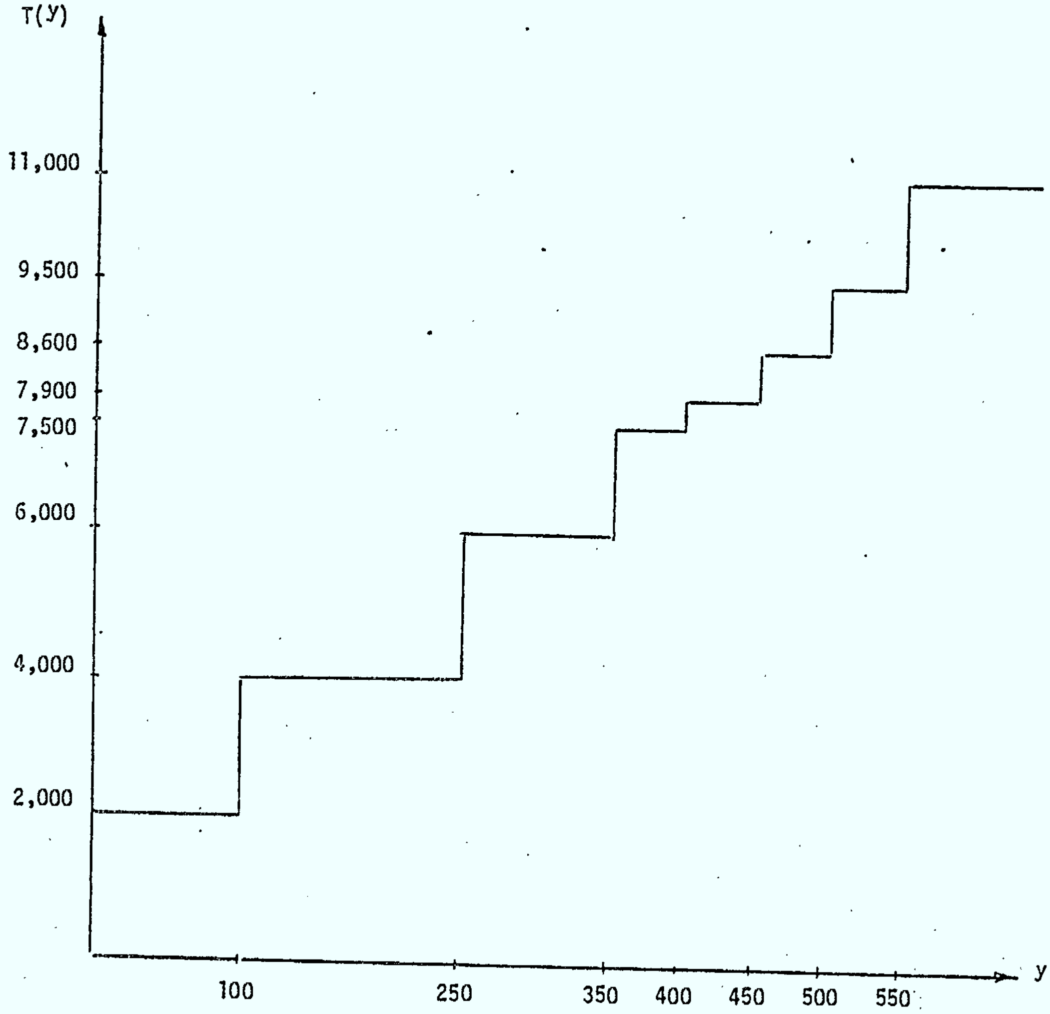


Figure 2.5

Traffic Cost Function for the Example Problem

File	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	F_{10}
Storage	100	200	300	400	500	600	700	800	900	1000

Figure 2.6(a)

Storage Requirements for the Files

	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	F_{10}
S_1	70/10	60/20	50/30	40/40	30/50	20/60	10/70	100/80	90/90	10/100
S_2	10/10	100/20	90/30	80/40	70/50	60/60	50/70	40/80	30/90	10/100
S_3	50/10	40/20	30/30	20/40	10/50	100/60	90/70	80/80	30/90	10/100
S_4	30/10	20/20	10/30	100/40	90/50	80/60	70/70	60/80	30/80	10/100
S_5	60/10	50/20	40/30	30/40	20/50	10/60	100/70	50/80	30/90	10/100
S_6	40/10	30/20	20/30	10/40	100/50	90/60	80/70	50/80	30/90	10/100

Figure 2.6(b)

The u/v Vectors for the Sites

	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	F_{10}
S_1	*	*	*					*		
S_2		*	*	*	*					
S_3	*	*				*	*			
S_4				*	*					
S_5	*									
S_6	*				*	*				

Figure 2.7

Optimal File Allocation Summary

(* indicates that the file is stored at the site)

Chapter III

ASSIGNMENT OF USERS AND INFORMATION PROVIDERS TO INFORMATION SERVERS

3.1 INTRODUCTION

Under our model of Chapter I, the Information Server Subsystem (ISS) plays the role of a communications message switcher within a videotex network. In Chapter II, the functional architecture which describes the internal relationship among the components of ISS, i.e., the information retrievers (IR), information update servers (IUS), and meta-service switchers (MSS), is applied the videotex file allocation problems. In this chapter, we turn our attention to some of the external relationships between the components of ISS and the other three subsystems (users U, information providers IP and meta-service providers MP). In fact, we investigate two problems : namely, the problem of assigning the users to the IR´s and the problem of assigning the IP´s to the IUS´s. The problem of assigning MP´s to the MSS´s is similar and thus will not be explicitly considered. In the following, we use the term ´server´ to mean either ´IR´ or ´IUS´ and the term ´ client´ to mean either ´user´ or ´IP´.

In practice, a server may service many clients located at different sites. The way in which the clients are assigned to the servers affects the total (communications, processing and/or storage) costs. Our objective is to minimize a certain combination of these costs, using analytical and approximation methods.

Notes

i) 'Assignment' here is a functional concept. Physical realization of an assignment is assumed to be available but is beyond the scope of study of this report.

ii) The minimization is from the standpoint of the entire system and is not for an individual client. A smaller total cost for the system may or may not result in lower service charges for some clients.

iii) For our study of the client assignment problems, it is assumed that the topology of the ISS and the locations of files have already been fixed. An integrated study of these problems is of extremely large scale.

In the next section, we first formulate a model for the minimization problems. We then apply this model to the different types of videotex networks as classified in Chapter I. Lastly, we consider some methods for simplifying the computations involved.

3.2 ASSIGNMENT OF USERS AND INFORMATION PROVIDERS

By the phrase ´assigning a client to a server´, we mean ´associating a client to a server for the purpose of physical connection´. Without loss of generality and just for the purpose of simplifying our problem formulation, we may assume that each client is assigned to one and only one server. More explanation follows.

In general, the data and services requested by a user may originate from several IR´s. On subscribing, a user is given the telephone numbers of one or several IR´s for connection purposes. Interactions with the other IR´s are switched through the connected IR. For our problem formulation, if a user is given the telephone numbers of more than one IR, we may either use just the primary number while ignoring the others or logically assume that there are several users.

Similarly, an IP may have to be connected to several IUS´s in order to update different files. However, we can, logically at least, partition such an IP into several IP´s so that each of them is serviced by only one IUS. Also, if there is more than one copy of the <u>same</u> file, the IP is connected to one of the IUS´s in order to directly update one of the copies. The other copies are indirectly updated through this IUS.

In the following, we first formulate the assignment problems as an analytical model and then apply the model to several types of videotex networks.

3.2.1 A model for assignment problems

We make the following assumptions for our model :

i) The functional architecture of the ISS is known. That is, we know whether each IR has a master database, whether an IUS services all or part of the IR's, etc.

ii) The locations of the files, users, IP's, MP's, IR's, IUS's and MS's are all known.

iii) Each user knows what data and meta-services (not necessarily their locations) he/she requests. Each information provider knows what data (and their locations) it provides. We shall refer to this as "client's demands".

iv) The communications and/or processing costs of servicing a client's demand by a server are known or estimable. How this is calculated depends on the problem. (See Section 3.2.2)

v) The number of clients each server can service is known. This can be estimated in terms of the hardware speeds, number of communications ports, etc., available at the server's computing facilities.

vi) Each client is assigned to one and only one server.

We shall use the following notation :

Notation	Explanation
m	Number of servers.
n	Number of clients.
c_{ij}	Total (communications and/or processing) cost of servicing the demands of the jth client by assigning it to the ith server.
b_i	Maximum number of clients the ith server can service.
x_{ij}	$x_{ij} = \begin{cases} 1 & \text{if the jth client is assigned to the ith server} \\ 0 & \text{otherwise.} \end{cases}$
$\sum_i$	scope of summation is from 1 to m.
$\sum_j$	scope of summation is from 1 to n.

Our minimization problem is then the following well known assignment problem in operations research:

$$\begin{aligned} \text{Minimize :} \quad & \sum_{i,j} c_{ij}\, x_{ij} \\ \text{subject to} \quad & \sum_i x_{ij} = 1 , && j=1,2,\ldots\ldots\ldots,n \\ & \sum_j x_{ij} \leq b_i , && i=1,2,\ldots\ldots\ldots,m \\ & x_{ij} = 0 \text{ or } 1 && i=1,2,\ldots\ldots\ldots,m; \\ & && j=1,2,\ldots\ldots\ldots,n. \end{aligned} \qquad (3)$$

There exist very efficient algorithms (DENN58) for solving (3).

3.2.2 Application to videotex networks

Based on the Minimization Model (3), we can now discuss the user and information provider assignment problems for the various types of networks as classified in Chapter I. Essentially, we explain how the cost parameters c_{ij} can be obtained in each case.

For Videotex Networks of Type 1

Since a network of this type has only one IR and one IUS, all users are assigned to the same IR and all IP's to the same IUS.

For Videotex Networks of Type 2.1

In this case, since each subnetwork has autonomy over its users and files, the users and IP's can only be assigned to the IR and IUS, respectively, of the subnetwork they subscribe to.

For Videotex Networks of Type 2.2

A network of this type has several information centres, each containing an IR and an IUS.

* A user may be assigned to any IR. If user U_j is assigned to IR_i , the parameter c_{ij} includes the communications, storage and processing costs for : (i) IR_i directly servicing U_j; and (ii) IR_i switching data and meta-services to and from other IR's.

* An IP must be assigned to the IUS whose associated IR contains those files belonging to this IP. Since each file

has only one copy in the entire network, such an assignment is unique.

For Videotex Networks of Type 3

A network of this type has one IUS and several IR's.

* A user U_j may be assigned to any IR_i. If IR_i contains a master database, the parameter c_{ij} includes only the communications and/or processing cost between IR_i and U_j. If IR_i contains only a portion of the entire database, c_{ij} should also include the cost of switching data and services between IR_i and the IR which contains the master database.

* Since there is only one IUS, all IP's should be assigned to it.

For Videotex Networks of Type 4

A network of this type has several IR's and IUS's.

* A user U_j may be assigned to any IR_i. Since all IR's contain a master database, the parameter c_{ij} includes only the communications and/or processing cost between IR_i and U_j ; i.e., no switching cost for data.

* An IP_j may be assigned to any IUS_i . The parameter c_{ij} includes the communications and/or processing costs between IUS_i and IP_j and the cost of updating (from IUS_i) the copies stored at all the IR's.

For Videotex Networks of Type 5

* For this type of networks, user assignment is the same as for Type 3.

* As for information provider assignment, it is the same as Type 4 except that a file to be updated may have copies at only some of the IR´s. (Computationally, there is no difference.)

3.2.3 Some Computational Aspects of the Model

The biggest obstacle when applying Model (3) is obviously the size of the problem, even though there exist reasonably efficient algorithms for its solution. In practice it is easier to handle the information provider assignment problem as there are usually not many IP´s. However, a videotex system, especially those open to the public, may have millions of users. Solving (3) for problems of such sizes is computationally intractible. The following observations may help reduce the sizes of the problems.

(i) Excluding some users from consideration

For some users, the selection of an IR for assigment purposes is quite obvious. For example, if a dominantly large portion of the files requested by a user U are stored at IR , U should definitely be assigned to IR . The following rough rule may be used: Let p be the cost imposed on U for retrieving data directly from IR and q be the cost for retrieving data from the other IR´s through IR . If p >> q, U should be assigned to IR and hence excluded from further consideration.

