Analysis of geographic information : a cognitive approach

Author:
Williams, Robert John

Publication Date:
1989

DOI:
https://doi.org/10.26190/unsworks/7162

Analysis of Geographic Information:

A Cognitive Approach

Robert John Williams

A thesis submitted for the degree of
Doctor of Philosophy
The University of New South Wales

1989

Certificate of Originality

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of a university or other institute of higher learning, except where due acknowledgement is made in the text of the thesis.

Robert John Williams

6 September 1989

Department of Geography and Oceanography
University College
The University of New South Wales
Australian Defence Force Academy

ACKNOWLEDGEMENTS

I wish to acknowledge the support of a number of people over many years. Firstly, I acknowledge the confidence and trust of, initially, LTCOL Don Ridge and LTCOL Peter Constantine who, as my commanding officers when I was a technician trained as a topographic surveyor, recommended and sponsored me in pursuing undergraduate studies in computer science and cartography. This trust has continued to be shown by a number of senior officers in the Australian Army, particularly COL Alex Laing and COL Don Swiney. Their support in sponsorships in post-graduate studies at Madison, Wisconsin in the USA and here at the Australian Defence Force Academy is appreciated. In addition, I acknowledge the companionship of COL Don Swiney during fortnightly commuting between Canberra and Bendigo - both of us being separated from our families during the past two years.

Secondly, I wish to acknowledge a number of people in academia. Firstly, I acknowledge the Head of the Department of Geography and Oceanography, Professor Roger McLean, and my supervisor, Dr Bill Reiger, who have supported my work in a radical field of research. Further, I appreciate the provision of resources, particularly the sole use of a *Macintosh IIx* computer for concept development. Next, there are several people who have offered assistance and shown interest in my work; these people being Mr Wally Wasserman from the Canberra College of Advanced Education, Dr David Rhind while a Visiting Fellow at the Australian National University and the Canberra CAE, and Dr Nick Chrisman at the University of Wisconsin at Madison. I, also, appreciate the time offered to me for discussion on research issues by Professor Hal Moellering and Professor David Mark during their visits to the Centre for Spatial Information Systems (CSIRO) in Canberra; as well as Dr Babs Buttenfield and Dr Tim Nyerges during my attendance at *Auto-Carto 9* held at Baltimore earlier this year.

Throughout all of the last fourteen years of study intertwined with related work, I have been fortunate to have had the support and love of my wife, Ros, and sons, Neil and Peter. I particularly acknowledge their dedication in this last two years. During this period they have remained at our home in Bendigo, Victoria [some 640 kilometres distant from Canberra] to enable the boys to continue their high school education in a continuous manner. I am indeed proud of how the boys have conducted themselves and have helped their mother through this difficult period. It is to them that I dedicate this thesis.

ABSTRACT

Current trends in managing geographic information indicate a shift toward *multi-product* and *decision-support systems*. This trend, however, requires data to have far more 'intelligence' than for the more conventional map and overlay analysis applications. This thesis identifies two fundamental, but integrated sources for this 'intelligence'. These sources are those of data relationships and structure; and techniques and procedures for manipulating and analyzing the data relationships. These characteristics are subsequently equated to the notions of *geographic knowledge bases* and *geographic knowledge rules.*

Initially these two notions are discussed at a conceptual level by examining fundamental definitions of geography and cognition. Discussion includes definitions of *cartography* from the literature noting that, as well as conventional maps, *cognitive* or *mental* maps are considered to be a part of cartography. Discussion then addresses cognition from an application and analysis viewpoint, and introduces non-conventional techniques for communicating geographic images of the environment.

Discussion on 'Geographic Knowledge-Bases' emphasizes that the structure of geographic information from a phenomenological viewpoint is concerned with finding out *what* things are. To address this aim, knowledge representation, particularly non-traditional representation and meta-knowledge, are examined. A domain of geographic features is discussed with themes based on *world views.* Two *identifiable concepts* - a *cognitive concept* and a *product concept*; the former corresponding to mental and dynamic interpretations of the domain of geographic features and the latter corresponding to formalized and symbolized representations of the domain, such maps and database products, are introduced. During discussion a conflict is identified between *identifiable concepts* and *world view* representations of data and proposes a database strategy that consists of a *subject database* that has data organized and managed independent of any one application but best replicating its *real world* structure; and a *product* or *operational database* configured for specialist purposes, the latter possibly including *expertise databases* that contain results of previous analyses thereby establishing a 'learning system'.

During discussion on 'Geographic Knowledge-Rules', techniques and rules to construct standard series map products, derived standard series map products, operational charts and standardized database products are examined; this being followed by phenomenon-based information systems, including algorithms, formulae and heuristic techniques applicable to infrastructure-related applications. The thesis concludes by suggesting that effective *decision-support systems* depend on analysis and integration of a diversity of geographic information along with evolving algorithmic and heuristic techniques. Resultant *decision-support systems* will operate on *operational databases* and, possibly, *expertise databases* created as the result of previous heuristic analyses.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ALGORITHMS

LIST OF FORMULAE

Chapter 1
INTRODUCTION

Technological advances in computer systems over the past twenty years have provided mapmakers and land resource managers with capabilities to perform increasingly sophisticated mapping and geographic analysis functions. For much of this period development has followed two distinct streams - one concerned with automated mapping and the other with land and natural resource management. Automated mapping systems are those that employ computer technology with an emphasis on computer graphics and with map production and with only limited capability for processing non-graphic attributes. These are differentiated from geographic information systems which combine linkages allowing complex query, map overlay, polygon processing, and spatial modeling operations.

There is now a trend in research to integrate these two streams of development. This integration requires that geographic data be structured and organized such that it will be useful for multiple purposes ranging from the production of standard series maps through to use in 'decision support systems'. Recent research papers (e.g. Thompson, 1986; and Starr, 1986) identify the approach to implementing this trend as *'product generation'* or *'product construction'* with products (including maps) being produced using a series of '*rules*' accessing carefully structured digital data bases.

1.1 Thesis aim

The aim of this thesis is to investigate structural relationships within the domain of geographic features, specifically infrastructure features; and to analyse various interpretations of the domain that result in 'products' (including maps) and operational 'decision-support' systems that use geographic information.

The thesis philosophy is fundamentally different to much contemporary research in the field of cartography noting that the development of automated mapping systems and geographic mapping systems to date have, in the main, followed a theory of *positive science*. Positive science is concerned with finding out **how** things work (Lee,1986). In this thesis this view is challenged. This thesis challenges that view and proposes a *phenomenological* and *hermeneutic* theory, by describing **what** things are and then applying various **interpretations** of the knowledge available.

1.2 The problem investigated

Most human activity depends on geographic information: on knowing where things are and understanding how they relate to each other. Many aspects of decision making - for management, planning and investment - by government and the commercial world depend on it. For example, government uses geographic information on the location of particular groups of people - such as the unemployed and elderly - to direct services; businesses use it to identify likely customers and to site their depots and branches, and it is essential to the operations of the armed forces (Chorley, 1987).

Until recently, the 'paper map' has proven to be an indispensable aid in studies of the physical and social environment. Maps have been used to record factual observations and describe the earth's surface by graphically representing its form and physical features, its natural and political divisions, the climate, productions and population (Haggett, 1972; Stamp,1966; Robinson *et al*, 1978; Trewartha *et al*, 1967).

Maps may be categorized according to their intended use. Morrison (1986) suggests that under this categorization a *reference map* is intended to serve a multiple of uses and in fact the cartographer who makes a reference map often does not consciously make the map with any one purpose in mind. Prime examples of this type of map are topographic maps or reference maps contained in an atlas. In contrast, Morrison further suggests, *thematic* *maps* have as their intent the display of the relative locations of a variety of different features, and the pure thematic map focuses on the difference from place to place of one class of features, that class being the subject or theme of the map.

Petchenik (1979) proposes that an alternate way to define a *reference map* or a *thematic map* is to consider the type of information which a user can obtain from the map. Within a computer environment, Petchenik suggests that it is not unreasonable to make this shift of view since the user may call forth whatever data sets are necessary to answer a query. Under this view a general reference map furnishes the user with "here is" information, e.g. here is a railway. In contrast, under this view the thematic map deals with the intellectual construct of space; and the thematic map deals with "about-things-in-space" information, such as "the railway runs parallel to the highway along the lake shore". This distinction is not based on the characteristics of a map but upon what is done with information contained on the map.

The two alternate ways of defining maps, *reference* and *thematic,* have influenced techniques used to digitally capture, store, and process data. Cartographers who make *reference* maps have been predominately concerned with *data* and its structure for graphic representation. Cartographers, geographic information analysts and resource managers who make *thematic* maps and associated products, however, have examined techniques to provide information for planning and monitoring purposes.

Technological advances in recent years have provided the tools and primitive operators to satisfy the requirements of the map making process, both reference and thematic; as well as being able to perform overlay analysis and a limited range of analytical operations.

The problem now is concerned with developing structures and tools to perform far more 'intelligent' operations on geographic data. Operations that have relevance include the optimal location of facilities and sites, terrain analysis including the identification of corridors and assessment of 'key' terrain, planning for emergency response, and terrain evaluation for environmental impact studies.

1.3 Thesis approach

A number of recent symposia and studies on research needs have emphasized the lack of a fundamental theory for geographic information systems and related fields (Boyle, *et al*, 1983; Chrisman,1987). Each report calls for more theory, but without specific suggestions.

The approach taken in this thesis is to investigate geographic information from *phenomenological* and *cognitive* viewpoints. This approach implies that structural relationships are investigated based on their occurrence in the 'real world' and the way in which features are managed and processed in the 'real world'. This approach differs from most other research which essentially investigates geographic data based on cartographic representations of features, thereby commencing with an abstraction and symbolic representation of data. Although the terms - *phenomenological* and *cognitive* - are used extensively throughout this thesis, detailed definitions and implications (such as appearing in behavioural science literature) have not been researched, such analysis being beyond the scope of this thesis.

Chapter 2, TRADITIONAL APPROACHES IN MANAGING DIGITAL GEOGRAPHIC DATA, summarizes past developments in managing and organizing geographic data and examines fundamental types of mapping and resource management organizations, motives for digitizing geographic data, techniques for managing data, and issues of data quality.

Chapter 3, TRADITIONAL TECHNIQUES IN STRUCTURING DIGITAL

GEOGRAPHIC DATA, discusses spatial data models and cartographic data structures and includes descriptions of vector data structures, tessellation data structures, and other miscellaneous data structures.

Management and use of digital data has been influenced by traditional approaches to mapping and resource management. However, in recent years, technological advances in the computer industry have made some of the earlier management techniques obsolete. Chapter 4, TRENDS IN DIGITAL CARTOGRAPHY AND GEOGRAPHIC INFORMATION SYSTEM DEVELOPMENT reviews this evolution and introduces artificial intelligence concepts.

Chapters 5, 6 ,7 and 8 examine theoretical issues involved in the structure and analysis of digital geographic information. Chapter 5 introduces ASPECTS OF PHENOMENOLOGY. Boland (1986) suggests that "phenomenology is concerned with finding out **what** things are through a methodical process of description". Consequently, Chapter 5 is concerned with describing data from a 'real world' point of view, including aspects of geographic location, geophysical considerations, and temporal aspects.

Chapter 6 introduces ASPECTS OF COGNITION. Moore and Golledge (1976) suggest that "cognition refers to awareness, attitudes, impressions, information, images, and beliefs that people have about their environments". Moore and Golledge further note that "environmental cognition refers to essentially large scale environments, from nation and geographic regions down to cities and spaces between buildings, to both built and natural environments, and to the entire range of physical, social, cultural, political, and economic aspects of man's world". This chapter discusses the 'communication of geographic images' and argues that conventional cartography and present geographic information systems are concerned only with a subset of geographic reality. The chapter concludes by postulating future directions by suggesting that systems should be more innovative through addressing more complex geographic problems and then communicating the results using a variety of methods.

Chapter 7, GEOGRAPHIC KNOWLEDGE BASES, investigates canonical (or information knowledge) structures or those structures required to describe 'real world' phenomena. The *hermeneutic* (or interpretation) problem is a central problem of phenomenology. It is through an appreciation of the hermeneutic problem that we best come to see the importance of phenomenology for information system research. Winograd and Flores (1986) note that "the goal of a hermeneutic theory is to develop methods by which we rid ourselves of all prejudices and produce an objective analysis of **what** is really there". Thus, Chapter 7 attempts to organize the domain of geographic features and introduces knowledge representation and the concepts of a *cognitive concept*, and *meta-knowledge*.