(ii) Group assignments by regional partitioning

In practice, one may assign the clients by groups instead of individually. For example, a district can be partitioned into several smaller regions according to the geographical environment, population, or management convenience of the system. All clients within a region will be assigned to the same server and thus conceptually become a single client when appling our Model. The total or average cost of servicing a region by a server can be easily estimated. There is an upper bound on the number of regions a server can service. A detailed explanation of this approximation method and its analytical foundations are given in (CHEU74).

Chapter IV

ISSUES OF DATABASE INTERFACES

4.1 INTRODUCTION

For most of the existing videotex systems, the term ´database´ means in fact a collection of conventional files whose records contain videotex information pages --hereafter we call them ´conventional files´. In this chapter, however, a database is a reservoir of data which are defined, organized and manipulated according to a data model, such as the relational model, the hierarchical model, the CODASYL model, etc.--hereafter we call them ´databases´.

The capability of a videotex system to access databases greatly enhances the system´s flexibility and sophistication. If access is limited to conventional files, the information contained in each page is pre-determined. Users have to search through numbers of pages in order to get what they want, and very often in vain. In the case of databases, users can specify the scopes and the conditions of the information they desire by means of a query language. The system then retrieves various segments of relevant information from different portions of the database and composes them dynamically into one or several pages for subsequent display at the terminals.

In a videotex environment, many issues about the design of such databases arise. Of particular concern are the following :

1. Methods for physically accessing the distributed databases.
2. Methods for allocating the distributed data and management tasks.
3. Security problems.
4. Issues of interfaces with videotex system users and information providers.

Among these 4 issues, analytical works on the first 3 are abundant. But, they are not "directly" related to videotex systems. In other words, they exist by themselves, though a videotex environment may make the problems more complicated. Thus, in accordance with our Guideline for Research Scope (see Introduction and Executive Summary), we shall simply collect their reference resources in Bibliographies I, II and III, respectively.

In this chapter, we consider the above Issue #4, namely, interfaces between the databases and the clients of a videotex system.

4.2 INTERFACES BETWEEN DATABASES AND CLIENTS

In general, a user interfaces with a database through two phases :

i) Database definition This phase includes defining the database schemas and subschemas, etc. It is known to be the most difficult job in the administration of databases and is usually handled only by experts called database adminstrators (DBA).

ii) Database manipulation This phase includes data creation, retrieval and update. Many data manipulation languages have been designed for the different well-known data models, such as relational, hierarchical, CODASYL, etc. From the users' point of view, those languages for relational databases are obviously the most powerful and easy to understand.

In many cases, a database is primarily utilized by users of a non-videotex database management system. Providing accesses to videotex system users is only one of its secondary functions. Such a database is called an 'external' or 'third-party' database by videotex system users. Thus, in designing its interface with the videotex clients (i.e., users or information providers), we should take into consideration the fact that the non-videotex users' methods for processing the databases should not be altered.

Our consideration on these interfaces is within the environment of a 'pure' videotex system, i.e., a videotex system possessing the following two characteristics which greatly influence its design :

(A) The terminals have very simple keypads and processors, small memory size, etc.

Because of these restrictions, their processing capabilities are very limited and interface procedures between clients and databases have to be very simple. We do not include integrated intelligent terminals in our consideration, because the design is then essentially for an integrated system, with the videotex technology simply fading into another format of data presentation. Thus, those techniques which require a greater processing power, such as downloading telesoftware into an intelligent terminal for handling user interfaces and imbedding a database interface in a high level language, are not within the scope of our study.

(B) The users and information providers have separate groups of operations.

The two groups of clients, the users (U) and the information providers (IP), interface with the databases by using the retrieval (output only) update (input only) operations, respectively. Such separation of operations may offset part of the disadvantages due to Property (A) mentioned above. More explanation follows.

(i) User interface

In a ´pure´ videotex system, a user is involved only with the retrieval of information, whether from conventional files or from databases. The creation and updating of data are not the users´ responsibility. In the case of databases, this fact has the following implications :

a) The users are released of the burden of defining and modifying databases. These processes are usually too complex for most of the non-technical videotex system users and should be handled by either the IP´s or the database administrators who are supposed to be more technically knowledgeable.

b) The simplicity of a videotex terminal greatly limits the data manipulation capability of a user language. However, this is compensated by a reduction in its total number of operators, because only retrieval operations are now required.

c) With slight extensions, the simple menu-lookup and indexing techniques used frequently for conventional file searching in current videotex systems can be utilized to implement quite powerful retrieval languages for databases. Examples illustrating how to do this in the cases of a relational database and a hierarchical database will be shown in the next section.

(ii) Information provider interface

If several copies of a database can be updated by different sources, one of the difficult system management problems is to maintain the consistence of these copies. In a videotex environment, however, the difficulty of maintaining data consistency may be alleviated, because, according to the current management practice of videotex systems, one and only one IP is responsible for and has sole control over the update of all copies of an information page. (Note: According to our model, an IP does not physically do the update. It sends the data to an IUS where the physical update is done. But, conceptually, the IP is reponsible for the update since it initiates the process.) More details are given in each of the following two cases where data inconsistence arises :

Case 1 Because of communications delay, two consecutive updates for the same file may reach its duplicate copies (located at different sites) in different chronological orders, resulting in permanent inconsistence of these copies. In a videotex environment, since update of all copies of a file is initiated by the same IP, the IP can easily assure their consistence by serializing the updates in the same order for each site. One way to do this is to wait until acknowledgements for one update have come back from all relevant sites before issuing the next update. (Note : This is not so simple if there is more than one source which are responsible for update.)

Case 2 Because of communications delay, an update issued from an IP may reach two different relevant sites at two different moments. Such inconsistence is temporary for the database, but may end up with the users getting two different versions of the data, even if they retrieve at the same instant of time. Such inconsistence can be avoided by using a simple locking scheme.

4.3 QUERY LANGUAGES FOR DATABASES IN A VIDEOTEX SYSTEM

A query language consists of a set of operations for information manipulation. From the users' point of view, query languages can be roughly classified into the following four groups in a decreasing degree of technical complexities:

Group 1 A language of this group is the most advanced. It includes all the facilities for defining database schemas and subschemas and for manipulating data in a highly sophisticated manner. It is usually imbedded in a high level programming language such as COBOL, FORTRAN, etc. An example is the DL/I of IBM's IMS. This group of query languages are definitely too complicated for non-techinical users. Their implementation at a 'pure' videotext terminal is either infeasible or extremely inefficient.

Group 2 A language of this group is usually a user-friendly data manipulation language of a certain data model (mostly relational). They can be easily learned by most users. Included in this group are SQL and SQUARE (REIS75, REIS81 in Bibliography V), QBE (REIS81, THOM75, ZLOO75 in Bibliography V), etc. However, in their existing forms, these languages cannot be implemented ´directly´ for ´pure´ videotex terminals, because these terminals lack the capability of inputting alphabetical character strings or special functions required in these languages.

Group 3 This group includes those languages of either Group 1 or Group 2, but implemented in an environment where only simple menu-lookup types of searching techniques and numeric key inputs are used. Though at least two languages of this sort (DBM82, RMS83 in Bibliography V) exist for the APPLE microcomputers, we do not know of any of them designed specially for videotex systems.

Group 4 This group includes the menu-lookup searching techniques for conventional files, as used in most of the existing videotex systems.

Since we limit our research to ´pure´ videotex terminals (as mentioned in the Introduction and Executive Summary), languages of Group 1 and 2 are not within our scope of study. Group 4 does not concern databases. In the following, we shall first illustrate by two examples how to execute a language of Group 3 in a videotex environment (Section 4.3.1) and then mention some activites of behavioural research on these languages (Section 4.3.2).

4.3.1 Execution of database manipulation languages by menu-lookup techniques

Even with limited capabilities, 'pure' videotex terminals can still implement many of the well known database query languages in a manner familiar to the videotex system users, i.e., by using the techniques of menu-lookups, indexing, etc. The following two examples illustrate the concepts of this approach without giving the details.

Execution of a relational algebra

A relational database consists of a set of table-like relations. A relational algebra is a set of operations, such as projections, restrictions, join, etc., on the relations. In a videotex environment, these operations can be executed as follows :

All operations begin with the display of the following page of information :

Operators :

1. Difference ; 2. Intersection ;
3. Join ; 4. Projection ;
5. Restriction ; 6. Union ;

......

Relations :

1. R1(A1, A2,.....);

2. R2(B1, B2,.....);

......

One way to project relation R1 onto attributes A2 and A4, for example, is to enter the sequence (4..1.2.4) through the keypad. (See the Note below.) In this sequence, the digit (here 4) in front of the two dots '..' refers to the operator (here Projection) in the displayed list. Its operand is indicated by the subsequence (1.2.4), in which the first digit indicates the relation (here R1) in the dispayed list of relations, and the remaining digits indicate the positions of the attributes (here the 2nd and the 4th) within that relation.

Similarly, a join operation of relations R1 and R2 over their attributes A1 and B2 can be executed by entering the sequence (3..1.1..2.2) on the keypad.

Note : Other symbols such as a comma ',', if available in the keypad, may be used to replace the double dots '..'. Some keypads (e.g., Vista's keypad), however, do not have the keys for these special symbols.

Execution of IBM's DL/I

DL/I is the data definition and manipulation language of IBM's IMS (Information Management System) system for implementing (essentially) hierarchical databases. Briefly, each database within IMS is a hierarchy of segments (i.e., records). DL/I consists of a set of operations such as GU (get unique), GN (get next), GNP (get next within parent), etc.

Execution of any operation begins with the display on the terminal the following page of information :

<u>Operators</u> :

1. Get Unique; 2. Get Next;

3. Get Next Within Parent;

<u>Databases</u> :

0. SO(A1, A2,.....)

1. S1(B1, B2,.....)

1.1 S1.1(C1, C2,.....)

2. S2(D1, D2,.....)

2.1 S2.1(E1, E2,.....)

2.2 S2.2(F1, F2,.....)

To execute the operation GN S1.1 (get the next segment occurrence of segment type S1.1), for example, a user enters the sequence 2..1.1 through the keypad.

4.4 BEHAVIOURAL RESEARCH ON QUERY LANGUAGES

Users' behaviour in response to executing a query language is one of the important criteria for evaluating how successful the language is. Behavioural researchers have recently done quite a lot of studies on these languages. Language characteristics such as ease-of-use, procedurality, data-retrieval-power, error-sensitivity, etc., are investigated using human factors methodology. Since the methodology used is essentially not analytical and thus is not within our scope of research, we simply mention in the following some of the main results without giving the details. A list of references are given in Bibliography V.

For languages of Group 1, Lochowsky (LOCH77,78 in Bibliography V) evaluated the user performance for several query languages of the relational, hierarchical and CODASYL data models. These languages are implemented in APL (EDBS75). For Group 2, QBE was evaluated by Thomas (THOM75 in Bibliography V) and SQL (known earlier as SEQUEL) by Reisner (REIS75 in Bibliography V). An excellent study on evaluating the performances of several query languages of Group 2 was made by Reisner (REIS81 in Bibliography V). The study reviews the methods for evaluating several query languages (e.g., QBE, SQL, SQUARE, TABLET, etc.), compares their results, and proposes models for evaluation. As for languages of Group 4, user behaviour of all existing videotex systems is measured during their field trials. In particular, Lee, et. al. (LATR81, LEE80, WHAL80 in Bibliography V), Phillips (PHIL81 in Bibliography V), and Mills (MILL81 in Bibliography V) have done behavioural research on videotex tree indices. Unfortunately, only some fragmentary statistical results of these evaluations are reported in the publicly available literature.

Chapter V

ISSUES OF DATA ENCRYPTION

5.1 INTRODUCTION

The security of a modern cryptosystem depends on several factors: the strength of its methods for key distribution and message authentication and the robustness of its encryption/decryption algorithms.

There exist many encryption-based techniques for the distribution of conventional or public keys and for the authentication of the participants' identities in a general communication network environment. Bibliography IV contains a long list of articles about these techniques. Since a videotex network is just a particular type of communication network, these techniques should, theoretically at least, also be applicable. However, in practice, the following four characteristics of a videotex system may affect the design and/or implementation of these algorithms:

i) A 'pure' videotex terminal is very simple

A videotex terminal has very limited storage space and processing power. Its keypad has only a few numeric and functional keys.

ii) Most of the users are not technical people

They get used only to very simple interactive processing techniques, such as menu-lookup types of searching, etc.

iii) A 'pure' videotex system is essentially an information retrieval system

Most of the data move in one direction, from the information centre to the user. There are no interactions among the users.

iv) Videotex data usually have special patterns

For example, Telidon data are coded in special formats of the Picture Description Instructions. These patterns are usually readily avaibable.