Chapter 8, GEOGRAPHIC KNOWLEDGE RULES, investigates knowledge rules which may be applicable to both mapping and managerial and decision support functions. There are two technologies within the information sciences that are applicable. One is the *expert system* approach. An expert system seeks to replicate, hence replace the abilities of a human expert in a specific domain problem. Expert systems typically involve a closed-world assumption; the problem domain is circumscribed, and the systems performance is confined within those boundaries. This approach is particularly useful for the production of standardized products such as maps. The second technology is the *knowledge-based decision support system* approach. A knowledge-based decision support system seeks to assist a human (manager) by taking over the more structured parts of a larger, only partially formalizable, problem domain. In decision support system contexts, the world is open. A knowledge-based decision support system must be adaptable and extendible to meet the evolving needs of the user and changing conditions in the environment (Lee, 1986). This technology is particularly applicable to terrain analysis and to querying infrastructure.

Chapter 2

TRADITIONAL APPROACHES IN MANAGING DIGITAL GEOGRAPHIC DATA

Many government, private and research organizations are involved in monitoring, evaluating and managing environmental and human resource data. As a result of the range and diversity of geographic data processing practitioners, there have been many different perspectives on the way that data should be captured, stored, manipulated, displayed and dispatched.

2.1 Fundamental types of organizations

The types of organizations that process geographic data can be broadly categorized according to areas of regional application. Agencies at different levels of government, and service bureaus, generally concentrate or specialize in federal, state, or local environments. In addition, military organizations produce maps and other terrain related products often within predetermined scale ranges and for specific uses.

During the 1970's the major mapping organizations in Australia, the United Kingdom, Canada and the United States of America embarked on digital mapping programs. The major topographic mapping organizations (producers of *reference maps)* mostly concentrated their computer efforts towards multipurpose maps and fundamental cartographic data bases to meet the requirements of their traditional users. Other federal organizations have collected data relating to geodesy, nautical charting, aeronautical charting, hydrology, geology, land surveying, and defence requirements.

Organizations and agencies at state level of authority have introduced computer mapping techniques to manage a variety of functions. In addition to topographic and cadastral mapping, applications at the state level focus on management functions, such as natural resource inventory, coastal/marine boundary determination, land information and land administration. Thus the roles of state and large regional organizations include both map and data base production as well as specific management applications. State and large regional organizations can be viewed as the interface between federal mapping organizations and the community as a whole. Their systems must exhibit the capacity to supplement standard mapping programs, to produce regional specific mapping programs, to produce land inventories, and to record the cadastre.

Local, or special project, organizations have traditionally been involved in the management of specific resources, such as forest management, utility management, or parcel-based applications at shire or county level of government. Because of (often) easily defined roles, computer-based systems in this type of application were amongst the earliest developed (CSIRO South Coast project [1]; and Forsyth County Land Records Information System [2]).

However, in the main, local government organizations have not had the expertise to develop systems 'in-house', and have had to rely upon contractors and consultants from the private sector and educational institutions.

Each of the different organizational categories has had different motives for adopting computer-based systems for handling geographic data. These motives have reflected their perceived roles in serving society.

---

1 The South Coast Data Bank/Mapping System was developed in CSIRO Division of Land Use Research during 1978 for the CSIRO South Coast Project. The project had the aim of developing and demonstrating a methodology for land use planning at a regional scale (Cocks,1979; Cook, 1978; Austin and Cocks,1978)

2 Forsyth County, North Carolina, has been building an integrated lands record information system since 1974. This system has had as its primary goal the integration of cadastral records and maps which historically had been kept by eight different public agencies. Forsyth County hosted the 'FIRST Workshop' in lands records systems at Winston-Salem in 1976. The letters F-I-R-S-T stood for Forsyth's Information and Retrieval System for Tomorrow - Today (Ayers,1984)

2.2 Motives for digitizing geographic data

Macomber and Franklin (1984) echo the views of major mapping organizations and those traditional producers of *reference maps* and suggest that conventional production of maps are "labor intensive, error prone, costly and require from 6 to 24 months pipeline time to produce a map or chart from scratch. Such a manual program provides little flexibility and does not respond well to supporting requirements such as:

a. new products,

b. revision of existing products,

c. production line changes, and

d. out-of-cycle production."

This situation confronts most mapping organizations and provides the reasons for undertaking automated mapping, or *computer-assisted mapping*, programs. Generally it is believed that *computer-assisted mapping* facilities will increase map and chart production (RASvy,1983). Key function of systems are digital data collection, verification, edit, compilation, and graphic output (Figure 1). Most of the civilian and military major mapping organizations e.g. Royal Australian Survey Corps [3] (Baker,1984), U.K. Military Survey [4] (Thompson,1986), U.S. Defense Mapping Agency [5] (Macomber and Franklin,1984), and

---

3 The Royal Australian Survey Corps first used computers to produce map grids and graticules and base sheets containing aerotriangulation points for compilation in 1971. Its first computer-assisted mapping system was installed in 1976 and its second system in 1983.

4 The Defense Mapping Agency (US) was established in 1972 in order to unite all Department of Defense mapping functions into a coordinated program under a single authority and commenced computer-assisted mapping soon after.

5 Military Survey (UK) has been involved in meeting the demand for digital geographic data required to support a wide range of defence applications since the early 1970s, with development work

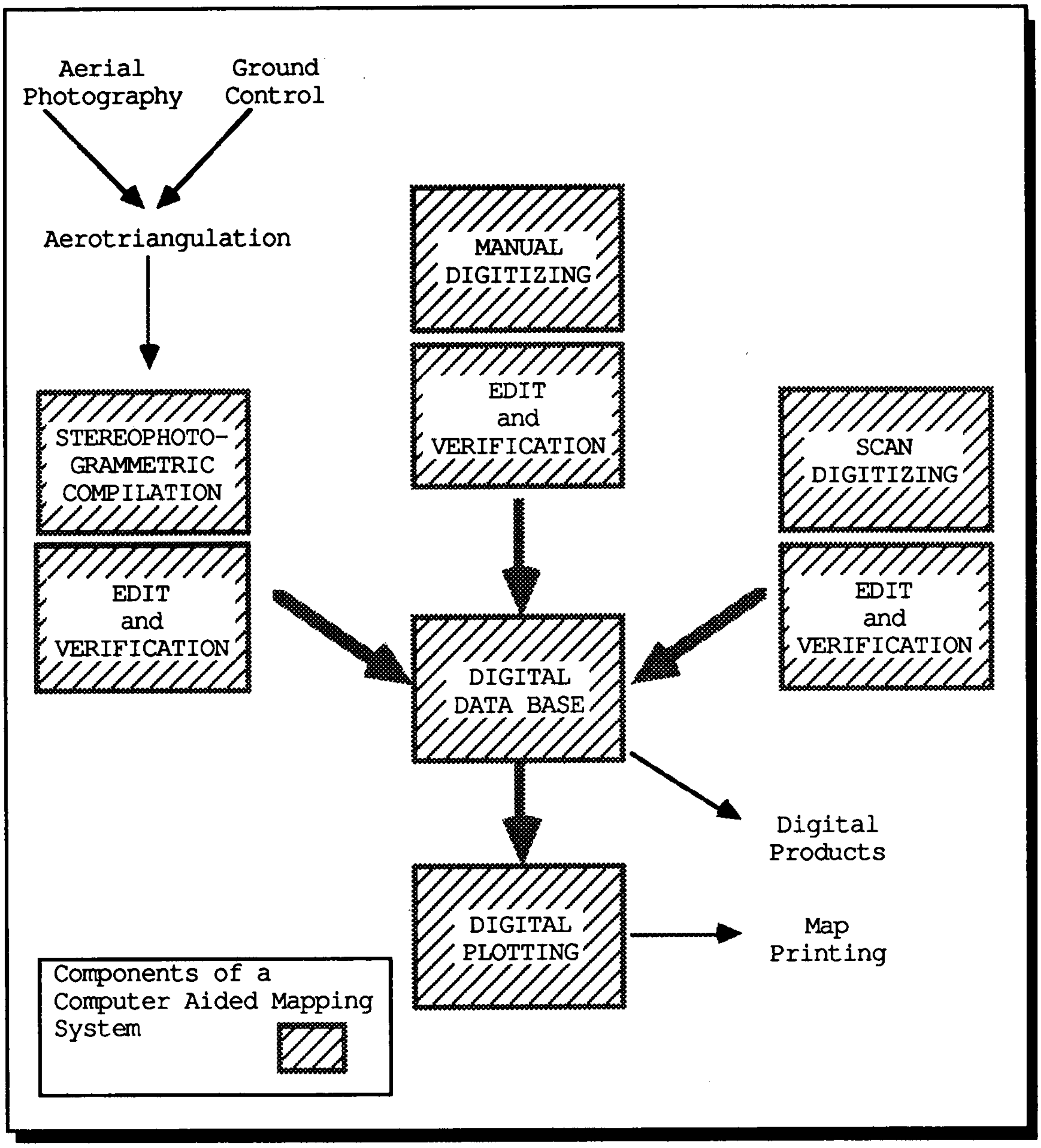


Figure 1: Functions of computer-assisted mapping systems

the National Mapping Division of the U.S. Geological Survey [6] (Southard,1984) believe that benefits of **computer-assisted mapping** systems can be achieved through:

a. increasing the rate of digital data acquisition using digital photogrammetric stereoscopic instruments;

b. capturing map data by scan digitizing, thus enabling the rapid digitization of the manuscript map archive;

c. using interactive computer procedures to reduce the time taken for digital data edit and verification and to increase map production, particularly derived maps;

d. enabling more frequent and easier map revision through the rapid access and manipulation of map data from the digital data base;

e. generating digital data in a form usable for other applications, including advanced weapon command and control systems.

Geographic information systems (GIS) [7] were originally conceived to meet the problems of manipulating and displaying very large data volumes of geographically referenced data, specifically for spatial analysis of that type of information found on *thematic maps* (as represented on Figure 2). These systems were needed for two reasons:

a. the volume of data to be processed was so large that manual methods would have been incapable of completing the task; or

----

6 The National Mapping Division of the U.S.Geological Survey has been actively exploring the implications of computer technology to support its collection and distribution of cartographic and geographic data in the United States. Data collection for land use/land cover mapping started in 1973, while digital line graph programs (for topographic maps) commenced in 1977.

7 The Canada Geographic Information System was the first full-scale geographic information system to carry out functions of reading, measurement, and comparison of spatial data within a computer environment. It has been under continuing development for over two decades and is still one of the largest and most sophisticated GIS in existence. CGIS is designed to handle data extracted from aerial photographs and maps, specifically, thematic maps such as those pertaining to land use, forestry, and soils (Marble and Peuquet, 1983; Tomlinson, 1987 and 1968).

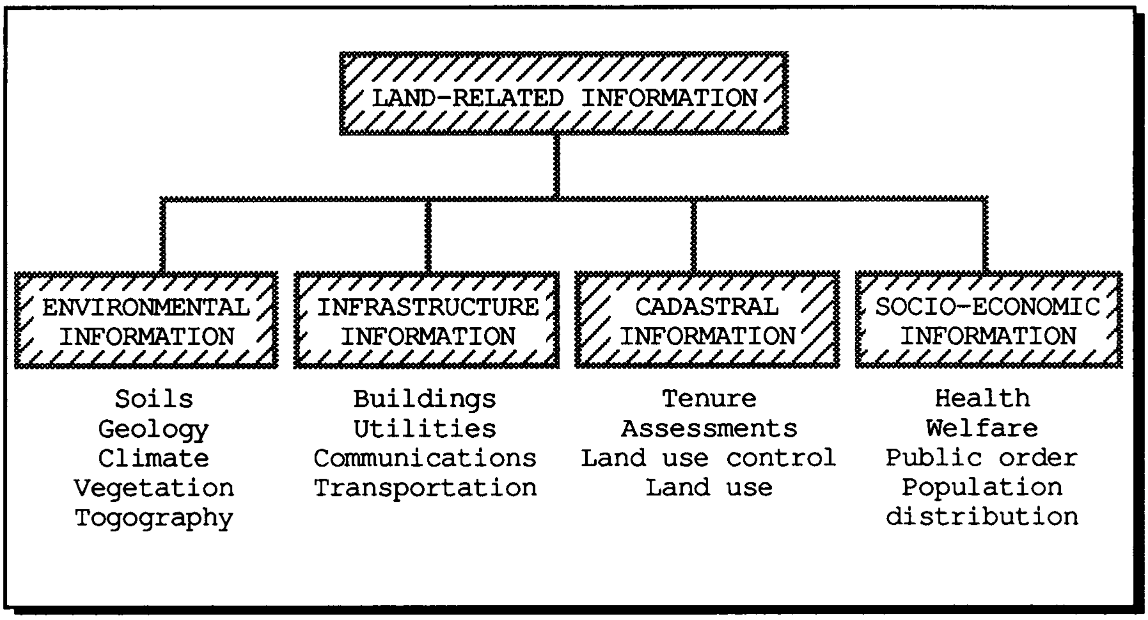


Figure 2: The land information environment

(from McLaughlin,1984)

b. the manipulations were sufficiently complex that, when coupled with large data volumes, the task could be completed without substantial error.