Because of the first three features mentioned above, implemention of encryption-based techniques in a videotex network is possible only if there are both hardware and software adjustments in the system. On the hardware side, some recent developments are moving in this direction. Two LSI chips, one for the DES (NBS's Data Encryption Standard) Algorithm (DATA82) and another for the MIT Algorithm (RIVE78) are being designed. Their speeds, however, may still be too slow for application in a real-time environment such as videotex networks. We do not know of any hardware developments for the purpose of key distribution or message authentication. As for the software aspects, adjustments will be similar to the interface techniques for database query languages as described in Chapter IV.

5.2 ROBUSTNESS OF ENCRYPTION DECRYPTION ALGORITHMS

The robustness of an encryption/decryption algorithm is related to its protective capability against cryptanalytic attacks.

In classical cryptography, the aim of a cryptanalyst is to discover the mathematical transformations for encryption. For modern cryptosystems, since the mathematical transformations are usually publicly known, the aim is either to discover the keys or to recover the plaintexts directly. Three approaches are commonly used for cryptanalytic attacks: ciphertext only attacks, known plaintext attacks and chosen plaintext attacks.

Surprisingly, though modern cryptography provides an elegant approach for building cryptosystems, there exist only a few 'strong' encryption algorithms, e.g., the DES Algorithm and, MIT Algorithm. On the other hand, there does not seem to be many analytical methods for 'proving' the strength of these algorithms. In the following, we shall consider such an analytic approach.

What we are interested in concerns the functional dependence between the plaintext and ciphertext (for a fixed key) and between the key and the ciphertext (for a fixed plaintext). If the attacker finds any such functional dependences, it will be much easier to break the system. This is specially true when the attacker knows that the plaintext is composed of data structured in special patterns, as in the case of most videotex data.

In order to test the independence of the data mentioned above, S.M. Wong has used the Chi-square test method and has done some computational experiments based on the DES Algorithm. (The details are given in Appendix C.) Though her method and results are not specifically for videotex data (partly because of inavaibability of the videotex hardware and data), we believe that her approach is a useful analytical method for testing the robustness of an encryption algorithm.

Appendix A

CONFIGURATIONS OF MAJOR VIDEOTEX SYSTEMS

This appendix consists of the configurations of several major videotex systems. They illustrate the different types of videotex networks under the classification scheme based on the model proposed in Chapter I.

Figure A.1 The first stage of Bell Canada's Vista System.

Figure A.2 Germany's current Bildschirmtext System.

Figure A.3 The early stage of Britain's Prestel System.

Figure A.4 The current stage of France's Antiope System.

Figure A.5 The current stage of Britain's Prestel System.

Figure A.6 Germany's new Bildschirmtext System.

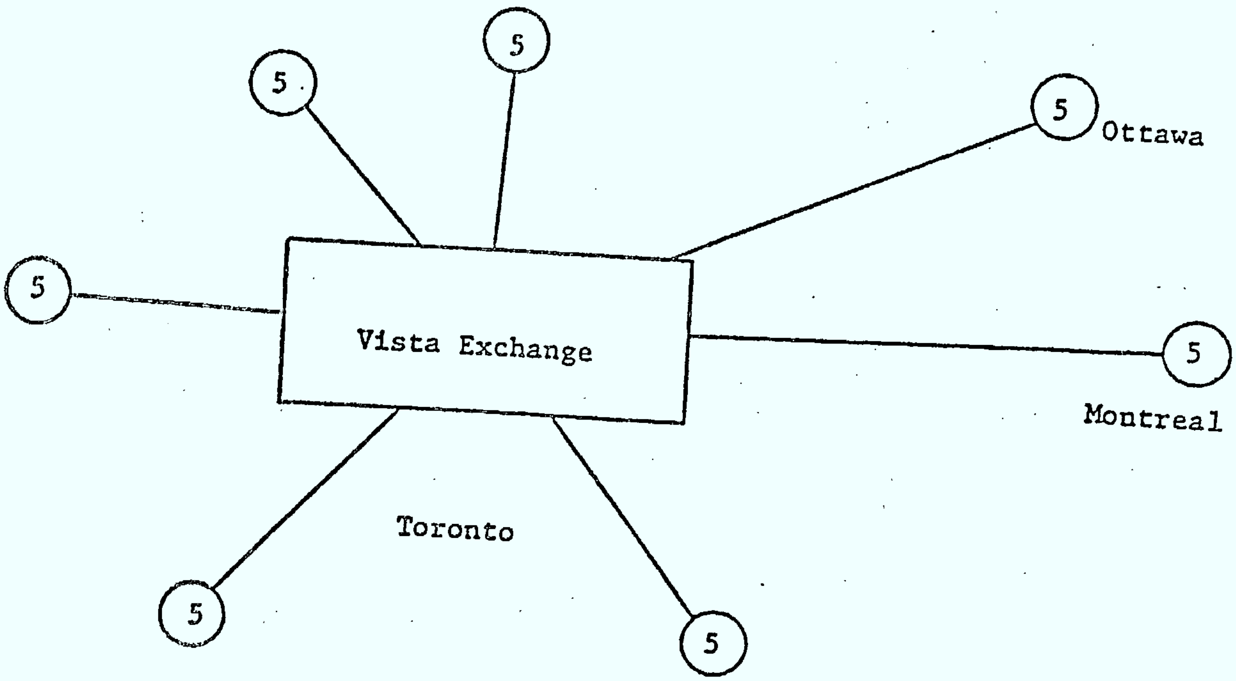
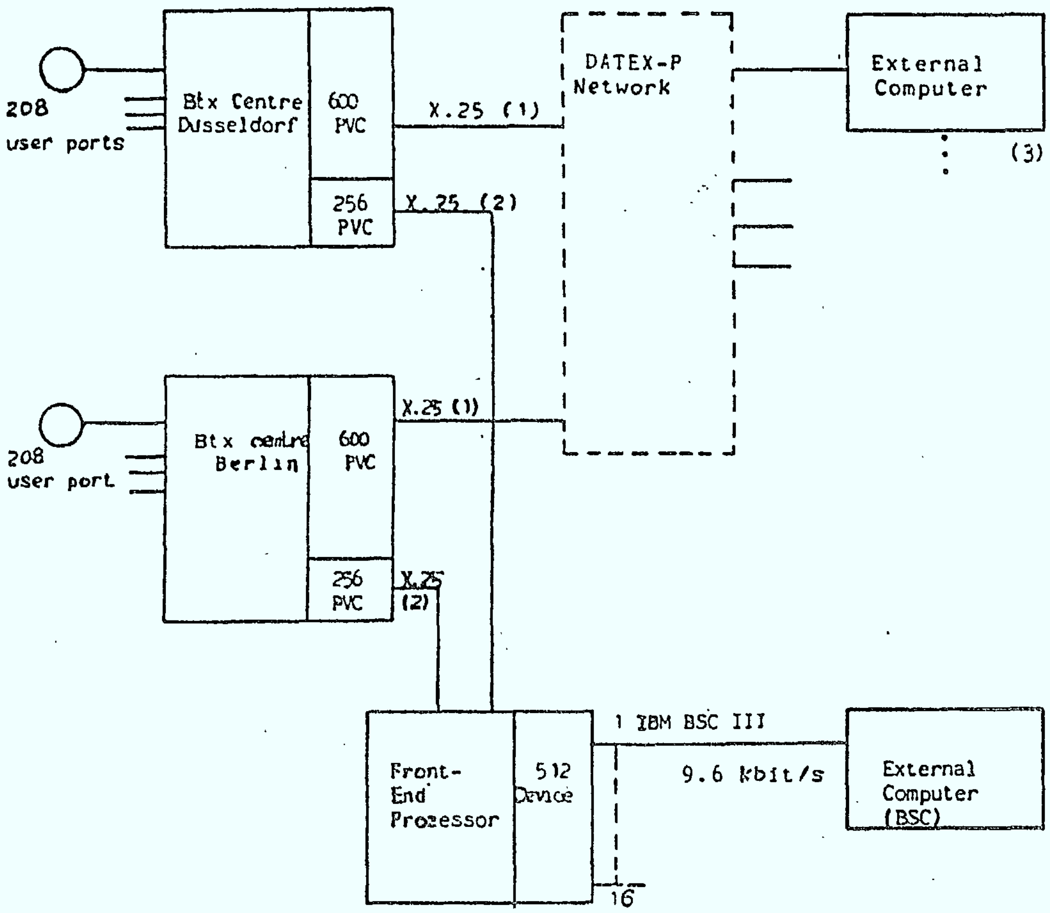


Figure A.1 The first stage of Bell Canada's Vista System.
(extracted from [MANN82])



(1) 5 links each 9.6 kbit/s
(2) 3 links each 9.6 kbit/s
(3) number of ext. computers only restricted
by total number of PVC:

Figure A.2 Germany's current Bildschirmtext System.
(extracted from [GRIE82])

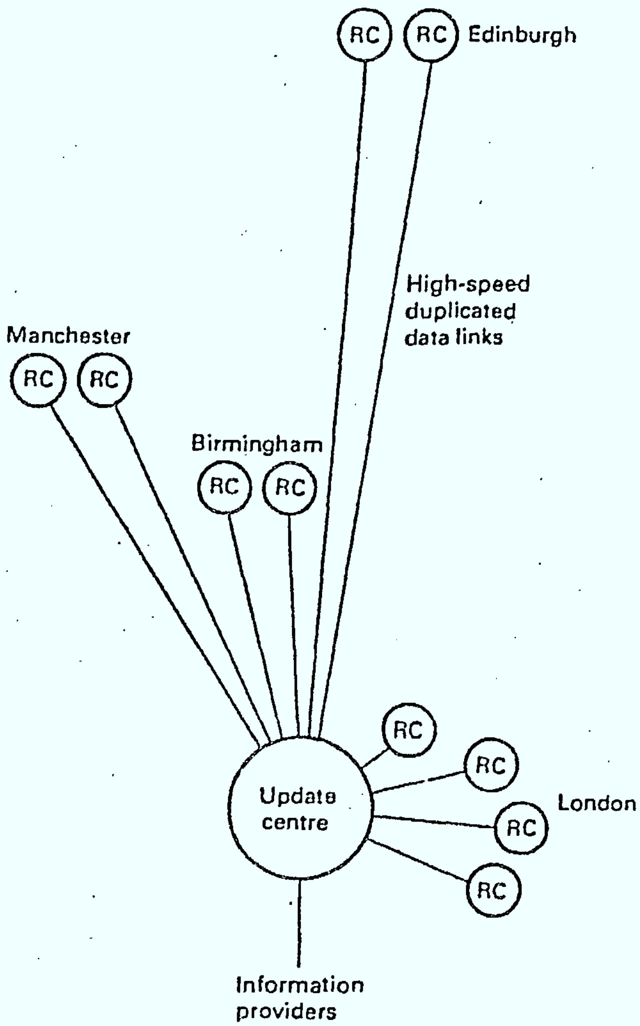


Figure A.3 The early stage of Britain's Prestel System.
(extracted from [CLAR81])

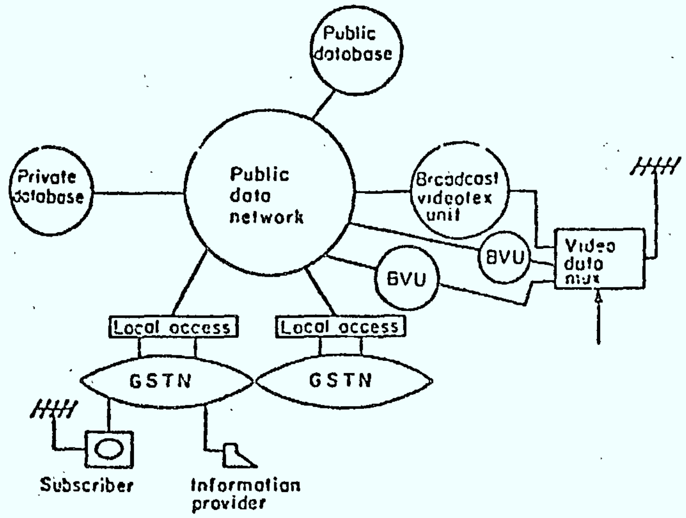


Figure A.4 The current stage of France's Antiope System.
(extracted from [MART79])