The need for *geographic information systems* stemmed from two major forces:

a. emerging natural resource and environmental problems that were becoming increasingly recognized by society; and

b. the large volumes of geographically referenced data becoming available, much of it based upon increased use of remote sensing technology in map production (Marble and Peuquet, 1983).

Early development of *geographic information systems* was performed in universities and private research organizations (Dutton [8],1978; Tomlin [9],1983; Males [10],1978; Bryant and Zobrist [11],1978).

Tomlinson (1972) places the value of the *GIS* concept on its future potential in spatial analysis and decision making (Figure 3), while Dangermond (1982) states that "at

---

8 ODYSSEY is a software system for the management, analysis and display of geographic information developed at the Laboratory for Computer Graphics and Spatial Analysis, Graduate School of Design, Harvard University in the late 1970s. The system includes map digitizing, editing, transformation, verification, overlay and cartographic display functions and features command protocols and dialects. Refer also to **Harvard Library of Computer Graphics** papers (1979 and 1980).

9 A Map Analysis package was developed by Dana Tomlin at the Yale School of Forestry and Environmental Studies in 1980. This package featured tools for overlay 'maps' such as residential areas, agricultural tracts, commercial zones, etc. The package also featured a user language, or algebra, that enables complex analysis such as comparing areas, mapping proximity, evaluating slope, etc.

10 The ADAPT (Area Design and Planning Tool) was designed by W.E.Gates and Associates during 1972-73. The system uses a triangulated network concept as a basis for organizing spatial information to support modeling of physical processes. Early applications included environmental management, engineering design and planning.

11 The Image Based Information System (IBIS) was developed at the Jet Propulsion Laboratory (JPL), California Institute of Technology in 1976. JPL recognized that combining the monitoring potential of satellite systems with the automated geo-referencing capabilities of geographic information systems had become technically feasible and economically viable.

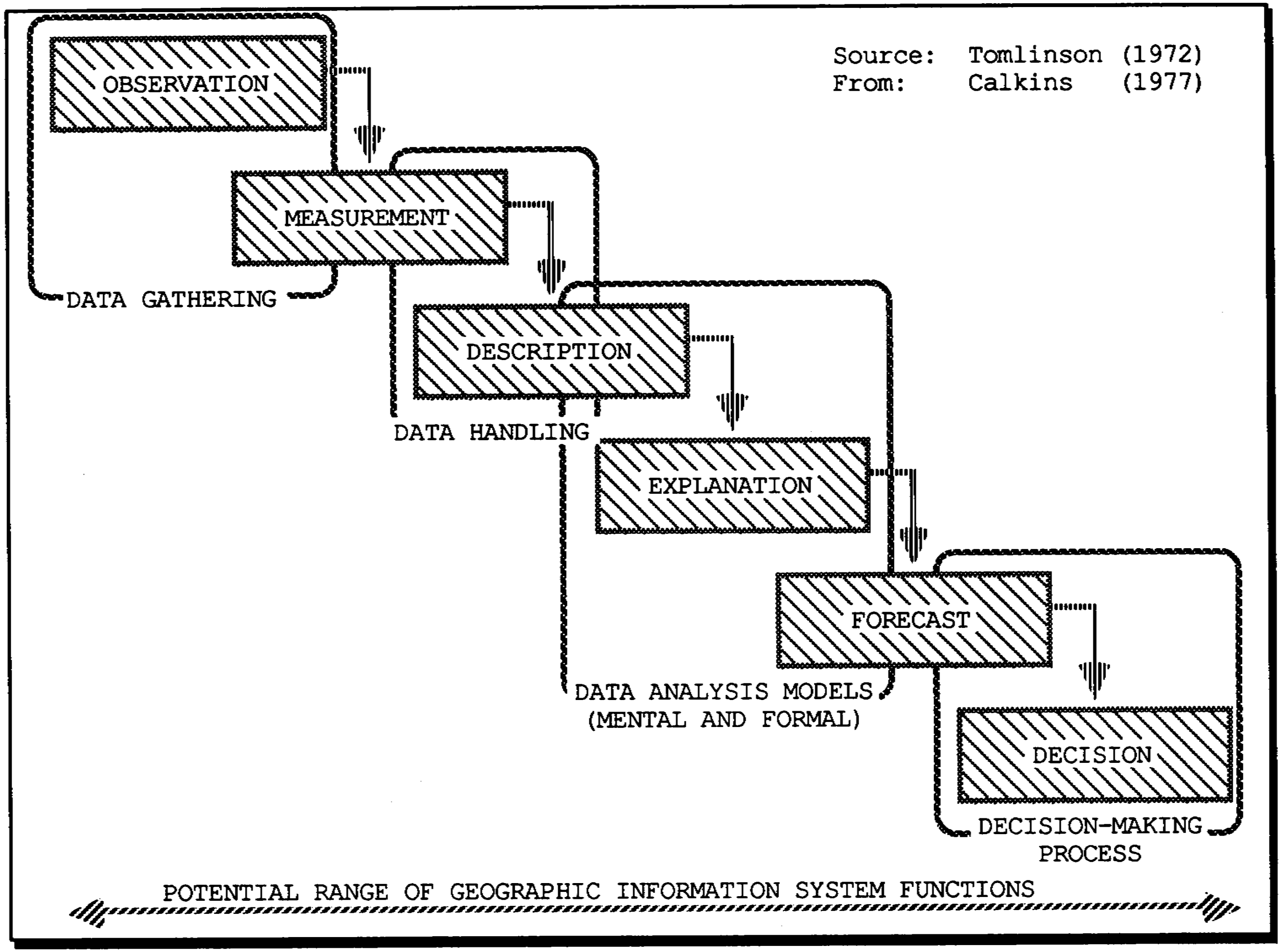


Figure 3: Geographic information functions

present, there are several categories of information technology which tend to be associated with vendor developed hardware / software systems. They generally fall into the following categories:

a. engineering mapping systems (typically a minicomputer CAD/CAM system for applications such as photogrammetry, topographic basemaps, road engineering, utilities, facility management, tax mapping, and land cadstral information);

b. property or parcel-based information systems (typically a mainframe based data base management system to handle attributes associated with the land parcel);

c. generalized thematic and statistical mapping systems (typically on both mini and mainframe computers and being used for natural resource management, forest inventories, vegetation, soils, census mapping, environmental planning and assessment);

d. bibliographic systems which catalog a variety of bibliographic data sets about geographic documents;

e. geographic base file systems associated with street networks and the areal units which they define; and

f. image processing systems (typically associated with processing of Landsat and related satellite image data)".

In summary, it can be seen that there have been two fundamental types of development; one being *computer-assisted cartography* which generally aligns to the requirements of *reference maps*, the other being *geographic information systems*, which generally aligns to the requirements of *thematic maps*. With respect to managing digital data, there have been two fundamental approaches, each corresponding to the type of development.

2.3 Techniques for managing data

Most mapping agencies capture data for standard series mapping. That is, each agency has a limited number of map scales and specifications for which they capture data. For example, McEwan and Calkins (1982) list the following digital data files for the USGS:

a. digital line graphs for 1:24,000 scale topographic series maps;
b. digital line graphs for 1:250,000 scale land use/land cover series maps;
c. digital elevation models in 7.5 minute quadrangles (a regular array of points on a 30 metre grid); and
d. digital elevation models for 1:250,000 scale Defense Mapping Agency digital terrain data.

In addition, mapping tasks tend to be done in a non-homogeneous coverage. That is, some areas have greater immediate priority than others and so coverage is non-continuous (Figure 4). Further, published map quality requires high resolution graphic design files that contain extremely large volumes of data. The result is that mapping agencies generally archive their data on magnetic tape files with only active project areas being held on 'on-line' disk storage.

On the other hand, users of *geographic information systems* generally work in much smaller 'project-size' areas. Their type of operation requires regular analysis and continual updating of data. Further, in many cases, because of a lesser requirement for high resolution data, files are smaller than mapping agency files. This results generally in 'on-line' data storage in continuous geographic areas.

In much the same way that data has been managed differently from the two perspectives, attitudes to data quality have also differed.

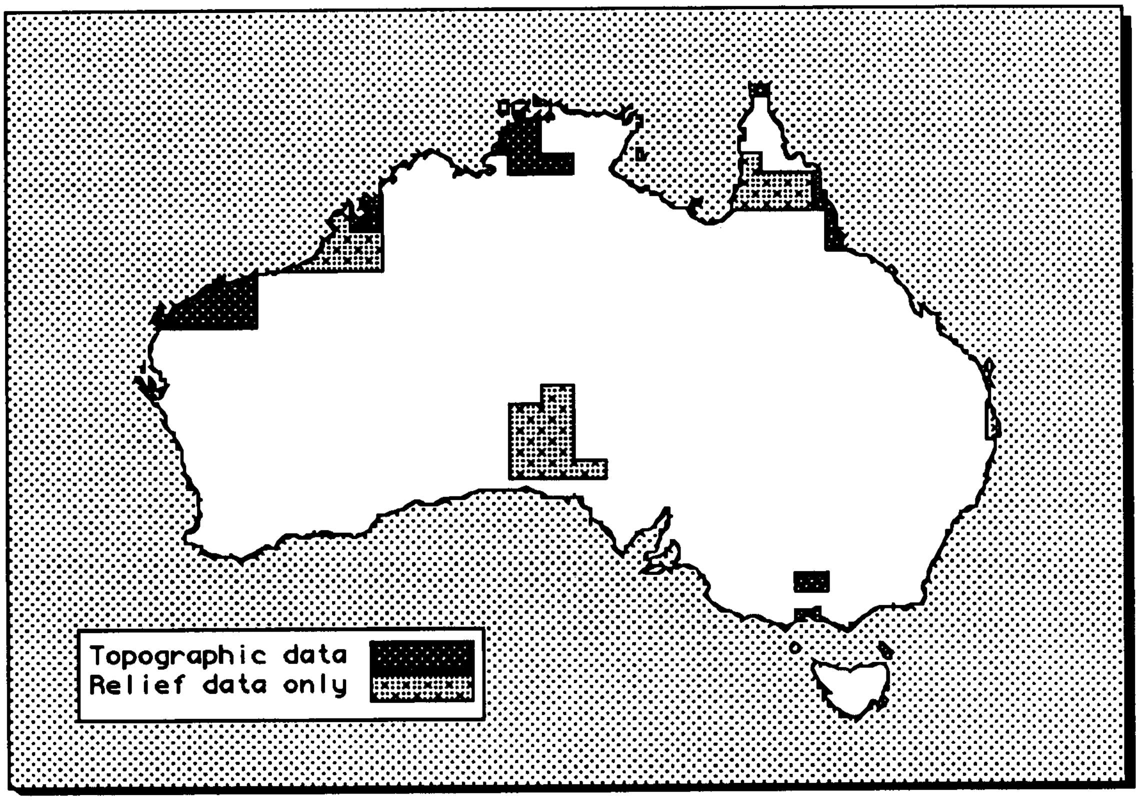


Figure 4: RASVY digital data coverage (1983)

(from Puniard,1987)

2.4 Quality aspects

Traditionally, standards for cartography have been primarily developed for the positional accuracy and the symbology on the printed map. The mapping agencies have traditionally operated within 'map specification' and 'map accuracy standards' designed for conventional maps. The 'standards' relate to planimetric and vertical accuracy of well-defined points scaled from maps. Specifications for map symbology, coupled with great attention to graphic quality have, however, resulted in series of maps that present an extremely uniform appearance.