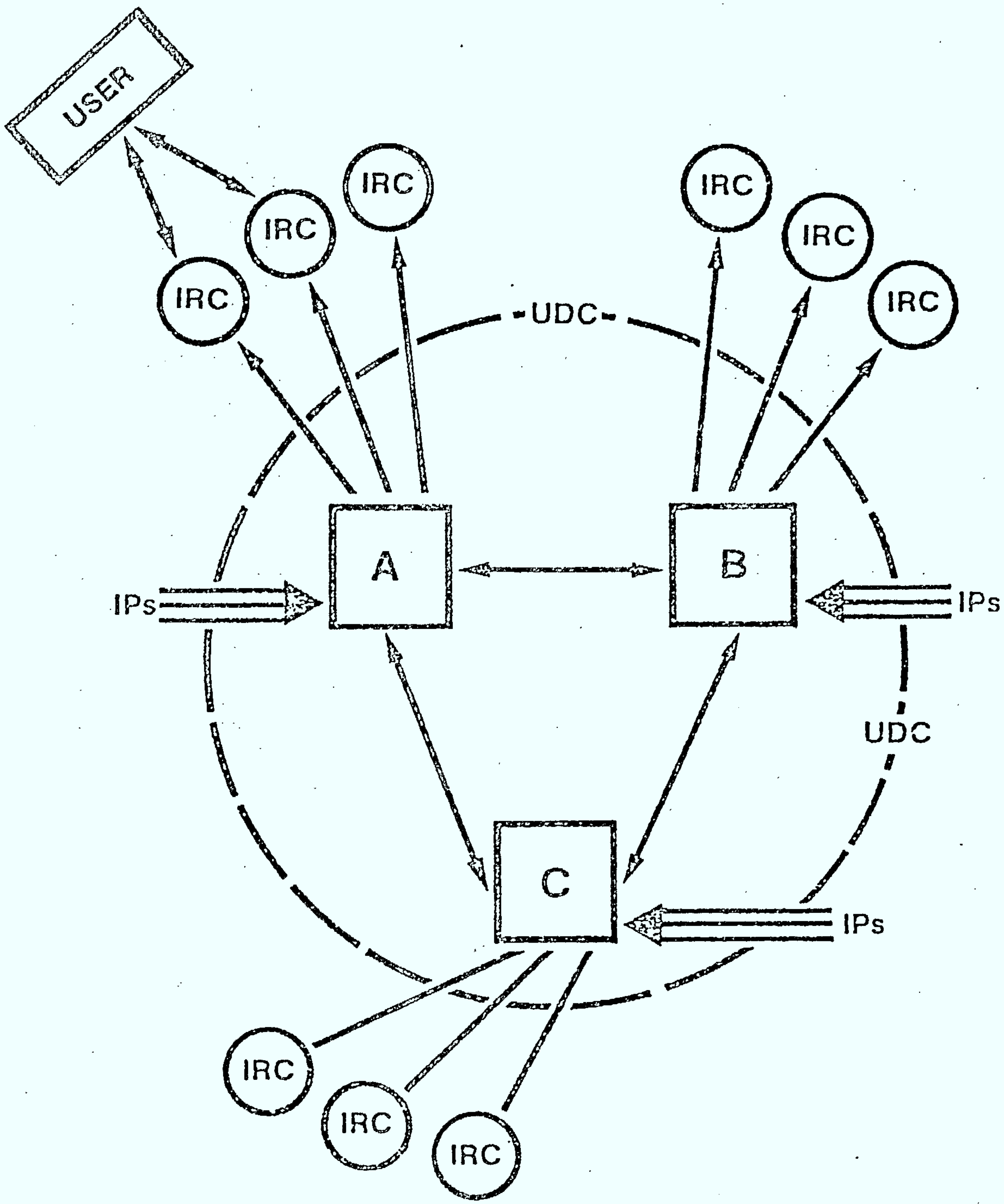


Figure A.5 The current stage of Britain's Prestel System.
(extracted from [TROU80])

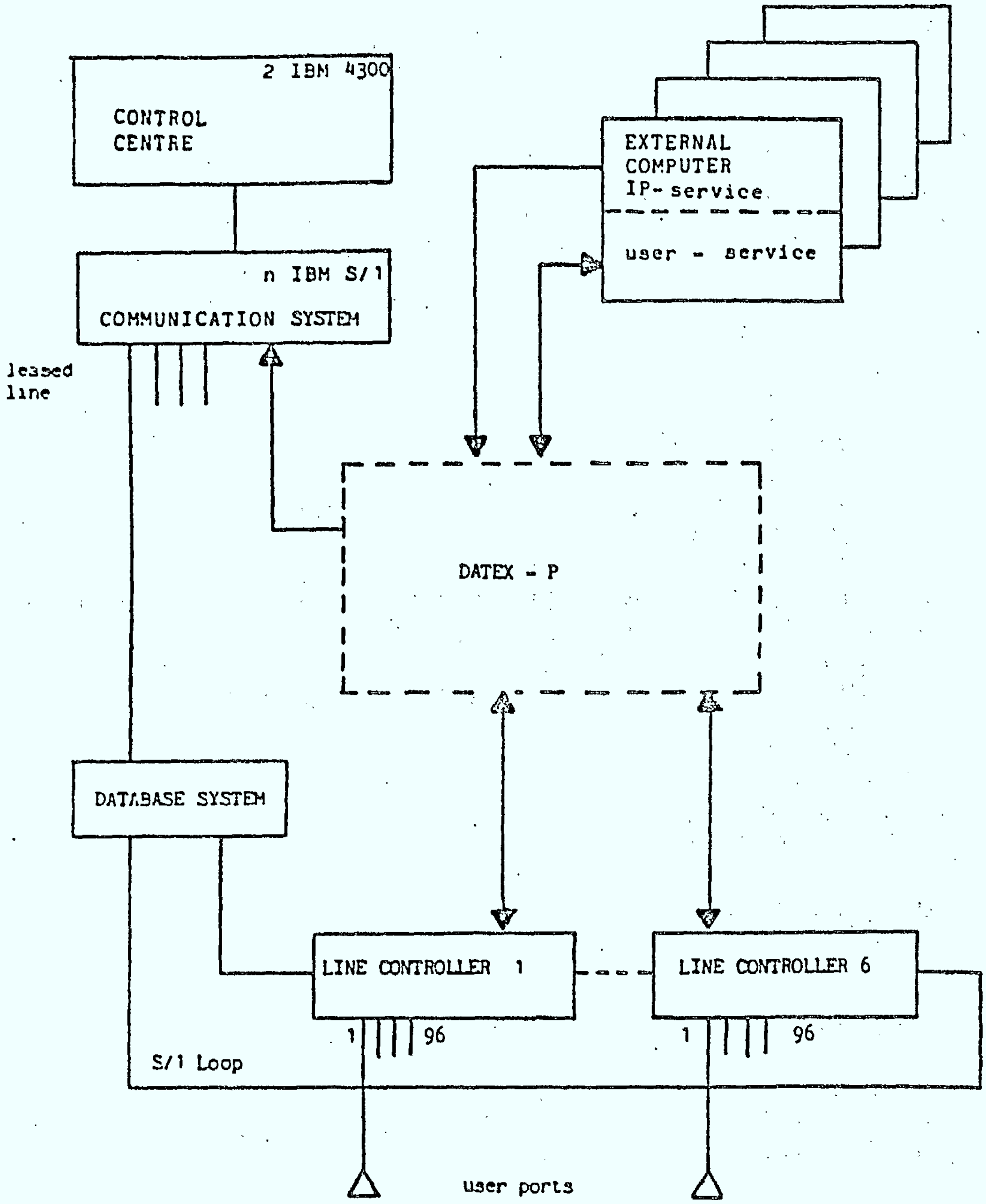


Figure A.6 Germany's new Bildschirmtext System.
(extracted from [GRIE82])