However, McEwan (1982) suggests that "while it is sometimes argued that too much attention and expense are devoted to maintaining standards, the evidence of the false economy for poor quality erroneous maps still abounds". McEwan continues saying "another fascinating and often unappreciated aspect of standards for map symbology relates to human perception and the ability of even a novice user to form a mental map from the symbols inscribed on this highly developed graphic art form. A tremendous amount of information is implicitly conveyed. Deleting the symbol for a boundary where it coincides with a road or a stream presents few problems for humans with our highly developed cognizant sense of relationships. In a computer environment the lack of explicit continuity is disastrous". (These aspects are discussed in subsequent chapters generally in discussion on *topology*).

Kennedy-Smith (1986) is surprised "just how contentious data quality is and how difficult it is to reach agreement on its definition. Much time has been spent in discussion of this most elusive of subjects; discussion of terminology; of such terms as completeness, currency, horizontal and vertical accuracy (relative and absolute), of precision, and standard error".

While producers of geographic information systems have been most concerned with the 'continuity problem' by ensuring topological structuring, their systems suffer from other quality conditions. Those systems that use 'map based' data have inherent errors as mentioned above in addition to the unknown quality of many miscellaneous maps (used for *thematic* information). This results in incompatibility problems (Vonderohe and Chrisman, 1985).

Those *geographic information systems* based on grid cell or raster technology (discussed in Chapter 3) are restricted by the resolution of the cell as well as the map data from with they were derived. A raster is considered to be indivisible and so contains a mean value for that area of coverage of the raster pixel. A grid cell, however, is divisible and so the option exists that a value could be given for data existing within the cell (for example, a 'road' may exist within the cell) or a value could be given for, say, the south-west corner of the cell (as is often the case with digital terrain data).

Smith *et al* (1987) warn that "map accuracy is still an important and unresolved research issue, and assessment of the accuracy of *thematic* maps is particularly difficult. The problem is compounded in *geographic information system* applications where *thematic* or other maps with differing accuracy attributes are combined to produce a new product". Smith suggests that "basic research is needed to test the sensitivity of models to errors of both labeling and positioning in input data sets".

In this discussion on data quality, mention has been made of the structure of data and geometric relationships. In the discussion to this point, it has been noted that the practitioners of *computer-assisted cartography* and *geographic information systems* have differed in their approaches to managing digital geographic data. Likewise, the two groups of practitioners have placed different emphases on the structure of data. Chapter 3 deals with traditional techniques in structuring geographic data.

Chapter 3
TRADITIONAL TECHNIQUES IN STRUCTURING DIGITAL GEOGRAPHIC DATA

3.1 Background

During the past two decades, techniques for the digital collection and manipulation of geographic data have evolved from experimental laboratory procedures into dominant forces that now pervade the disciplines of geography and cartography. Digital mapping techniques have provided a variety of new and powerful capabilities to digitally collect, manipulate, analyze, and display spatial data.

3.2 Geographic data

Geographic data can be viewed as consisting of four major components:

a. geographic content;
b. location;
c. topology; and
d. data quality.

The components - geographic content, location, and quality - are not usually included in discussion on geographic data structure, but all attribute to the subject.

Geographic content includes data described and represented on a map such as natural and artificial features. This information has been formalized by the mapping agencies and assigned feature codes and applicable modifiers by the major mapping organizations (AS-2482, 1984; NCDCDS, 1987 [also in Moellering, 1987]). For example, features such as roads, railways, buildings, etc. are assigned map feature codes. An example of feature modification is that a 'building' could be of type 'post office'.

Traditionally, two fundamental methods have been used for locating data on the Earth's surface. These methods are by latitude and longitude (spherical or ellipsoidal) and by grid referencing. Alternate techniques for each of the methods have been to use either absolute location or as incremental off-sets to an origin included with the data set.

Quality aspects have become the topic of much discussion in recent years (Chrisman, 1983; Moellering, 1987; Kennedy-Smith, 1986; Williams, 1987). While the mapping agencies have traditionally operated with 'map specifications' and 'map accuracy standards' designed for conventional mapping, the details, specifically with respect to currency, lineage, absolute and relative accuracy, and resolution have only infrequently been added explicitly to digital data files. Along with these deficiencies, users of *geographic information systems* have had the added problem of trying to integrate data from a variety of sources, often with unknown quality descriptions (Vonderohe and Chrisman, 1985).

The components of geographic content, location and data quality will be examined further in following chapters. The issue that has received most attention (with respect to data structure) in the literature is that of *topology*, or models and structures for spatial data.

3.3 Spatial data models and data structures [12]

Chrisman (1987) suggests that throughout the development of digital mapping and

----

12 A *data model* specifies the sets of components and the relationships among the components pertaining to the specific phenomena defined by the data reality (phenomena that actually exist). A *data model* is independent of specific systems or data structures that organize and manage the data. A *data structure* specifies the logical organization of the components of a data model and the manner in which relationships among components are to be explicitly defined. These terms are discussed in detail in later chapters.

geographic information systems, there has been a competition between three basic models for data structure: raster, computer-aided design, and topological. The raster model describes the geometric elements as cells in an integer space. Using the simplicity of enumerating objects in the integer space, the raster approach has many proponents, but most of the arguments are based on technical considerations (Peuquet, 1979). Grid cell and raster models are types of **tessellation models**. The two **vector models** adopt a geometry of continuous space to position points, lines, and areas. The computer-aided design model places the primitive objects into separate layers, but does not introduce any further *data structure*. The topological model takes the same primitive objects, but places them into a network of relationships.

These data models were originally driven by technology. The reason for the grid cell was simplicity of programming, and the related raster pixel was determined by the simplicity of hardware designs for remote sensing. Similarly, the vector approach reduced complex graphics to tractable primitives.

The purpose of a spatial data structure is to provide a model of *spatial knowledge* (Chrisman, 1978). The spatial data structure provides a basis upon which spatial queries may be performed; these queries entail an examination of the encoded spatial entities and their attributes and relationships (Tomlinson, 1978). Smith *et al* (1987) suggests that the characteristic feature of geographic data is that they are spatially indexed. Smith observes that the two basic models (*vector* and *tessellation*) are available in the construction of a data model that incorporates spatial addressing:

a. objects may be represented with each object having spatial location as an essential property *(vector model)*;

b. locations may be represented with each location being characterized by a set of object properties *(tessellation model)*.

In addition to the two basic data models, there are hybrid structures, relational structures and irregular network structures. Consequentially, this review is divided into sections corresponding to these developments.

3.4 Vector data structures

The basic logical unit in a vector model is a line that is used to encode the locational description of a feature and represented as a string of coordinate pairs (x,y), or triplets (x,y,z). Closed areas, modeled as polygons, are represented by the set of lines that constitute their boundaries. Vector models of geographic space may be classified as *unlinked* or *topological.*

3.4.1 Unlinked model. In the *unlinked model* each map feature is encoded separately in point and line string form without reference to related, or adjoining, features. This model is commonly termed the *spaghetti model* - a term first used by N.R.Chrisman at the Auto-Carto I conference. This model has been adopted for routine map production by the major mapping agencies and is characteristic of the traditional *computer-assisted mapping* systems.

With the mapping organizations, the 'map' traditionally has been the 'product'. The information used to draw the map generally has not been used for computation or analysis. Early *computer-assisted mapping* systems merely overplotted layers of data with no analytical capability to relate data across layers. Roads, railways, streams, contours, etc. were digitized in layers applicable to the map production process and the relationships among the layers were only discernible visually. This inability to relate data across layers was due to a lack of data structure (Dueker,1985).

More recent *computer-assisted mapping* systems include cartographic structures designed to support graphic display or plotting equipment of high cartographic quality

(Gilbert and Rooke [13] ,1987).

3.4.2 Topological model. *Topology* refers to essentially nonmetric spatial relationships among the various features on the surface. Topological relationships are not changed by geometric distortions or transformations of the surface as long as the surface is not disrupted. The definitions of the terms *neighbourhood function* and *adjacency* are derived from topological relationships. They reflect an over-riding need in the analytical use of cartographic data to know the position of a feature, not only in absolute space, but also with respect to its neighbouring features (Peucker and Chrisman, 1975; Fegeas, 1982).

One of the first known attempts to incorporate explicit topological structure into a geographic data base was the Dual Independent Map Encoding (DIME) system of the U.S. Bureau of the Census. The basic element of the DIME file is a line segment defined by two end points. It is assumed that the segment is straight and not crossed by any other line. Complex lines are represented by a series of segments approximating the line. The segment has two 'node' identifiers, along with the coordinates of its two end points and codes for the polygon on each side of the segment (Peucker and Chrisman, 1975).

While DIME topology makes much information accessible to urban researchers, neighbourhood relationships are not made explicit. In addition, the Dime structure is cumbersome to use for many cartographic applications involving areas made up of complex lines.

Researchers at the Laboratory for Computer Graphics and Spatial Analysis, Harvard University, developed a data structure (POLYVRT) that was designed to contain

---

13 An automated screening and stippling system has been developed at Army Survey Regiment, Bendigo, Victoria. The screening and stippling system makes extensive use of the Optronics X4040 raster/scanner plotter. The 1:50,000 scale topographic series map 2757-4 DE GREY was the first map produced without manual intervention in any part of the cartographic process.

all the information needed to construct polygons. The basic object of POLYVRT is the 'chain'. Like a DIME segment, a chain has nodes at its two ends, separates two areas, and is assumed to be uncrossed. It differs in that the POLYVRT chain may be made up of many points whereas the DIME unit has only two points. A boundary between two polygons can be referenced by a single chain no matter how complicated, because the line detail is topologically unimportant (Figure 5). This data structure is the generic structure used by most users and suppliers of topologically structured vector bases.

Topological structures permit the solution of topological and geometric problems such as those pertaining to graph theory. These types of problems include routes through networks, adjacency determination, analysis of points and lines within polygons, and similar constructs. The modification of this structure with linkages to attributes, that is non-locational and non-topological data items, resulted in vector-based *geographic information systems*. Such an interface enables the user to interact with information related to the point, line and area representations (Morehouse, 1985). Figure 6 (from Dueker, 1985) shows a summary of the vector models ranging from the simple non-structured form through to the geo-relational model [14] [15].

The vector models have, in general, been used by the major mapping agencies and users of 'parcel-based' geographic information systems (or those systems commonly referred to as Land Information Systems). This model, however, has limitations for use with many resource applications when features cannot be properly organized with point, line and polygon representation. Such is the case for users of image-based information typical of satellite imagery for which *tessellation models* are more suitable.

---

14 Independently, and at about the same time, Bruce Cook from the CSIRO Division of Land Use Research developed his 'structural and algorithmic basis for a geographic data base'. His structure consisted of 'junctions', 'lines', and 'regions' (Cook,1978).

15 Refer to Moellering (1987) for technical definitions of terms used.

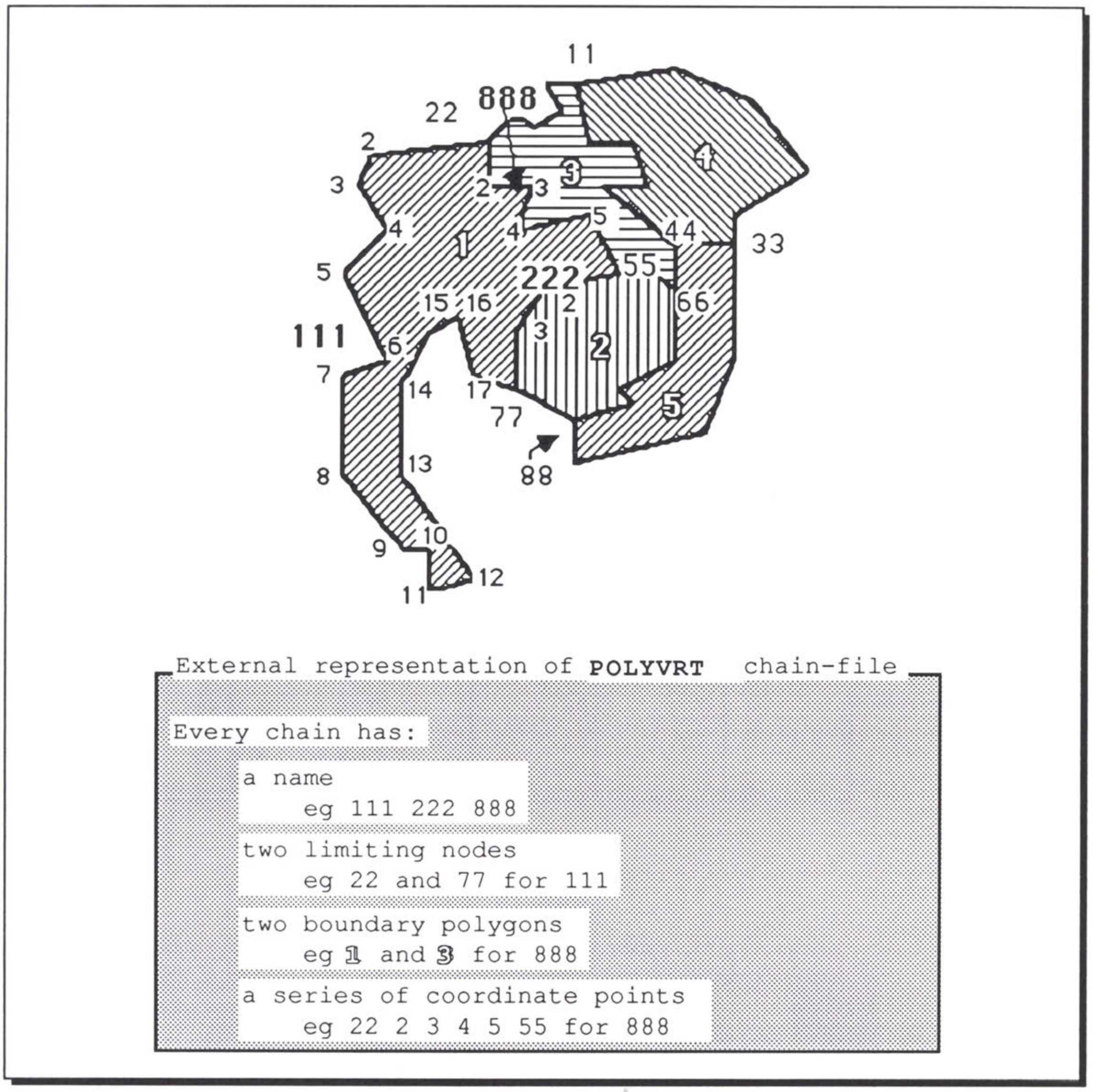


Figure 5a: Vector topology - external representation

(from Peucker and Chrisman, 1975)

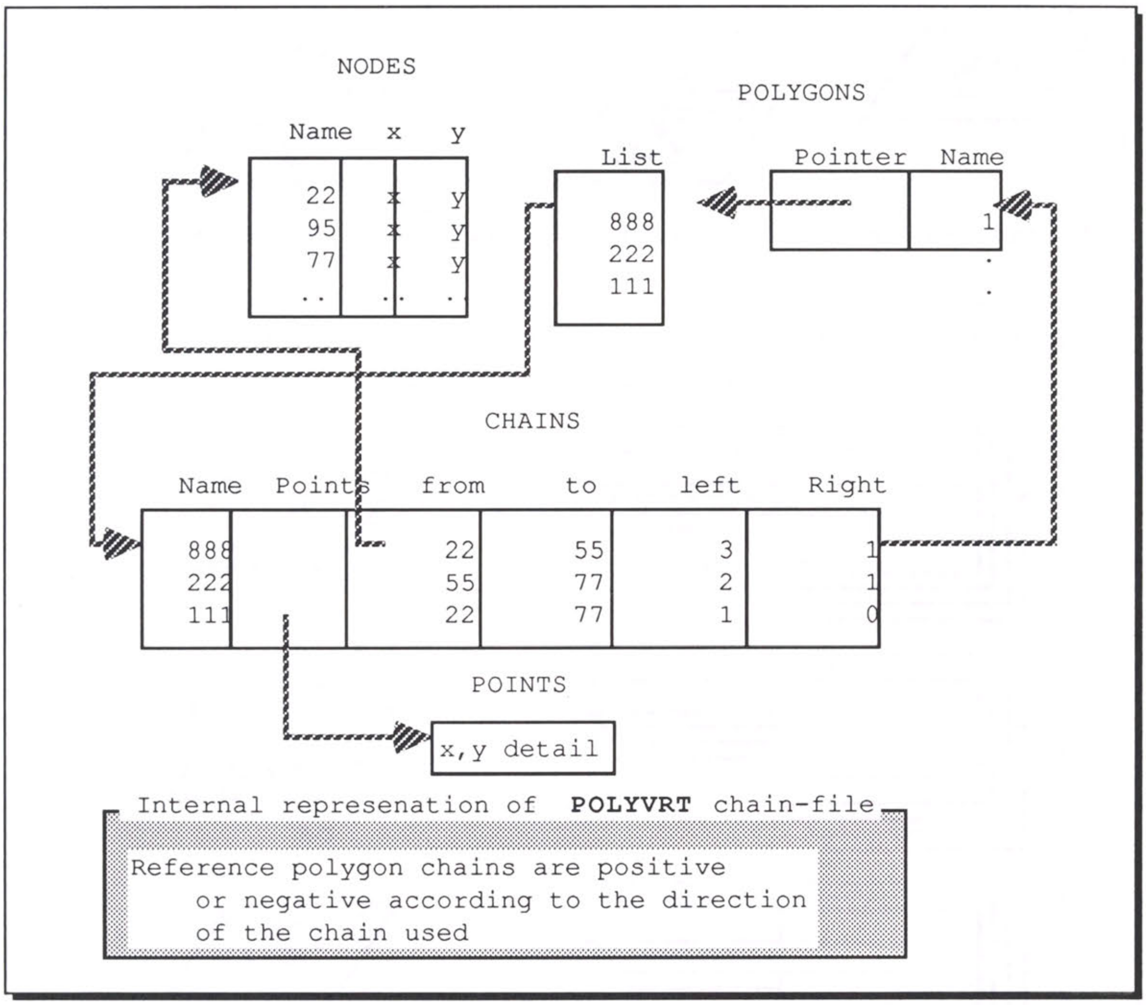


Figure 5b: Vector topology - internal representation

(from Peucker and Chrisman, 1975)

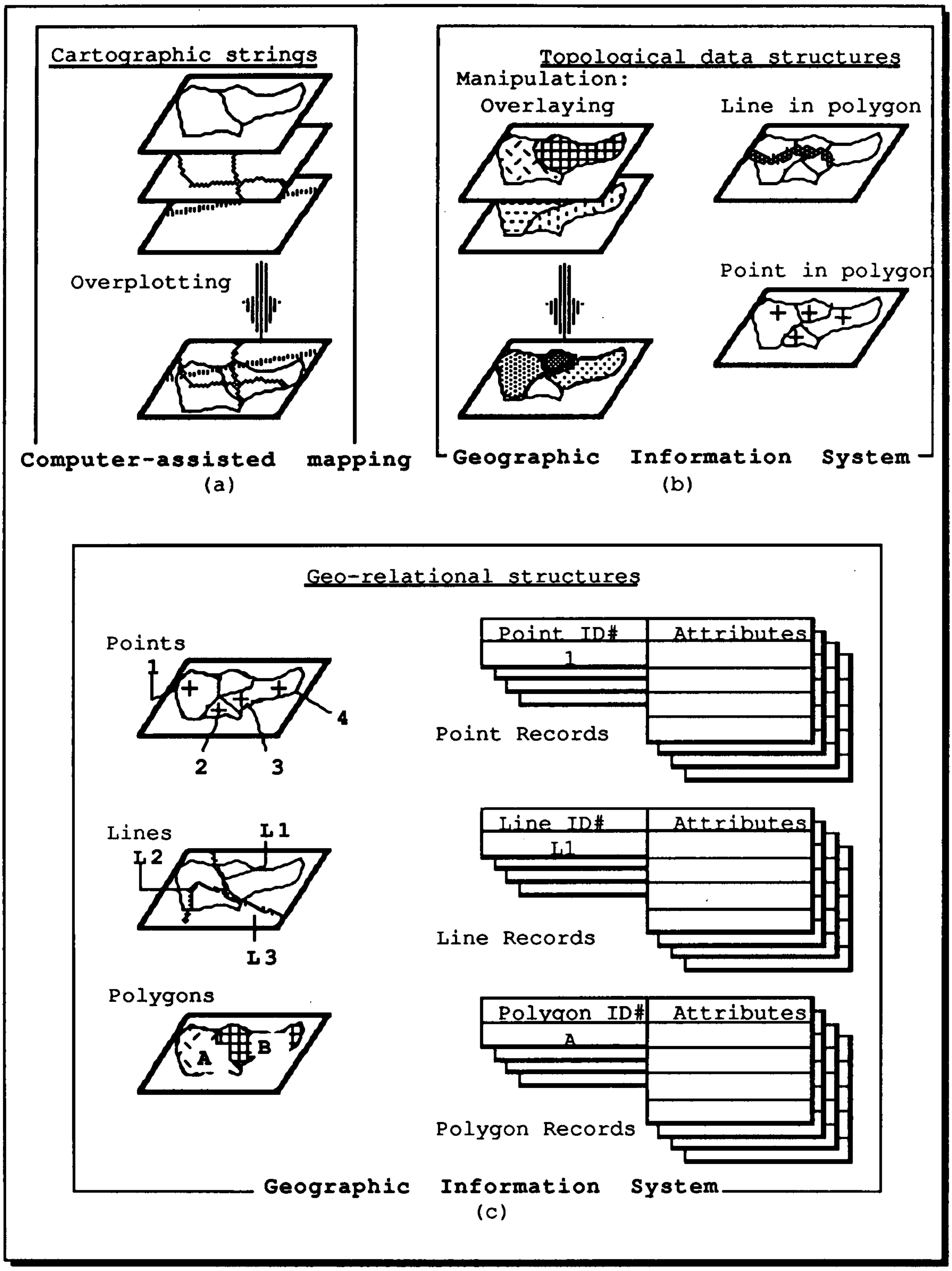


Figure 6: Summary of vector models

3.5 Tessellation data structures

A tessellation of a plane is an aggregate of cells that partition the plane. The logical unit of data in tessellation models is thus a unit of space. Each unit of space has an associated set of object properties. The essential property of such a data model is that spatial relations between logical units are implicit in the tessellation data storage and can thus be made to mirror arrangements in geographical space (Smith *et al*, 1987). Planar tessellations that are useful for representing spatial data should satisfy two criteria:

a. the tessellation should result in an infinitely repetitive pattern in the plane;

b. the tessellation should be infinitely recursively decomposable into similar patterns of smaller size.

Smith suggests that the first property allows data bases of any size to be represented, while the second makes it possible to use hierarchical data structures. Of the three regular tessellations of the plane, i.e. squares, triangles and hexagons, only the square has been used extensively for geographic data representation. The tessellation based on the square corresponds to the *grid cell* and *raster* data structures. These structures are easily traversed in both x any y directions, while run-length encoding techniques can be used for data compression (Figure 7). Most scanning devices used for data capture, such as multispectral scanners on satellites and optical scanners used for mass digitizing of analog maps, produce raster data sets.

The distinction between the terms *grid cell* and *pixel* is vague. The terms are often associated (by common usage) to resolution.