Appendix B

PROGRAM FOR FILE ALLOCATION PROBLEMS

```
      REAL M,FW,FP,FS,FT
      REAL PFTIN(100),WGTIN(100),OCOST,OS,OT,OTCOST,OSCOST,COST
      REAL PROFIT(100),WEIGHT(100),PFTWGT(100)
      REAL S(100),U(100),V(100),H(100),TX(10),TY(10),SX(10),SY(10)
      REAL TEMP,Z1,Z2,Z3,Z4
      INTEGER N,I,J,MAXT,MAXS,NBAR,SITE
      INTEGER*2 D(100),Y(100),X(100),DPTR(100),PTR(100),OX(100),Z(100)
C     M, MAXIMUM WEIGHT/TRAFFIC FOR KNAPSACK
C     FW, FINAL WEIGHT/TRAFFIC FROM KNAPSACK - NOT USED
C     FP, FINAL PROFIT/STORAGE FROM KNAPSACK - NOT USED
C     FS, FINAL STORAGE VALUE
C     FT, FINAL TRAFFIC VALUE
C     PFTIN, SUBSET OF TRAFFIC H VECTOR; VALUES GT 0
C     WGTIN, CORRESPONDING STORAGE VALUES
C     OCOST, OPTIMAL TOTAL COST OF A SITE
C     OS, OPTIMAL STORAGE VALUE OF A SITE
C     OT, OPTIMAL TRAFFIC VALUE OF A SITE
C     OTCOST, OPTIMAL TRAFFIC COST OF A SITE
C     OSCOST, OPTIMAL STORAGE COST OF A SITE
C
      DATA PROFIT/100*0/,WEIGHT/100*0/,PFTWGT/100*0/
C
C     PROFIT, SORTED PFTIN ;  SORT IS SUCH THAT P/W RATIO
C     WEIGHT, SORTED WGTIN ;  IS ASCENDING;NECESSARY FOR KNAPSACK
C     PFTWGT, PROFIT/WEIGHT RATIO ARRAY
C
      DATA V/10,20,30,40,50,60,70,80,90,100,90*0/,Z1/550/,DPTR/100*0/
      DATA S/100,200,300,400,500,600,700,800,900,1000,90*0/,Z2/5500/
      DATA D/100*0/,X/100*0/,Y/100*0/,Z/100*0/
C     V, TRAFFIC COST FOR STORING A FILE
C     S, STORAGE COST FOR STORING A FILE
C     Z1, TOTAL OF V VECTOR
C     Z2, TOTAL OF S VECTOR
C     DPTR, POINTER FOR H VECTOR TO MAP INTO ORIGINAL U,V VECTORS
C     D,X,Y,Z - BINARY VECTORS TO DENOTE SELECTION OF A FILE
C
      DATA TX/100,250,350,400,450,500,550,3*0/,MAXT/7/
      DATA TY/2000,4000,6000,7500,7900,8600,9500,3*0/
      DATA SX/1000,2000,3200,4500,5000,5500,4*0/,MAXS/6/
      DATA SY/1500,3000,5000,6500,8000,10000,4*0/
```

```
C
C      TX, TRAFFIC VALUE/NODE ALONG X-AXIS
C      TY, TRAFFIC COST  ALONG Y-AXIS
C      SX, STORAGE VALUE/NODE ALONG X-AXIS
C      SY, STORAGE COST ALONG Y-AXIS
C      MAXT,MAXS  MAXIMUM NUMBER OF STEPS IN  TX AND SX
C               THE ABOVE GRAPH IS A STEP FUNCTION
C
C      OUTPUT THE TRAFFIC, STORAGE COST FUNCTION
C
       WRITE(6,67)  (TX(I),I=1,MAXT)
       WRITE(6,68)  (TY(I),I=1,MAXT)
       WRITE(6,49)  (SX(I),I=1,MAXS)
       WRITE(6,48)  (SY(I),I=1,MAXS)
 67    FORMAT('1TX = ',10(1X,F6.0))
 68    FORMAT(' TY = ',10(1X,F6.0))
 49    FORMAT(' SX = ',10(1X,F6.0))
 48    FORMAT(' SY = ',10(1X,F6.0))
C
C      CREATE DIFFERENT U VECTORS BY ROTATING V VECTOR
C      CREATE H VECTOR CONTAING U-V .G.T 0
C      ALSO DETERMINE CORRESPONDING TRAFFIC ,STORAGE VALUES AND COSTS
C
       DO 65 SITE=1,30
       N=10
       CALL UVECTR(U,V,N)
       CALL HVECTR(U,V,H,S,N,NBAS,DPTR,Z,PFTIN,WGTIN,Z1,Z2,Z3,Z4)
C
C      OUTPUT SITE,U,V,S,H VECTORS AND THE TRAFFIC,STORAGE VALUES/COSTS
C
       WRITE(6,85)  SITE
       WRITE(6,91)  (S(I),I=1,N)
       WRITE(6,92)  (V(I),I=1,N)
       WRITE(6,93)  (U(I),I=1,N)
       WRITE(6,73)  (H(I),I=1,N)
       WRITE(6,74)  Z1,Z2,Z3,Z4
 85    FORMAT('0',' ******   EXAMINE SITE ',I5)
 91    FORMAT(' ','S = ' ,10(1X,F5.0))
 92    FORMAT(' ','V = ' ,10(1X,F5.0))
 93    FORMAT(' ','U = ' ,10(1X,F5.0))
 73    FORMAT(' ','H = ' ,10(1X,F5.0))
 74    FORMAT(' ','Z1 = ',F5.0,3X,'Z2 = ',F5.0,3X,'Z3 = ',F5.0,
      13X,'Z4 = ',F5.0)
```

```
C
C     SET INITIAL VALUE AS OPTIMUM VALUE
C
      OT=Z3
      OS=Z4
      CALL FNDCST(TX,TY,MAXT,OT,OTCOST,SX,SY,MAXS,OS,OSCOST,OCOST)
      DO 27 II=1,N
        OX(II)=Z(II)
 27   CONTINUE
C
C     ALL ITEMS SELECTED SINCE H IS NEGATIVE; THIS IS OPTIMUM VALUE
C
      IF (NBAR.EQ.0) GO TO 28
C
C     SORT PROFIT(STORAGE)/WEIGHT(TRAFFIC) RATIO ; NECESSARY FOR KNAPSAC
C
      CALL SETPW(PFTIN,WGTIN,PROFIT,WEIGHT,PFTWGT,PTR,NBAR)
C
C     FIND THE OPTIMUM KNAPSACK SOLUTION USING BOUND/BACKTRACKING
C     PROCEDURES DEFINED BY HOROWITZ & SAHNI IN
C     "FUNDAMENTALS OF COMPUTER ALGORITHMS"
C
C     TRY EACH STEP ON THE X-AXIS OF TRAFFIC FUNCTION
C     IF M.LT.O, KNAPSACK CANNOT GIVE A SOLUTION;SO TRY NEXT STEP
C
      DO 10 J=1,MAXT
      M=TX(J)-Z3
      IF (M.LE.0) GO TO 10
      DO 60 II=1,N
      D(II)=Z(II)
 60   CONTINUE
      CALL KNAPSK(M,NBAR,PROFIT,WEIGHT,FW,FP,X,Y)
C
C     USING X, CONTAINING THE ITEMS CHOSEN FOR KNAPSACK
C     AND PFTWGT CONTAING INDEX FOR ORIGINAL INPUTS
C     PRINT OUT THE CORRESPONDING PROFITS & WEIGHTS
C
      FT=Z3
      FS=Z4
      WRITE(6,53) J,TX(J)
      CALL FNDCS(X,PFTIN,WGTIN,DPTR,PTR,D,FT,FS,NBAR)
 53   FORMAT('OKNAPSACK SOLUTION FOR ALPHA = ',I3,3X,'(',F8.0,')')
```

```
C
C     FIND THE COST OF THE TRAFFIC AND STORAGE AND OUTPUT  THEM
C
      CALL FNDCST(TX,TY,MAXT,FT,TCOST,SX,SY,MAXS,FS,SCOST,COST)
      CALL OUTCST(D,FS,SCOST,FT,TCOST,COST,N)
C
C     DETERMINE IF OPTIMUM;SAVE IF SO
C
      IF(COST.GE.OCOST) GO TO 11
      OCOST=COST
      OTCOST=TCOST
      OSCOST=SCOST
      OS=FS
      OT=FT
      DO 64 II=1,N
        OX(II)=D(II)
 64   CONTINUE
      GO TO 10
 11   CONTINUE
C
C     TERMINATE IF ALL ITEMS SELECTED AND NOT LAST NODE
C
      IF (FS.EQ.0.AND.J.NE.MAXT) GO TO 12
 10   CONTINUE
      GO TO 28
 12   WRITE(6,66)
 66   FORMAT(' <<< TERMINATED BECAUSE ALL ITEMS SELECTED')
C
C     OUTPUT OPTIMUM COST FOR THE SITE;INCLUDE D-VECTOR AND THE
C     TRAFFIC/STORAGE VALUES AND COSTS
C
 28   CONTINUE
      WRITE(6,62) SITE
      IF (Z1.EQ.Z3) GO TO 42
 62   FORMAT('0 ******   OPTIMUM ALLOCATION FOR SITE = ',I5,30X,'****')
      CALL OUTCST(OX,OS,OSCOST,OT,OTCOST,OCOST,N)
      GO TO 65
C
C     TERMINATE SINCE THE MAX. VALUE OF TRAFFIC IS NOT SUFFICIENT
C
 42   WRITE(6,63)
 63   FORMAT(' <<< COULD NOT PROCEED BECAUSE OF INSUFFICIENT ',
     1       'NUMBER OF TX STEPS >>>')
 65   CONTINUE
      STOP
      END
```

```
      SUBROUTINE KNAPSK(M,N,PROFIT,WEIGHT,FW,FP,X,Y)
C
C     M, THE SIZE OF THE KNAPSACK
C     N, THE NUMBER OF WEIGHTS AND PROFITS
C     PROFIT(1:N), THE CORRESPONDING PROFITS
C     WEIGHT(1:N), THE WEIGHTS
C     ****  NOTE THAT P(I)/W(I) >= P(I+1)/W(I+1); PRESORTED ****
C     FW, THE FINAL WEIGHT OF THE KNAPSACK
C     FP, THE FINAL MAXIMUM PROFIT
C     X(1:N) EITHER 0 OR 1. X(K)=0 IF W(K) IS NOT IN KNAPSACK,
C     ELSE X(K)=1
C     Y(1:N) TEMPORARY WORKING ARRAY FOR X
C
      INTEGER N,K,I
      REAL FW,FP,CW,CP,M,WEIGHT(100),PROFIT(100)
      INTEGER*2 Y(100),X(100)
C
C     INITIALIZE
C     CW, THE CURRENT WEIGHT
C     CP, THE CURRENT PROFIT
C     K,  THE CURRENT NODE
C     FP, MAXIMUM PROFIT (SET NEGATIVE)
C     N1, ADD 1 TO THE NUMBER OF ITEMS SO THAT LAST ITEM IS TESTED
C
      DO 12 I=1,N
         X(I)=0
         Y(I)=0
 12   CONTINUE
      CW=0
      CP=0
      K=0
      FP=-1
      FW=0
      N1=N+1
      PP=0
      WW=0
      IBND=0
      J=0
C
C     FIND A BOUND FOR THE CURRENT PATH
C     TERMINATE PRESENT PATH IF BOUND<=FP
C     SINCE THE PATH CANNOT LEAD TO A BETTER SOLUTION
C
 10   CONTINUE
      BND=BOUND(CP,CW,K,PP,WW,J,M,N1,PROFIT,WEIGHT,Y)
      IBND=INT(BND)
      IF (IBND.GT.FP) GO TO 50
 20   CONTINUE
```

```
C
C     FIND THE LAST WEIGHT INCLUDED IN THE KNAPSACK SO AS TO
C     TRACE BACK ALONG THE RECENT PATH TOMOST RECENT
C     NODE FROM WHICH AN UNTRIED MOVE CAN BE MADE
C
      IF (K.EQ.0) RETURN
      IF (Y(K).EQ.0) GO TO 30
      GO TO 40
 30   CONTINUE
      K=K-1
      GO TO 20
C
C     ALL NODES TRIED SINCE WE ARE BACK TO THE FIRST NODE;
C     OPTIMUM SOLUTION IS FP
C
 40   IF (K.EQ.0) GO TO 70
C
C     REMOVE ITEM K FROM THE KNAPSACK
C
      Y(K)=0
      CW=CW-WEIGHT(K)
      CP=CP-PROFIT(K)
      GO TO 10
C
C     PLACE ITEM K INTO KNAPSACK
C
 50   CONTINUE
      CP=PP
      CW=WW
      K=J
C
C     IF K<=N THEN ITEM K DOES NOT FIT; MAKE A RIGHT CHILD MOVE
C
      IF (K.GT.N) GO TO 60
      Y(K)=0
      GO TO 10
C
C     UPDATE FOR CURRENT OPTIMUM SOLUTION
C
 60   CONTINUE
      FP=CP
      FW=CW
      K=N
C
C     TRANSFER FROM TEMP TO PERM TO INDICATE THE ITEM CHOSEN
C
      DO 80 I=1,N
         X(I)=Y(I)
 80   CONTINUE
      GO TO 10
 70   CONTINUE
      RETURN
      END
```

```
      FUNCTION BOUND(P,W,K,PP,WW,I,M,N,PROFIT,WEIGHT,Y)
C
C     TREE ORGANIZATION IS USED TO FIND THE BOUND BY BACKTRACKING
C     AND KILLING AND EXPANDING NODES OF THE TREE.
C
C     P, THE CURRENT PROFIT
C     W, THE CURRENT WEIGHT
C     K, THE CURRENT NODE
C     PP, THE NEW PROFIT CORRESPONDING TO THE LAST LEFT CHILD MOVE
C     WW, THE NEW WEIGHT CORRESPONDING TO THE LAST LEFT CHILD MOVE
C     I, INDEX OF THE FIRST INDEX OBJECT THAT DOES NOT FIT; N+1 OF NONE
C     M, THE SIZE OF THE KNAPSACK
C     N, THE NUMBER OF WEIGHTS AND PROFITS IN THE PROBLEM + 1
C     **** PLUS ONE SO THAT LAST NODE IS NOT IGNORED ****
C     PROFIT(1:N), THE CORRESPONDING PROFITS IN THE PROBLEM
C     WEIGHT(1:N), THE CORRESPONDING WEIGHTS IN THE PROBLEM
C     Y(1:N) EITHER 0 OR 1. Y(K)=0 IF W(K) IS NOT IN KNAPSACK,
C     ELSE Y(K)=1
C
C
      INTEGER K,I,J,N
      REAL P,W,PP,WW,M,PROFIT(100),WEIGHT(100)
      INTEGER*2 Y(100)
C
C     SET THE CURRENT PROFIT & WEIGHT IN THE KNAPSACK
C
      PP=P
      WW=W
C
C     LOCATE THE NEXT NOTE AS A CANDIDATE FOR THE KNAPSACK
C
      J=K+1
C
C     FIT AS MANY ITEMS IN THE KNAPSACK UNTIL FULL
C
      DO 10 I=J,N
        IF(WW+WEIGHT(I).GT.M) GO TO 20
        WW=WW+WEIGHT(I)
        PP=PP+PROFIT(I)
        Y(I)=1
 999    GO TO 10
 20     CONTINUE
        BOUND=PP+(M-WW)*PROFIT(I)/WEIGHT(I)
        RETURN
 10   CONTINUE
      BOUND=PP
 60   CONTINUE
      RETURN
      END
```

```
      SUBROUTINE PART(A,M,P)
C
C     THE ELEMENTS IN THE ARRAY A ARE REARRANGED IN SUCH A WAY
C     THAT IF INITIALLY T=A(M)