3.5.1 Grid cell. The *grid cell* data structure stores information as numerical values in arrays. Each cell represents a uniform parcel of land (e.g. one acre, a square kilometre, etc) located somewhere within the overall rectangular grid. The row and column

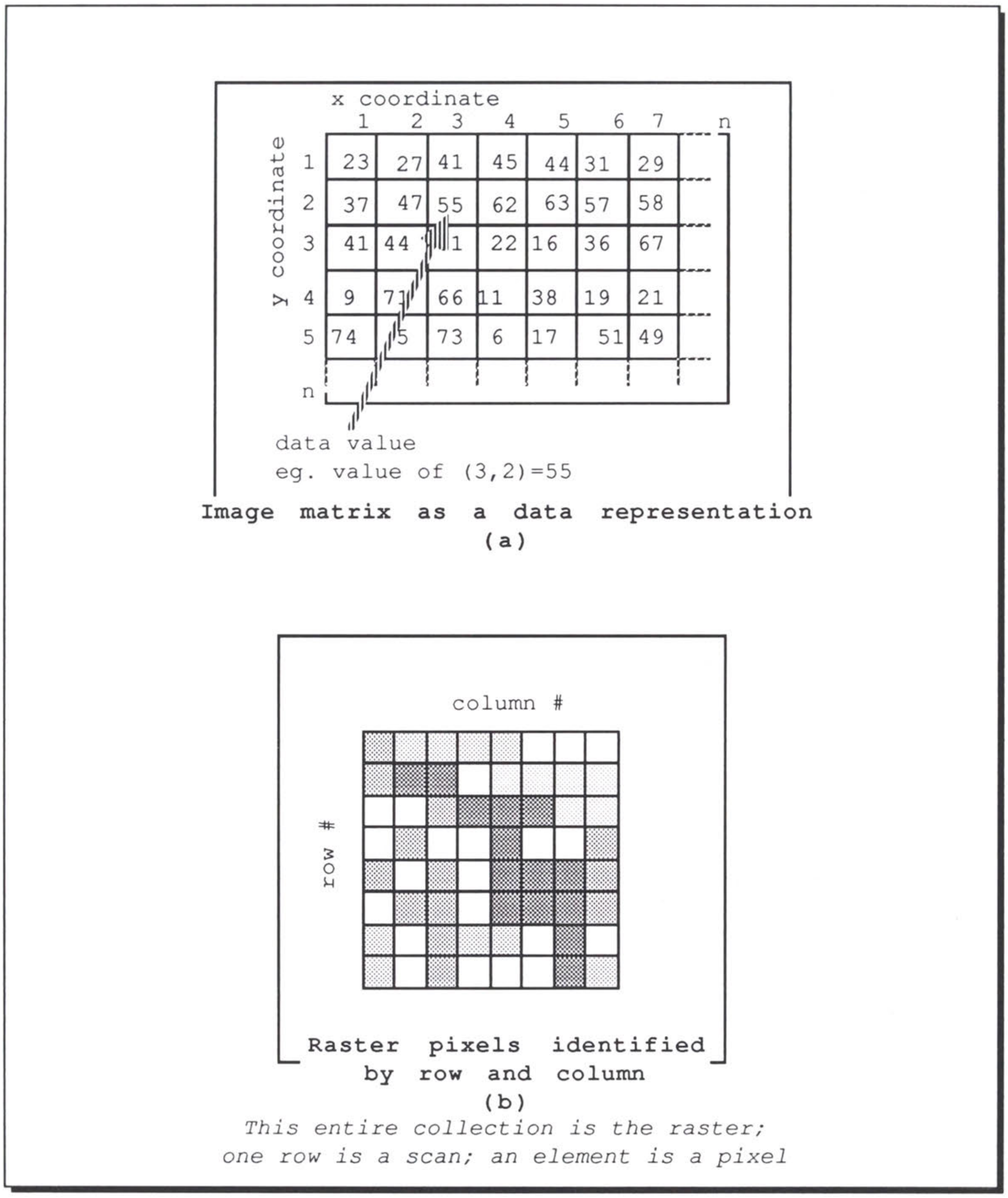


Figure 7 (a) and (b): Grid cell data structure

(a) Image matrix as a data representation

(b) Raster pixels identified by row and column

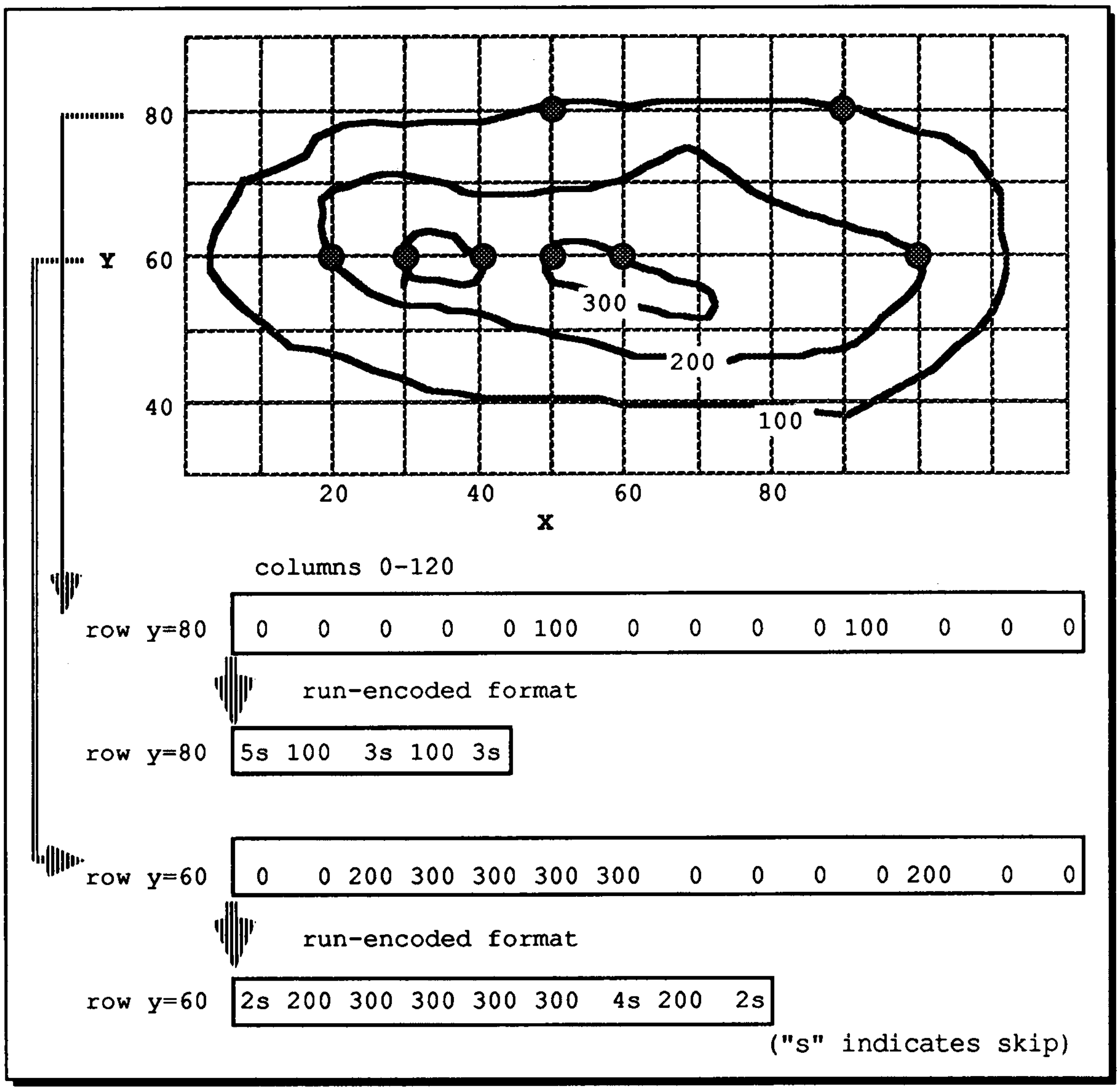


Figure 7c: Grid cell data structure

(c) Representation of grid (raster) data in list form and run-encoded indices of the grid identify the position, or "locational attribute", of each grid cell. These locations are assigned a numerical value, or "thematic attribute", and identify the map feature at each location. This data structure may be observed as a set of spatially referenced maps, each identifying a different map theme as an array of numbers (Bryant and Zobrist, 1978; Berry and Reed, 1987).

3.5.2 Raster data structure. The raster structure is an "ultra-fine mesh" grid cell data set (Bryant and Zobrist, 1978). This structure is well suited to organizing geographic data obtained via image scanning techniques. Imaging devices collect data in the form of high resolution digital matrices organized along scan lines, or rasters. Each data value comprises a *pixel* (picture element), which is an approximately rectangular area on the ground.

3.5.3 Analytic operations. The grid cell data structure lends itself to conventional mathematical and statistical operations as well as analytical operations concerned with spatial relationships (Peuquet, 1979; Berry and Reed, 1987; Berry, 1987) (Figure 8). Fundamental classes of analytic operations include:

a. reclassifying maps, such as splitting continuous ranges of values into discrete levels, or grouping similar data values based on contiguity;
b. overlaying maps, such as determining intersection and cover, or compositing areas based on values on different map levels, or performing statistical operations;
c. measuring distance and connectivity, such as delineating paths based on connectivity, or determining viewsheds involved in establishing intervisibility among locations;
d. characterizing neighbourhoods, such as determining slope and orientation characteristics, and profiles.

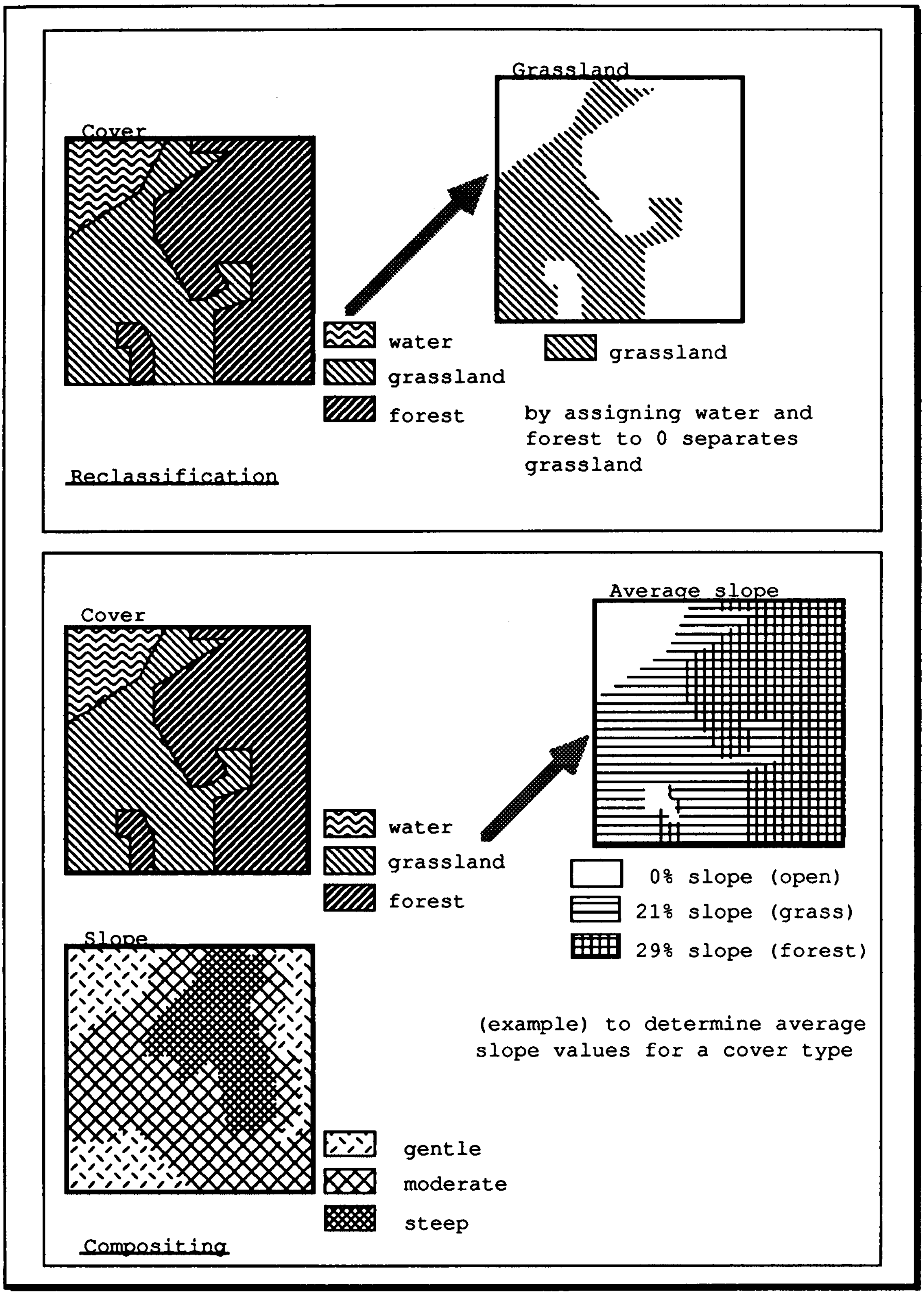


Figure 8: Some operations with grid cell based structures

(modified from Berry, 1987)

3.5.4 Integration with information. Most development, to date, with grid cell based systems has been with "overlay analysis" as discussed in the paragraph above.

However, like the vector approach, the integration of attribute data offers powerful capabilities for decision making. This integration has proven to be difficult due to the lack of robust algorithms and techniques to convert and transfer the diversity of data available from satellites [16], mapping agencies, and land and resource managers.

In addition to the *vector* and *raster* data models, a number of other structures have been researched with varying degrees of success.

3.6 Other miscellaneous data structures

In the discussion on *tessellation models*, principle properties were cited as repetitive patterns and decomposition. Such properties also imply hierarchical characteristics. The model that addresses this aspect is the *quadtree*.