C     THEN AFTER COMPLETION A(Q)=T FOR M<=Q<=P-1,
C     A(K)<=T FOR M<=K<=Q AND A(K)>=T FOR Q<K<P
C     THE FINAL VALUE OF P IS Q
C
C     A, CONTAINS ELEMENTS TO BE PARTITIONED
C     **** NOTE THAT N+1 ELEMENT MUST BE ZERO ****
C     M, NUMBER OF ELEMENTS TO BE PARTITIONED
C     P, POSITION IN A WHERE PARTITION OCCURS
C     V,I,TEMP WORKING VARIABLES
C
      INTEGER P,I
      REAL A(100),V,TEMP
C
C     INITIALIZE TO DEFINE THE FIRST & LAST
C     ELEMENTS FOR PARTITION
C
      V=A(M)
      I=M
C
 10   CONTINUE
C
C     I MOVES LEFT TO RIGHT
C
      I=I+1
      IF (A(I).LE.V) GO TO 20
      GO TO 10
 20   CONTINUE
C
C     P MOVES RIGHT TO LEFT
C
      P=P-1
      IF (A(P).GE.V) GO TO 30
      GO TO 20
 30   CONTINUE
      IF (I.GE.P) GO TO 40
C
C     INTERCHANGE A(I) & A(P)
C
      TEMP=A(I)
      A(I)=A(P)
      A(P)=TEMP
      GO TO 10
C
C     PARTITION IS AT POSITION P
C
 40   CONTINUE
      A(M)=A(P)
      A(P)=V
      RETURN
      END
```

```
      SUBROUTINE SORT(A,N)
C
C     THE ELEMENTS IN THE ARRAY A ARE REARRANGED IN SUCH A WAY
C     THAT IF INITIALLY T=A(M)
C     THEN AFTER COMPLETION A(Q)=T FOR M<=Q<=P-1,
C     A(K)<=T FOR M<=K<=Q AND A(K)>=T FOR Q<K<P
C     THE FINAL VALUE OF P IS Q
C
C     A, CONTAINS ELEMENTS TO BE SORTED
C     **** NOTE THAT N+1 ELEMENT MUST BE ZERO ****
C     N, NUMBER OF ELEMENTS IN THE ARRAY
C
C     STACK, CONTAINS A PAIRED SET DEFINING THE FIRST & THE LAST
C        OF A FOR PARTITIONING
C     TOP, THE CURRENT INDEX FOR STACK
C     J,P,Q, WORKING VARIABLES
C
      INTEGER STACK(100)/100*0/,TOP
      INTEGER N,J,P,Q
      REAL A(100)
C
C     INITIALIZE
C
      TOP=0
      P=1
      Q=N
C
 10   CONTINUE
      IF (P.GE.Q) GO TO 40
C
C     PARTITION THE ARRAY BETWEEN A & P
C     J RETURNS THE INDEX WHERE PARTITION TAKES PLACE
C
      J=Q+1
      CALL PART(A,P,J)
C
C     DEPENDING ON THE INDEX J, SAVE IN THE STACK THE FIRST & LAST
C     ELEMENTS OF THE PARTITION
C
      IF ((J-P).GE.(Q-J)) GO TO 20
      STACK(TOP+1)=J+1
      STACK(TOP+2)=Q
      Q=J-1
      GO TO 30
 20   CONTINUE
      STACK(TOP+1)=P
      STACK(TOP+2)=J-1
      P=J+1
 30   CONTINUE
```

```
C
C     UPDATE LOCATION IN STACK
C
      TOP=TOP+2
C
C     NOW SORT THE SMALLER SUBFILE
C
      GO TO 10
 40   CONTINUE
C
C     NOTHING IN STACK; ARRAY SORTED
C
      IF (TOP.EQ.0) GO TO 60
C
C     NOW SORT THE ELEMENTS DEFINED BE STACK;THOSE IN ARRAY
C     ALREADY SORTED
C
      Q=STACK(TOP)
      P=STACK(TOP-1)
      TOP=TOP-2
      GO TO 10
C
 60   CONTINUE
      RETURN
      END
```

```
      SUBROUTINE FNDCST(TX,TY,MAXT,T,TCOST,SX,SY,MAXS,S,SCOST,COST)
C
C     THE TRAFFIC COST, STORAGE COST AND THE TOTAL COST ARE COMPUTED
C     FOR THE FILES INCURRING A TRFFIC OF T AND STORAGE OF S
C
C     TX, TRAFFIC VALUES ALONG THE X-AXIS
C     TY, TRAFFIC COST ALONG THE Y-AXIS
C     MAXT, MAXIMUM TRAFFIC VALUE
C     T,  CURRENT TRAFFIC
C     TCOST,  TRAFFIC COST CORRESPONDING TO THE CURRENT TRAFFIC
C     SX, STORAGE VALUES ALONG THE X-AXIS
C     SY, STORAGE COST ALONG THE Y-AXIS
C     MAXS, MAXIMUM STORAGE VALUE
C     S,  CURRENT STORAGE
C     SCOST,  STORAGE COST CORRESPONDING TO THE CURRENT STORAGE
C     COST,  TOTAL COST = TCOST+SCOST
C
      INTEGER I,MAXT,MAXS
      REAL TX(100),TY(100),SX(100),SY(100),T,S,TCOST,SCOST,COST
C
C     DETERMINE TRAFFIC COST
C     IF NOT WITHIN THE RANGE SPECIFIED, THEN MAXIMUM COST
C
      DO 10 I=1,MAXT
         IF (TX(I).GE.T) GO TO 20
 10   CONTINUE
      TCOST = TY(MAXT)
      GO TO 30
 20   TCOST = TY(I)
C
C     DETERMINE STORAGE COST
C     IF NOT WITHIN THE RANGE SPECIFIED, THEN MAXIMUM COST
C
 30   CONTINUE
      DO 40 I=1,MAXS
         IF (SX(I).GE.S) GO TO 50
 40   CONTINUE
      SCOST = SY(MAXS)
      GO TO 60
 50   SCOST = SY(I)
C
C     SET TOTAL COST
C
 60   COST=TCOST+SCOST
      RETURN
      END
```

```
      SUBROUTINE OUTCST(D,S,SCOST,T,TCOST,COST,N)
C
C     THE D-VECTOR, STORAGE AND TRAFFIC AND THE CORRESPONDING COSTS
C     ARE OUTPUTTTED
C
C     D,  BINARY VECTOR DEFINING WHETHER A FILE IS STORED OR NOT
C     S,  STORAGE VALUE
C     SCOST,  STORAGE COST CORRESPONDING FOR S
C     T,  TRAFFIC VALUE
C     TCOST,  TRAFFIC COST CORRESPONDING FOR T
C     COST, TOTAL COST
C     N, NUMBER OF ELEMENTS IN D
C
      INTEGER N,I
      INTEGER*2 D(100)
      REAL S,SCOST,T,TCOST,COST
      WRITE(6,10)  (D(I),I=1,N)
      WRITE(6,20)  S
      WRITE(6,30)  SCOST
      WRITE(6,40)  T
      WRITE(6,50)  TCOST
      WRITE(6,60)  COST
 10   FORMAT('0D = ',10(1X,I5))
 20   FORMAT(' X(D)  = ',F10.0)
 30   FORMAT(' S(X)  = ',F10.0)
 40   FORMAT(' Y(D)  = ',F10.0)
 50   FORMAT(' T(Y)  = ',F10.0)
 60   FORMAT(' C     = ',F10.0)
      RETURN
      END
```

```
      SUBROUTINE HVECTR(U,V,H,S,N,NBAR,DPTR,Z,PFTIN,WGTIN,Z1,Z2,Z3,Z4)
C
C     THE H-VECTOR IS COMPUTED,AS U-V
C     ARE OUTPUTTTED
C
C     U,  VECTOR CONTAINING TRAFFIC COST FOR FILES NOT STORED
C     V,  VECTOR CONTAINING TRAFFIC COST FOR FILES STORED
C     H,  (U-V) .GT. 0
C     S,  VECTOR CONTAINING STORAGE COST FOR FILES STORED
C     N,  NUMBER OF FILES UNDER CONSIDERATION; NUMBER OF ITEMS
C         IN THE U,V,S VECTORS
C     NBAR, NUMBER OF ITEMS
C     DPTR, POINTERS FOR H, TO THE ORIGINAL LOCATION IN U,V
C     Z, BINARY VECTOR DEFINING WHICH FILES ARE TO BE STORED/NOT STORED
         1 - IF NOT STORED;ELSE 0
C     PFTIN, PROFIT FOR SUSEQUENT KNAPSACK PROBLEM; STORAGE COST
C     WGTIN, WEIGHT FOR SUSEQUENT KNAPSACK PROBLEM; TRAFFIC COST
C     Z1, TOTAL TRAFFIC COST FOR STORING FILES
C     Z2, TOTAL STORAGE COST
C     Z3, TRAFFIC COST FOR NOT STORING ALL FILES
C     Z4, STORAGE COST FOR NOT STORING ALL FILES
C
      INTEGER NBAR,N
      REAL U(100),V(100),H(100),S(100),PFTIN(100),WGTIN(100)
      REAL DIFF,Z1,Z2,Z3,Z4
      INTEGER*2 DPTR(100),Z(100)
C
C     INITIALIZE
C
      SUMD=0
      Z3=0
      Z4=0
      NBAR=0
C
C     FOR H, CHOOSE ALL FILES WHERE U.GT.V
C     ALSO KEEP RUNNING TAB ON THE STORAGE AND TRAFFIC COSTS
C
      DO 10 I=1,N
         DIFF=U(I)-V(I)
         H(I)=DIFF
         IF(DIFF.GT.0)GO TO 50
         Z(I)=1
         Z3=Z3+DIFF
         Z4=Z4+S(I)
         GO TO 10
 50      CONTINUE
         Z(I)=0
         NBAR=NBAR+1
         DPTR(NBAR)=I
         WGTIN(NBAR)=DIFF
         PFTIN(NBAR)=S(I)
 10   CONTINUE
      Z3= Z1+Z3
      Z4= Z2-Z4
      RETURN
      END
```

```
      SUBROUTINE UVECTR(U,V,N)
C
C     THE U-VECTOR IS DERIVED BY ROTATING THE V-VECTOR
C
C     U,  VECTOR CONTAINING TRAFFIC COST FOR FILES NOT STORED
C     V,  VECTOR CONTAINING TRAFFIC COST FOR FILES STORED
C     N,  NUMBER OF FILES UNDER CONSIDERATION; NUMBER OF ITEMS
C         IN THE U,V VECTORS
C
      INTEGER N,ISTP/100/,N1/0/,N2,INXT,IBEG
      REAL U(100),V(100)
C
C     INITIALIZE
C
      IF(ISTP.LE.N) GO TO 30
      N2=N-N1
      N1=N1+1
      ISTP=N1+1
   30 CONTINUE
      INXT=N+N1-ISTP
      DO 10 I=1,N2
         IBEG=INXT-I
         IF(IBEG.LE.0) IBEG=IBEG+N
         U(I)=V(IBEG)
   10 CONTINUE
      ISTP=ISTP+1
      RETURN
      END
```

```
      SUBROUTINE SETPW(PFTIN,WGTIN,PROFIT,WEIGHT,PFTWGT,PTR,N)
C
C     PFTIN, THE STORAGE COST
C     WGTIN, THE TRAFFIC COST
C     PROFIT, THE SORTED STORAGE COST
C     WEIGHT, THE SORTED TRAFFIC COST
C     PFTWGT, PROFIT/WEIGHT RATIO FOR SORTING
C     PTR,    POINTERS TO THE PRESORTED ARRAYS
C     N, NUMBER OF ITEMS IN THE ARRAYS
C
      INTEGER N,I,J
      REAL PFTIN(100),WGTIN(100)
      REAL PROFIT(100),WEIGHT(100),PFTWGT(100)
      REAL TEMP
      INTEGER*2 PTR(100)
C
C     CREATE PROFIT/WEIGHT RATIO ARRAY(1:N) FOR SORTING
C     SUCH THAT PROFIT(I)/WEIGHT(I) >= PROFIT(I+1)/WEIGHT(I+1)
C
      DO 10 I=1,N
        PFTWGT(I)=PFTIN(I)/WGTIN(I)
 10   CONTINUE
      PFTWGT(N+1)=0
C
C     SORT THE PROFIT/WEIGHT RATIO IN DESCENDING ORDER
C
C
C     SORT THE PROFIT/WEIGHT RATIO IN DESCENDING ORDER
C     USING QUICKSORT/PARTITION
C     PROCEDURES DEFINED BY HOROWITZ & SAHNI IN
C     "FUNDAMENTALS OF COMPUTER ALGORITHMS"
C     *** NOTE THAT N+1 ELEMENT IN PFTWGT MUST BE 0
C
      CALL SORT(PFTWGT,N)
C
C     CREATE PROFIT & WEIGHT ARRAYS AS DEFINED BY THE SORTED
C     PROFIT/WEIGHT RATIO
C     PFTIN POINTERS IN PTR ARRAY TO KEEP TRACK OF ORGINAL ORDER
C     IN PROFIT & WEIGHT
C
      DO 30 I=1,N
        TEMP=PFTIN(I)/WGTIN(I)
        DO 20 J=1,N
          IF (TEMP.EQ.PFTWGT(J)) GO TO 40
 20     CONTINUE
 40     PTR(J) = I
        PFTWGT(J) = -I
        PROFIT(J) = PFTIN(I)
        WEIGHT(J) = WGTIN(I)
 30   CONTINUE
C
C     LAST ITEMS MUST BE 0 FOR PROPER SORTING
C
      PROFIT(N+1)= 0
      WEIGHT(N+1)= 0
      RETURN
      END
```

```
      SUBROUTINE FNDCS(X,PFTIN,WGTIN,DPTR,PTR,D,FT,FS,N)
C
C     THE FINAL TRAFFIC VALUE AND THE STORAGE VALUES ARE DETERMINED
C     AS DEFINED BY THE BINARY VECTOR X FROM PFTIN & WGTIN VECTORS
C
C     X, BINARY VECTOR FROM THE KNAPSACK DEFINING FILES TO BE SELECTED
C     PFTIN, STORAGE VALUES
C     MAXT, MAXIMUM TRAFFIC VALUE
C     WGTIN, TRAFFIC VALUES
C     DPTR, POINTER TO THE ORIGINAL U,V VECTORS
C     PTR, POINTER TO THE PRESORTED H VECTOR
C     D, OPTIMUM BINARY D-VECTOR
C     FT, THE FINAL TRAFFIC COST
C     FS, THE FINAL STORAGE COST
C     N, NUMBER OF ITEMS IN X
C
      INTEGER N
      REAL PFTIN(100),WGTIN(100),FS,FT
      INTEGER*2 IPTR,I,J,X(100),DPTR(100),PTR(100),D(100)
C
C     CHOOSE ONLY IF X=1; FINF THE INDEX FROM PTR;THEN FROM DPTR
C     KEEP RUNNING TOTAL OFTRAFFIC AND STORAGE
C
      DO 10 I=1,N
        IF (X(I).EQ.0) GO TO 10
        J=PTR(I)
        IPTR=DPTR(J)
        D(IPTR)=1
        FT=FT+WGTIN(J)
        FS=FS-PFTIN(J)
   10 CONTINUE
      RETURN
      END
```

Appendix C

CHI-SQUARE TEST FOR INDEPENDENCE OF ENCRYPTED DATA

(S.M. Wong)

C.1 INTRODUCTION

The following two problems are relevant to those schemes cryptanalysts often use for breaking a cryptosystem which uses a publicly available encryption algorithm:

<u>Problem #1</u> For a fixed but arbitrary key, is there any relationship between a certain portion of the plaintext and a certain portion of the ciphertext?

<u>Problem #2</u> For a fixed but arbitrary plaintext, is there any relationship between a certain portion of the key and a certain portion of the ciphertext?

If the answer to Problem #1 is 'yes', a cryptanalyst will be able to derive that portion of the plaintext by analyzing the corresponding portion of the ciphertext for a cryptosystem which is using a fixed key (though unknown to the attack). Although that portion may be just a small part of the entire plaintext, an experienced cryptanalyst may find it very helpful for conjecturing or deducing the whole plaintext. Similarly, if the answer to Problem #2 is 'yes', a cryptanalyst will be able to derive the key by applying the algorithm on a known plaintext. In short, if some portions of the key, the plaintext and the ciphertext are found to be dependent, the encryption algorithm will become unsecure or even totally useless.

Thus, these two problems should be an important concern for encryption algorithm designers and users. However, as far as we know, very little research has been done with the objective of showing, either mathematically or experimentally, that the existing encryption algorithms are insensitive to this kind of troubles. Because of the complexity of these algorithms, rigorous mathematical proofs seem to be out of reach. In the following, we investigate these two problems by means of a statistical technique, namely the Chi-square test for data independence. The technique is applicable to a general encryption algorithm. However, our tests are done on the DES (Data Encryption Standard) algorithm, because it is well known.

In Section C.2, we review briefly the method of Chi-square test of independence. Section C.3 describes our test process of applying this technique on the DES Algorithm. Section C.4 presents the test results and discussions.

C.2 CHI-SQUARE TEST OF INDEPENDENCE

For completeness, we briefly review the Chi-square test here.

Suppose a sample of N outcomes have been collected from a population. These outcomes are grouped according to their values of two nominal variables describing the population. For example, a population of students may be described by their examination marks and their heights. We want to find out whether these two variables are independent or not by applying the Chi-square test on the observed frequencies of these groups.

Procedure of the Chi-square test

In a Chi-square test, we begin with the null hypothesis that the two nominal variables are independent. The test is then used to determine whether the hypothesis should be accepted or rejected. The process has the following steps:

i) Form a contingency table of cells using the two nominal variables as its row and column indices. The pair of values of the two variables for an outcome specify the cell it belongs to. After N outcomes are measured, the observed frequency O_{ij}, i.e., the number of outcomes belonging to cell (i,j), is recorded.

ii) From the observed values of this contingency table, calculate the expected frequencies E_{ij} as follows:

$$E_{ij} = \frac{R_i C_j}{N} , \qquad i = 1,2,\ldots\ldots r. \quad j = 1,2,\ldots\ldots c.$$

where E_{ij} = expected frequency for cell (i,j),

R_i = sum of the frequencies in row i,

C_j = sum of the frequencies in column j,

N = sum of the frequencies in all cells,

r = number of rows of the contingency table,

c = number of columns of the contingenct table,

iii) Compute the Chi-square value, x^2, by the following formula

$$x^2 = \sum_{i=1}^{r} \sum_{j=1}^{c} \frac{(O_{ij} - E_{ij})^2}{E_{ij}}$$

where O_{ij} = observed frequency in cell (i,j) of the contingency table.

iv) Compare the computed Chi-square value x^2 with a critical value obtained from a Chi-square table (also called rejection regions) at a specified significance level α and degree of freedom, df. Only a one-tailed test is appropriate.

v) If the computed Chi-square value equals or exceeds the Chi-square table value, the null hypothesis of independence is rejected. Otherwise, it is accepted.

C.3 APPLICATION OF CHI-SQUARE TEST ON THE DES ALGORITHM

We have conducted two sets of tests, one for Problem #1 and another for Problem #2. The test processes are explained below while the results will be described in Section C.4.

i) Experimental process for Problem #1 (fixed key)

For Problem #1, with the key unchanged, the set of all possible (plaintext, ciphertext) pairs form the population. The two norminal variables describing the population are a specified portion of the plaintext and a specified portion of the ciphertext.

Each experiment consists of N cycles. Each cycle applies the DES algorithm once to get a (plaintext, ciphertext) pair as an outcome. The first cycle chooses an arbitary key and plaintext, both 64 bits long. In the other cycles, the same key is used but the ciphertext of the previous cycle is used as the plaintext. (It is reported (GAIT77) that the DES algorithm can be used as a random bit generator. Thus, a plaintext generated in this way can be considered as random.)

In each cycle, the value of a specified portion of the plaintext and the value of a specified portion of the ciphertext are used as the row and column numbers, respectively, for determining the cell location in the contingency table. The frequency of that cell is then increased by one.

After N cycles, the Chi-square value is computed and the hypothesis is tested according to the method described in Section C.2.

ii) Experimental process for Problem #2 (fixed plaintext)

The same concept and process as for Problem #1 are adopted for Problem #2, except that the plaintext and the key exchange their roles. The plaintext is now fixed in all cycles while, in each cycle, the ciphertext of the previous cycle is used as the new key.

C.4 TESTS AND DISCUSSIONS

Tests: (see also Section C.3)

The data and results of our test are explained in the following:

i) Since software for the DES encryption and decryption algorithms is not available in the literature, a lot of efforts have been spent in their coding. Table C.1 shows part of our tests on the validity of our coding. The 64-bit key and plaintext are chosen arbitrarily. The encryption algorithm is then applied to generate the 64-bit ciphertext. Then, this ciphertext is used as the plaintext for the decryption algorithm. The same key as for the encryption test is used. The output of the decryption test shows the complete recovery of the plaintext in the encryption test by the decryption algorithm.

ii) Twenty-one tests have been performed for each of Problem #1 and Problem #2. Results are summarised in Tables C.2 and C.3, respectively. In these tables, each row shows the data and the results of one test. The total frequency (i.e., sample size) for each test has been chosen between 500 to 3000, depending on the degree of freedom used. The bit positions of the plaintext and the ciphertext are chosen arbitrarily. Rejection regions are obtained from the Table of Chi-square distribution (BEYE) with 1% significance level. The Chi-square values are calculated by the method described in Section C.2.

For a statistical test, increase in the sample size will decrease the two types of errors mentioned in Section C.2. Also, according to Roscoe (ROSC69), a sample size between 30 to 500 is usually adequate for this type of behavioural research. The sample size for our Chi-square data independence tests are between 500 to 3000. These are much greater than this requirement and should therefore give us a high level of confidence about our test results.

As shown in Tables C.2 and C.3, the computed Chi-square values are all less than the rejection regions at a significance level of 1%. Therefore, the hypothesis of independence between the specified portion of the plaintext and the specified portion of the ciphertext is accepted. The hypothesis of independence between the specified portion of the key and the specified portion of the ciphertext is also accepted in all of our tests.

iii) As illustrations, two typical examples of our Chi-square tests for Problem #1 and #2 are given and shown in Figures C.1 and C.2. These figures are self-explanatory. The inputs and outputs for both examples are explained below and Figure C.3 shows the actual input data of Example 2.

<u>The following data are input</u> (see Figure C.3):

* First line: Total frequency, Nnmber of bits to be tested in the plaintext or key, and number of bits to be tested in the ciphertext.
* Secone line: Positions of the bits in the plaintext/key.
* 3rd line: Positions of the bits in the ciphertext.
* 4th line: Fixed key? Print table? ('1' for 'yes', '0' for 'no').

* 5th line: significance level and rejection region.
* Lines 6 to 86:Data required for the DES algorithm (NBS 77).
* Last 4 lines: 64-bit long plaintext and key.

<u>The following data are output</u> (see Figures C.1 and C.2):

* Statement of hypothesis.
* The 64-bit fixed key (for Problem #1) or plaintext (for Problem #2) used.
* Contingency table (output is optional).
* Sum of the frequencies in all cells.
* Positions ofthe specidied but fixed portion of the plaintext/key.
* Positions of the specified but fixed portion of the ciphertext.
* Degrees of freedom.
* Significance level.
* Rejection regions.
* Computed Chi-square value.
* Conclusion about the hypothesis.
* Total CPU time for the run.

The results recorded in Figure C.1 show that the hypothesis of independence between the specified portion (bits 1 and 2) of the plaintext and the specified portion (bits 3, 4 and 5) of the ciphertext is accepted. Also, the results recorded in Figure C.2 show that the hypothesis of independence between the specified portion of the ciphertext (bits 1, 2 and 3) and the specified portion (bits 1, 2 and 3) of the key is accepted.

Table C.1 Data of the DES Encryption and Decryption Algorithms.

Data for the DES encryption algorithm:

Key	10101110	00100110	10110000	00111100
	01001111	11110010	10011010	00001111
Input (Plaintext)	11001000	00111010	10111010	01111100
	10100101	10000001	11101010	01100011
Output (Ciphertext)	11100010	11000111	01101100	01101011
	00101100	10000101	01001101	00100011

Data of the DES decryption algorithm:

Key	10101110	00100110	10110000	00111100
	01001111	11110010	10011010	00001111
Input (Ciphertext)	11100010	11000111	01101100	01101011
	00101100	10000101	01001101	00100011
Output (Plaintext)	11001000	00111010	10111010	01111100
	10100101	10000001	11101010	01100011

Table C.2 For a fixed key, Chi-square Independence Test between any portion of the plaintext and any portion of the ciphertext of the Data Encryption Standard Algorithm (DES).

Test No.	Total Frequency	Bit Positions of Plaintext	Bit Positions of Ciphertext	Degree of Freedom	Rejection Regions	Chi-square	Significance Level	Hypothesis
1	500	1,2	1,2	9	21.67	6.53	0.01	accepted
2	500	7,8	7,8	9	21.67	13.94	0.01	accepted
3	500	6,7	6,7	9	21.67	3.67	0.01	accepted
4	500	1,2	3,4	9	21.67	10.93	0.01	accepted
5	500	1,2	3,4,5	21	38.93	22.02	0.01	accepted
6	500	3,6	1,2,5,8	45	69.96	36.90	0.01	accepted
7	500	5,7	1,2,3,4,5,6	189	238.28	192.73	0.01	accepted
8	1000	4,5	1,2,3,4,5,6,7	381	468.72	427.60	0.01	accepted
9	2000	1,7	1,2,3,4,5,6,7,8	765	843.00	783.60	0.01	accepted
10	500	1,2,3	1,2,3	49	74.92	45.90	0.01	accepted
11	500	3,4,5	3,4,5	49	74.92	47.08	0.01	accepted
12	500	1,3,5	2,4,6,8	105	141.62	100.34	0.01	accepted
13	500	3,4,5	1,2,3,4,5	217	271.12	222.34	0.01	accepted
14	1000	1,2,3	1,2,3,4,5,6	441	522.72	473.80	0.01	accepted
15	1500	1,2,3	1,2,3,4,5,6,7	889	1001.61	921.77	0.01	accepted
16	2000	1,3,5	1,2,3,4,5,6,7,8	1785	2150.00	1730.59	0.01	accepted
17	500	2,5,7,8	2,5,7,8	225	277.29	191.85	0.01	accepted
18	500	1,2,3,4	5,6,7,8	225	277.29	220.30	0.01	accepted
19	2000	1,3,4,5	1,2,3,4,5,6,7,8	3825	4210.80	3774.35	0.01	accepted
20	1000	1,2,3,4,5	1,2,3,4,5	961	1054.31	985.53	0.01	accepted
21	3000	1,2,3,4,5,6,7	1,2,3,4,5,6,7	16129	22700	16000	0.01	accepted

Table C.3 For a fixed plaintext, Chi-square Independence Test between any portion of the key and any portion of the ciphertext of the Data Encryption Standard Algorithm (DES).