3.6.1 Quadtrees. The term *quadtree* is used to describe a class of hierarchical data structures whose common property is that they are based on the principle of recursive decomposition of space (Samet, 1984 and Figure 9). They can be differentiated on the following bases:

a. the type of data that they are used to represent;

b. the principle guiding the decomposition process;

c. the resolution (variable or not).

---

16 Remotely sensed (satellite) image scanners contain a number of image error sources. These include geometric errors due to mirror scan velocity profile, detector sampling delay, panoramic distortion, scan skew, earth rotation, spacecraft velocity, perspective geometry, attitude (roll, pitch, yaw), altitude, desired map projection; and radiometric errors due to detector response (bias and gain), calibration source errors, atmospheric attenuation, film recorder gamma (Bernstein, 1983).

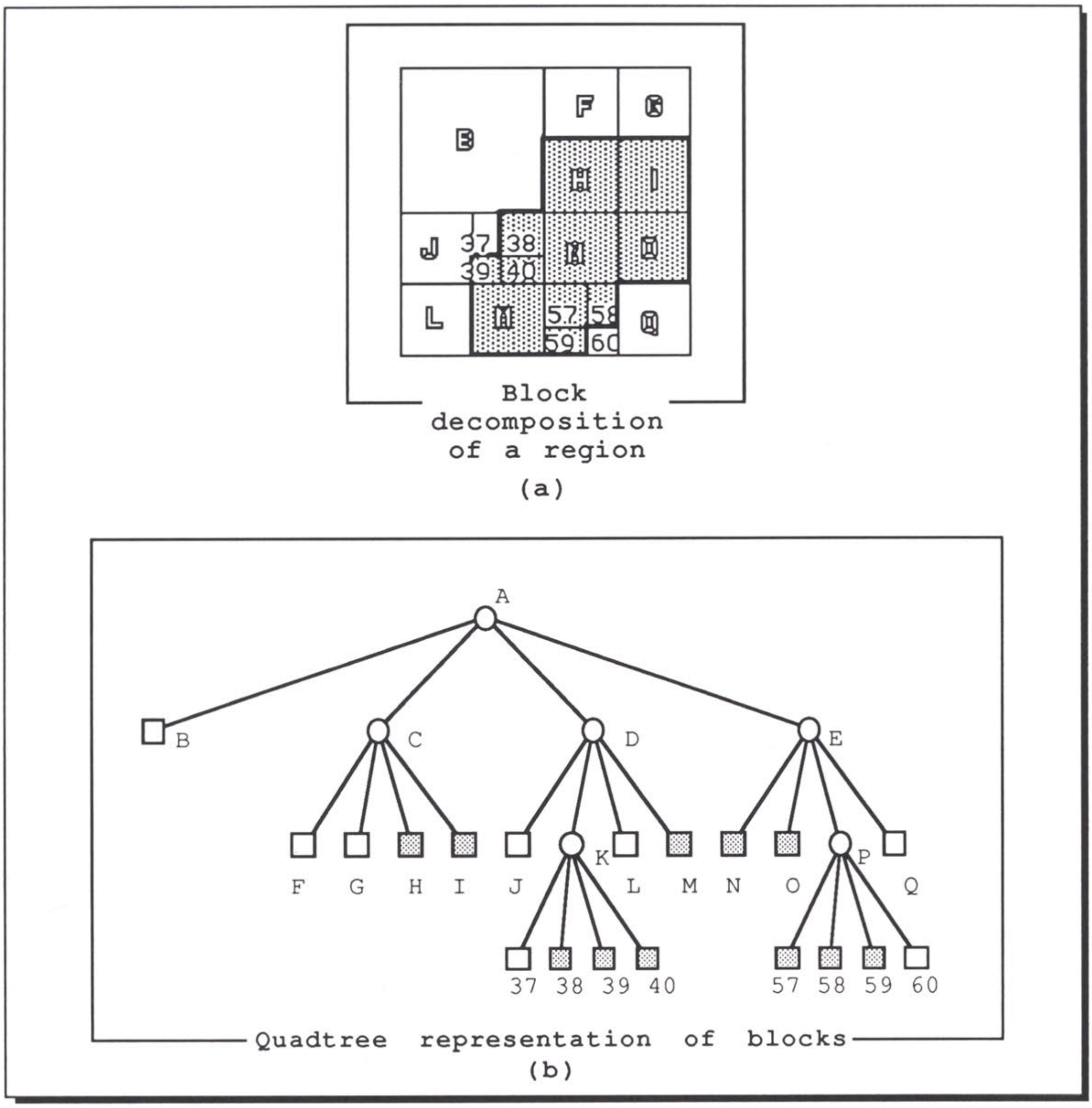


Figure 9: The Quadtree data structure

Samet suggests that the *quadtree* structure can be used for point data, regions, curves, surfaces and volumes. The structure has yet to be used by major mapping and geographic information processing organizations but is well suited to resource management applications.

Although the term *quadtree* is of recent origin (Samet attributes the use of *Q-Tree* and hence *quadtree* to Klinger (1971)), the technique has been used for many years by mapping organizations, not so much as for a structure of data, but for the storage of map data [17]. The *quadtree* model is useful because of its ability to focus on interesting, or more detailed, subsets of the data.

3.6.2 Triangulated irregular network. Another model that is characterized by this ability to focus on detail is the *triangulated irregular network* model (first developed by Peucker). The *triangulated irregular network* (TIN) is a topological data structure used to represent three-dimensional topographic surfaces. The TIN model consists of a collection of triangular planes joined at their boundaries (Figure 10). The spacing and shape of the triangles is determined by the terrain and by a desired degree of fit. McKenna (1987) notes that TIN systems result in a more accurate surface representation with far less storage than regular grid or contouring techniques. McKenna further suggests that the grid systems do not permit vertical surfaces, and irregular boundaries or interior holes in a surface area are difficult to define with grid. TIN systems, on the other hand, can describe nearly any surface, including those with holes, irregular boundaries, or vertical surfaces.

In addition, the resolution of a gridded surface representation is limited to the

---

17 Quadtree structures have been used by military mapping organizations in the US, UK and Australia for over a quarter of a century. The scheme which is used to subdivide geographic quadrangles for medium scale (1:100,000 scale, 1:50:000 scale and 1:25,000 scale) originated out of NATO (North Atlantic Treaty Organization) standardization agreements after the World War II (and possibly used by the US military mapping agencies in the 1950s). The scheme, along with standardized series mapping, was introduced into the Australian Army in 1960 after a SEATO (South East Asia Treaty Organization) meeting at Bangkok in 1958 (personal conversation with N.R.J.Hillier, Colonel retired) former Director of the Royal Australian Survey Corps).

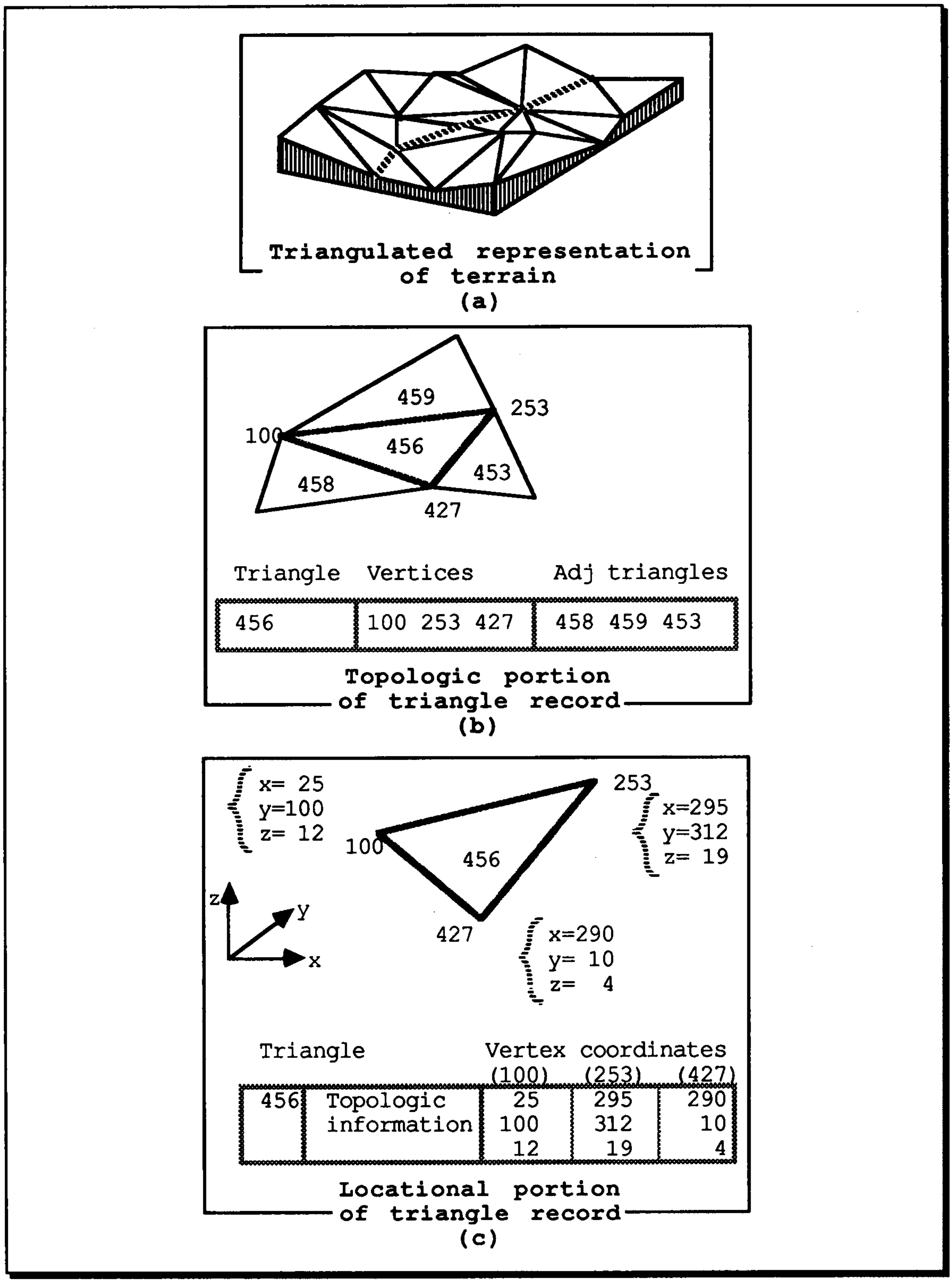


Figure 10: The triangulated irregular network structure

resolution of the superimposed grid, while the TIN representation is limited only to the resolution of the original data. McKenna claims that these benefits have been exploited for a variety of applications. The TIN is commonly utilized by automated survey systems, contour map generation software, earthwork calculation software and geographic information systems.

The preceding models, *quadtree* and *triangulated irregular network*, are useful in that important data can be structured to a resolution applicable to a user's needs. Another structure that has similar characteristics is the *Freeman chain.*

3.6.3 Freeman chain. Chain coding, often called *Freeman coding* (after Freeman,1974), is a technique for (x,y) coordinate description of line strings and is commonly used in cartographic applications. Line strings can be specified relative to a given starting point, as a sequence of unit vectors. Each line can be approximated by a series of eight possible steps numbered from 0 to 7 as in Figure 11. The choice of the unit's length (the grid size) according to the exactness required for representation is important. The method is well suited for the representation of fine outlines of areas, for the computation of areas and for scaling, but is poor for finding intersections of lines, rotations, and shading areas (Peucker, 1972; Samet, 1984).

3.7 Summary

This chapter briefly reviewed traditional techniques in structuring digital geographic data. As with the management of digital geographic data, different techniques are used depending upon the perspective of the organization.

These techniques have been influenced greatly by the need to either produce data for general purposes and, essentially, graphical representation, or the requirements for information suitable for land and resource management.