Test No.	Total Frequency	Bit Positions of Key	Bit Positions of Ciphertext	Degree of Freedom	Rejection Fegions	Chi-square	Significance Level	Hypothesis
1	500	1,2	1,2	9	21.67	10.28	0.01	accepted
2	500	7,8	7,8	9	21.67	8.67	0.01	accepted
3	500	6,7	6,7	9	21.67	5.58	0.01	accepted
4	500	1,2	3,4	9	21.67	8.64	0.01	accepted
5	500	1,2	3,4,5	21	38.93	18.42	0.01	accepted
6	500	3,6	1,2,5,8	45	69.96	43.20	0.01	accepted
7	500	5,7	1,2,3,4,5,6	189	238.28	204.33	0.01	accepted
8	1000	4,5	1,2,3,4,5,6,7	381	468.72	385.88	0.01	accepted
9	2000	1,7	1,2,3,4,5,6,7,8	765	843.00	806.55	0.01	accepted
10	500	1,2,3	1,2,3	49	74.92	46.71	0.01	accepted
11	500	3,4,5	3,4,5	49	74.92	40.30	0.01	accepted
12	500	1,3,5	2,4,6,8	105	141.62	89.23	0.01	accepted
13	500	3,4,5	1,2,3,4,5	217	271.12	237.79	0.01	accepted
14	1000	1,2,3	1,2,3,4,5,6	441	522.72	454.61	0.01	accepted
15	1500	1,2,3	1,2,3,4,5,6,7	889	1001.61	812.89	0.01	accepted
16	2000	1,3,5	1,2,3,4,5,6,7,8	1785	2150.00	1852.18	0.01	accepted
17	500	2,5,7,8	2,5,7,8	225	277.29	258.97	0.01	accepted
18	500	1,2,3,4	5,6,7,8	225	277.29	204.16	0.01	accepted
19	2000	1,3,4,5	1,2,3,4,5,6,7,8	3825	4210.80	3812.26	0.01	accepted
20	1000	1,2,3,4,5	1,2,3,4,5	961	1054.31	927.31	0.01	accepted
21	3000	1,2,3,4,5,6,7	1,2,3,4,5,6,7	16129	22700	16200	0.01	accepted

Example 1

HYPOTHESIS : FOR A FIXED KEY, A CHOSEN BUT FIXED PORTION OF CIPHERTEXT IS INDEPENDENT TO A CHOSEN BUT FIXED PORTION OF THE PLAINTEXT.

FIXED KEY : 10101110 00100110 10110000 00111100 01001111 11110010 10011010 00001111

CONTINGENCY TABLE :

	0	1	2	3	4	5	6	7	TOTAL
0	13	17	15	27	17	9	10	14	122
1	9	16	17	16	22	14	14	14	122
2	20	15	22	16	19	14	15	13	134
3	19	18	18	14	11	19	14	9	122
TOTAL	61	66	72	73	69	56	53	50	500

SUM OF THE FREQUENCIES FOR ALL CELLS : 500

POSITIONS OF THE CHOSEN BUT FIXED PORTION OF THE PLAINTEXT: 1 2

POSITIONS OF THE CHOSEN BUT FIXED PORTION OF THE CIPHERTEXT: 3 4 5

DEGREE OF FREEDOM : 21

SIGNIFICANCE LEVEL: 0.0100

REJECTION REGIONS : 38.9300

CHI SQUARE : 22.0154

CONCLUSION FROM THE TEST ABOUT THE HYPOTHESIS: THE HYPOTHESIS OF INDEPENDENCE IS ACCEPTED.

TOTAL CPU TIME USED : 21.2200 SECONDS.

Figure C.1 Computer output of the Chi-square independence test between the plaintext and the ciphertext (for a fixed key) of the DES Algorithm.

Example 2

HYPOTHESIS : FOR A FIXED PLAINTEXT, A CHOSEN BUT FIXED PORTION OF THE CIPHERTEXT
IS INDEPENDENT TO A CHOSEN BUT FIXED PORTION OF THE KEY.

FIXED PLAINTEXT : 11001000 00111010 10111010 01111100 10100101 10000001 11101010 01100011

CONTINGENCY TABLE :

	0	1	2	3	4	5	6	7	TOTAL
0	10	9	11	15	6	7	5	6	69
1	6	6	12	5	5	11	7	9	61
2	10	7	8	9	6	3	8	6	57
3	12	7	10	7	4	13	12	7	72
4	8	8	4	5	7	10	7	4	53
5	6	8	5	9	6	10	11	10	65
6	10	7	3	14	10	5	9	9	67
7	7	10	4	8	9	5	8	5	56
TOTAL	69	62	57	72	53	64	67	56	500

SUM OF THE FREQUENCIES FOR ALL CELLS : 500

POSITIONS OF THE CHOSEN BUT FIXED PORTION OF THE KEY: 1 2 3

POSITIONS OF THE CHOSEN BUT FIXED PORTION OF THE CIPHERTEXT: 1 2 3

DEGREE OF FREEDOM : 49

SIGNIFICANCE LEVEL: 0.0100

REJECTION REGIONS : 74.9200

CHI SQUARE : 46.7069

CONCLUSION FROM THE TEST ABOUT THE HYPOTHESIS: THE HYPOTHESIS OF INDEPENDENCE IS ACCEPTED.

TOTAL CPU TIME USED : 21.2580 SECONDS.

Figure C.2 Computer output of the Chi-square independence test between the key and the ciphertext (for a fixed

```
300 5 5
1 2 3
1 2 3
0 1
0.01 74.92
38 50 42 54 26 18 10 2
60 32 44 56 28 20 12 4
62 34 46 58 50 22 14 6
64 36 48 40 52 24 16 8
37 49 41 55 25 17  9 1
39 51 45 55 27 19 11 3
61 35 45 57 29 21 13 5
63 55 47 59 31 23 15 7
40  8 48 16 36 24 64 52
39  7 47 15 55 25 63 31
38  6 46 14 54 22 62 50
37  5 45 15 53 21 61 29
36  4 44 12 52 20 60 28
35  5 43 11 51 19 59 27
34  2 42 10 50 18 58 26
35  1 41  9 49 17 57 25
32  1  2  5  4  5
 4  3  6  7  8  9
 8  9 10 11 12 13
12 13 14 15 16 17
16 17 18 19 20 21
20 21 22 23 24 25
24 23 26 27 28 29
28 29 30 51 32  1
14  4 13  1  2 15 11  8  5 10  6 12  5  9  0  7
 0 13  7  4 14  2 15  1 10  6 12 11  9  5  5  8
 4  1 14  8 13  6  2 11 15 12  9  7  5 10  5  0
13 12  8  2  4  9  1  7  5 11  5 14 10  0  6 15
13  1  8 14  6 11  5  4  9  7  2 15 12  0  5 10
 3 15  4  7 15  2  8 14 12  0  1 10  6  9 11  5
 0 14  7 11 10  4 13  1  5  8 12  6  9  5  2 15
13  8 10  1  5 15  4  2 11  6  7 12  0  5 14  9
10  0  9 14  6  3 15  5  1 15 12  7 11  4  2  8
13  7  0  9  5  4  6 10  2  8  5 14 12 11 15  1
13  6  4  9  8 15  5  0 11  1  2 12  5 10 14  7
 1 10 13  0  6  9  8  7  4 15 14  5 11  5  2 12
 7 13 14  5  0  6  9 10  1  2  8  5 11 12  4 15
13  8 11  5  6 15  0  5  4  7  2 12  1 10 14  9
10  6  9  0 12 11  7 13 15  1  5 14  5  2  8  4
 3 15  0  6 10  1 15  8  9  4  5 11 12  7  2 14
 2 12  4  1  7 10 11  6  8  3  5 15 15  0 14  9
14 11  2 12  4  7 13  1  5  0 15 10  5  9  8  6
 4  2  1 11 10 13  7  8 15  9 12  5  6  5  0 14
11  8 12  7  1 14  2 13  6 15  0  9 10  4  5  5
12  1 10 13  9  2  6  8  0 15  5  4 14  7  5 11
10 13  4  2  7 12  9  5  6  1 15 14  0 11  5  8
 9 14 13  5  2  8 12  5  7  0  4 10  1 15 11  6
 4  3  2 12  9  5 15 10 11 14  1  7  6  0  8 15
 4 11  2 14 13  0  8 15  5 12  9  7  5 10  6  1
```

```
13  0 11  7  4  9  1 10 14  5  5 12  2 15  8  6
 1  4 11 13 12  5  7 14 10 15  6  8  0  5  9  2
 6 11 13  8  1  4 10  7  9  5  0 15 14  2  5 12
13  2  8  4  6 15 11  1 10  9  5 14  5  0 12  7
 1 13 15  8 10  5  7  4 12  5  6 11  0 14  9  2
 7 11  4  1  9 12 14  2  0  6 10 13 15  5  5  8
 2  1 14  7  4 10  8 13 15 12  9  0  5  5  6 11
16  7 20 21
29 12 28 17
 1 13 25 26
 3 18 51 10
 2  8 24 14
32 27  5  9
19 13 50  6
22 11  4 23
37 49 41 55 25 17  9
 1 38 50 42 54 26 18
10  2 39 51 45 55 27
19 11  3 60 52 44 56
63 55 47 59 31 23 15
 7 62 34 46 58 50 22
14  6 61 35 45 57 29
21 13  5 28 20 12  4
14 17 11 24  1  3
 3 28 15  6 21 10
23 19 12  4 26  8
16  7 27 20 13  2
41 32 51 57 47 55
30 40 51 45 53 48
44 49 39 56 54 53
46 42 30 56 29 52
1 1 2 2 2 2 2 2 1 2 2 2 2 2 2 1
1 1 0 0 1 0 0 0 0 0 1 1 1 0 1 0 1 0 1 1 1 0 1 0 0 1 1 1 1 1 0 0 1 0 1
0 0 1 0 1 1 0 0 0 0 0 0 1 1 1 1 0 1 0 1 0 0 1 1 0 0 0 1 1
1 0 1 0 1 1 1 0 0 0 1 0 0 1 1 0 1 0 1 1 0 0 0 0 0 0 1 1 1 1 0 0 0 1 0
0 1 1 1 1 1 1 1 1 0 0 1 0 1 0 0 1 1 0 1 0 0 0 0 0 1 1 1 1
```

Figure C.3 Example of input data.

Discussions:

From the results of our tests, we can make the following remarks:

i) The DES algorithm is insensitive to cryptanalytic attacks

The results as recorded in Table C.2 show that, at a 1% significance level, there is no close relationship between a portion of the plaintext and a portion of the ciphertext. Thus, a cryptananalyst will not be able to derive the plaintext from the ciphertext without knowing the encryption key. This implies that a DES cryptosystem can be ruled out from ciphertext-only attacks.

Similarly, the results as recorded in Table C.5 show that, for a fixed plaintext, a portion of the key is independent of a portion of the ciphertext. Thus, it is impossible for a cryptanalyst to derive the key by applying the DES algorithm on a known plaintext. In other words, the known plaintext attack and chosen plaintext attack can also be ruled out for the DES algorithm.

ii) Applicability of our method to Telidon instructions

A Telidon system is more susceptible to ciphertext-only attacks because Telidon data streams have special structures.

A Telidon PDI has only 32 different opcode formats. They are also publicly known. If the opcode portion of a PDI is found to be related with a certain portion of the ciphertext, a cryptanalyst will be able to deduce the most important part, i.e., the opcode, of the PDI without having to know the key being used. The probability of success in this kind of attacks is high since the number of possible PDI variations is small and they usually appear in certain patterns.

Our results imply that DES is a secure cryptosystem for data composed of Telidon instructions.

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PART II

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