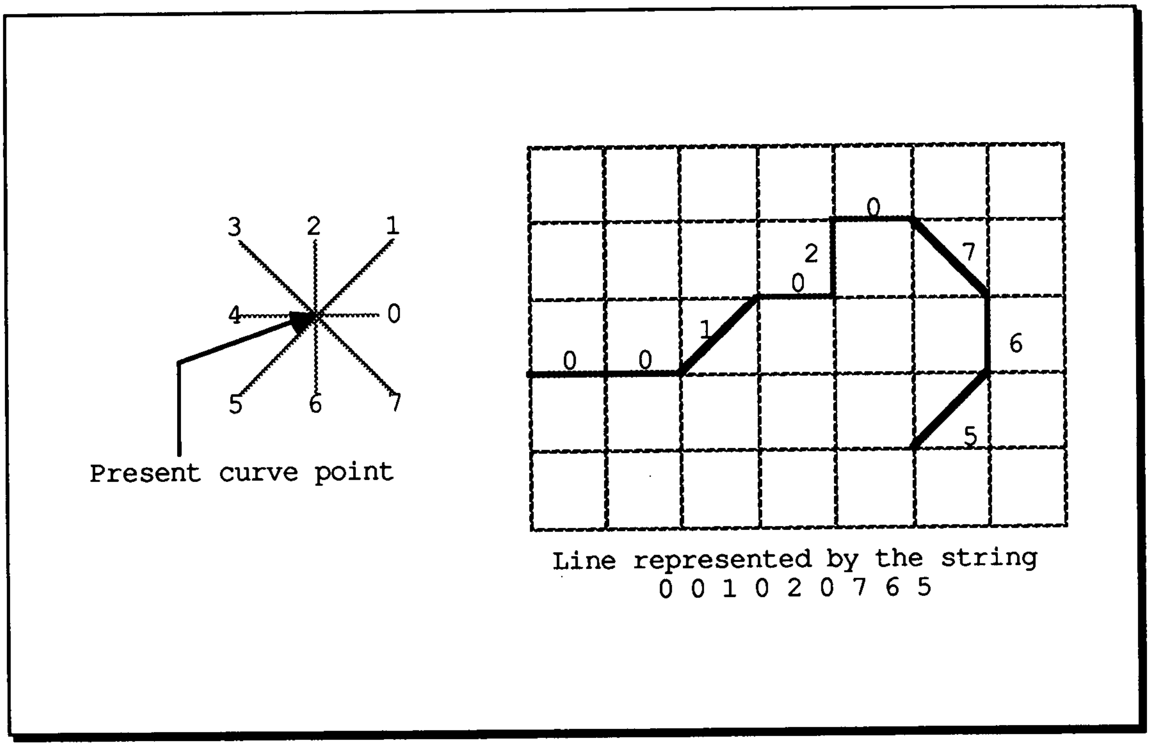


Figure 11: Freeman chain coding

Society is becoming information conscious. Each year there is an ever growing need to know more about the environment. Therefore there is pressure on those involved with land studies to provide accurate information and credible advice on subjects pertaining to the environment (Williams, 1986). Developments to date - computer-assisted cartography and geographic information systems - have been influenced by perceived roles of organizations and limitations in equipment and theory. In fact, development has been restricted by *traditional* approaches to the management of geographic data. The next chapter examines this aspect and discusses trends in digital cartography and geographic information system development.

Chapter 4

TRENDS IN DIGITAL CARTOGRAPHY AND GEOGRAPHIC INFORMATION SYSTEM DEVELOPMENT

The word - *traditional* - has been used in the previous chapters when referring to past developments in *digital cartography*. It is now appropriate that the qualifier - *traditional* - and the term - *digital cartography* - be examined more closely.

4.1 Rationalistic tradition

Winograd and Flores (1986) suggest that *traditional* approaches to many computer related subjects have been *rational*. They comment that "current thinking about computers and their impact on society has been shaped by a *rationalistic tradition*. The rationalistic orientation can be depicted in a series of steps:

a. characterize the situation in terms of identifiable objects with well-defined properties;

b. find general rules that apply to situations in terms of those objects and properties;

c. apply the rules logically to the situation of concern, drawing conclusions about what should be done."

Winograd and Flores also note that "there is a close correlation between the rationalistic tradition and the approach of organized science. This method consists of a series of basic steps. [The scientific method] can be described as involving the following operations:

a. observation of a phenomenon that, henceforth, is taken as a problem to be explained;

b. proposition of an explanatory hypothesis in the form of a deterministic system that can generate a phenomenon isomorphic with the one observed;

c. proposition of a computed state or process in the system specified by the hypothesis as a predicted to be observed;

d. observation of the predicted phenomenon."

Winograd and Flores stress that the rationalistic orientation not only underlies both pure and applied science but is also regarded, perhaps because of the prestige and success that modern science enjoys, as the very paradigm of what it means to think and be intelligent. In studies of thought, emphasis is placed on the form of the rules and on the nature of the processes by which they are logically applied. Areas of mathematics, such as symbolic logic and automata theory, are taken as the basis for formalizing what goes on when a person perceives, thinks and acts. For someone trained in science and technology it may seem self-evident that this is the right (or even the only) approach to serious thinking.

4.2 The traditional approach to digital cartography

Discussion in the preceding chapters highlighted different views and techniques by the different practitioners of digital cartography. Yet each of the approaches has been *rational*. In the case of the mapping organizations and their approach to *computer-assisted mapping*, the phenomenon to be processed was perceived to be the automation of the map making process. The compilation of the map, be it from photogrammetric techniques or derivative mapping procedures; the production of grids, graticules and legend panels; the cartographic representation of roads, drainage systems, and contours; the symbolic representation of cultural features; and the area symbology of vegetation and other thematic overlays, are all time consuming and (formerly) labour intensive tasks. Consequently, the sub-tasks involved were separated into identifiable objects. For example, the grid and legend panel of a map can be mathematically defined and by using a simple set of rules it is possible to produce these items on a plotting device. Similarly other tasks were characterized into well-defined objects and processing rules applied. Traditionally, the map making organizations have perceived there role as producers of general reference maps and have not generally considered the information relationships of geographic data contained in their data. Further, up until now, producers of digital cartographic data have usually targeted a single application. Secondary users of data have problems because most secondary users want to solve a new problem using data assembled and structured for a previous and different application (Williams, 1987).

On the other hand, to those organizations involved in resource and land management, the phenomena to be processed are the characteristics of features and the relationships between different feature types. These organizations, generally, have had less of an interest in the 'cartographic quality' of their products and so, *rationally*, developed deterministic systems to overlay and compare different sets of *geographic information.*

Both trends have been evolving for two decades and until recently were often viewed as non-compatible approaches designed for different markets. But today's mapping market is seeing a major shift toward decision support and operations management. The success of this shift will be influenced, not only by technological advancement, but by also overcoming a number of institutional problems.

4.3 Institutional issues

Over the last ten years, widespread attention to a host of problems in the current land records, resource management and base mapping systems indicates increasing concern over the crisis of inefficiency in present lands records procedures. Problems of usefulness, duplication, availability, integratibility, accuracy and cost effectiveness show an urgent need, according to many experts (e.g. Portner, 1982), for automated improvement and modernization of the entire system. Agencies at each level of government independently go to great expense to compile and display land data without knowledge of, or regard for, what others are doing, planning, or have already done. Seemingly everywhere, land data are gathered, developed, and manipulated without a correlated plan for reducing cost, for avoiding duplication of effort, or for exchanging information laboriously compiled.

Portner (1982) suggests that a 'social component' within current land information systems poses a serious obstacle to modernization. Portner argues that the autonomy with which groups have *traditionally* acted in the performance of their duties has led to a system which is inefficient, duplicative, and over costly. Each group has been rightfully concerned only with its own unique function. But the very usefulness and quality of land records for planning and management has been diminished by this lack of integration. Although such independence is perfectly reasonable on the autonomous level, on the societal, collective level this kind of behaviour must be seen as irrational.

These institutional problems occur at all levels of government and as discussed previously, the major organizations that capture and manage geographic information, both from mapping and analysis points of view, are government departments at national and state levels. Chorley [18] (1987) reports that "government will have an essential part to play in realizing the benefits brought by the wider use of *geographic information systems*. It is the biggest user and the largest single supplier of geographic information in the United Kingdom". Chorley (p.10) further observes:

> 'We are convinced that a fundamental change towards the routine use of geographic data on computers has already begun. The consequences of this cannot be predicted in general terms and by analogy. The introduction of computer accounting systems 25 years ago was hesitant at

---

18 Lord Chorley chaired a Committee of Enquiry into the Handling of Geographic Information.The Committee was appointed by the Secretary of State for the Environment (UK) with the following terms of reference:

> 'To advise the Secretary of State for the Environment within two years on the future handling of geographic information in the United Kingdom, taking into account of modern developments in information technology and the market need.'

first and many mistakes were made. However, as costs fell the value of new forms of information from the systems was discovered and, in due course, these systems became commonplace in quite small organizations. A return to manual systems is now inconceivable. We believe that the use of Geographic Information Systems will develop in a similar manner'.

It is now the responsibility of research organizations to address both the technological issues and the institutional [interface] issues to develop sophisticated information systems.

It has been apparent that throughout the research for this thesis, technology and the management of technology are interrelated. Institutional reform and technological advancement need to evolve together. While it is not the subject of this research to investigate in detail the institutional problems, it is important to note that technological trends are worthless without institutional evolvement [19].

In light of these technological and institutional trends, the concept of digital cartography now needs to be re-examined.

4.4 Re-examination of the concept of digital cartography

In analyzing the motives for digitizing digital geographic data and the techniques for managing data, it was apparent that different types of organizations perceive geographic data differently. As a result, a number of terms have come into common use. But,

---

19 In March 1986, the Australian Land Information Council (ALIC) was formed with its role formally endorsed by the Prime Minister, State Premiers (except Queensland), and the Chief Minister of the Northern Territory. New Zealand has observer status (AACLI,1987).
The principle roles of ALIC are to:

a. provide a forum for debate in land information policies at the national level;
b. explore the scope for the adoption of national land information policies and standards.

depending upon the organization the terms can have different meanings.

Zarzycki and Jiwini (1986) state that:

"*digital mapping* [cartography] and *computer-assisted cartography* are two separate but related activities and it is important that the distinction between them is fully understood so that new concepts can be developed and formulated that are applicable to a digital era.

Digital mapping [cartography] is a system for collecting, classifying, storing, retrieving, and managing of terrain data in digital form in a manner that is not tied specifically to a single application and that facilitates the use of this data for a multitude of users.

The result of digital mapping [cartography] is a 'digital map', a digital topographic or thematic data base [not a graphic] from which data can be retrieved selectively in an orderly manner, brought into association to fulfill users' requirements as inputs to users' mathematical models for analysis or employed to create cartographic files for production of a multitude of graphics by computer-assisted methods. This 'digital map' has no scale in the traditional sense; therefore the criteria of accuracy and content associated with map scale must be replaced by new concepts that are applicable to the 'digital map'.

Computer-assisted cartography, on the other hand, is a system for producing graphics from the data contained in the 'digital map' by means of computer-assisted cartographic methods employing proper symbolization to provide a clear and pleasing visual representation of the terrain".

This definition clearly separates the tasks of organizing digital data from the process of producing digital map products. This separation, however, has not usually existed [in purity] in *computer-assisted mapping* systems. Many of these systems has organized data specifically for a restricted range of products thereby minimizing the generalized classification of data items and 'short-cutting' the full process [according to

Zarzycki's definition] [20] [21].

Apart from differentiating between these fundamental concepts of *digital cartography* and *computer-assisted mapping*, the very nature of the definition of cartography needs to be reexamined.

Guptill and Starr (1984) have redefined **cartography** as:

> 'an information transfer process that is centered about a spatial data base which can be considered, in itself, a multifaceted model of geographic reality. Such a spatial data base then serves as the central core of an entire sequence of cartographic processes, receiving data inputs and dispersing various types of information products' (from Morrison, 1986).

This definition incorporates the notion of *geographic reality* and the multiplicity of use of the geographic data.

4.5 Digital mapping trend

The major trend in research is to structure data suitable for multiple purposes. Starr (1986) reports that "the National Mapping Division at the United States Geological Survey (USGS) has begun a major new system development effort, MARK II". Starr states that "a series of development tasks are being implemented to:

---

20 The decision to 'short-cut' this process is not unrealistic. It has been estimated that medium scale map production (even using the most modern automated processes) could take greater than one hundred years for the 1:24000 series of the United States, and a similar period for the 1:50000 series for all of Australia.

21 With the trend now for mapping organizations to create digital data bases, the term *computer-assisted mapping (cartography)* is becoming obsolete.

a. expand and improve mass digitization capabilities;

b. modify data structures to support increased content and access requirements;

c. develop digital revision capability;

d. develop product generation capability for standard, derivative, and digital products;

e. improve quality control, and

f. support advanced analysis and applications".

Similar trends have been reported by Franklin (1986) stating that a Multi-Product Operations concept is being designed into U.S. Defense Mapping Agency (DMA) modernization program with the aim of integrating mapping, charting and geodetic data to support all [approved] product requirements. Thompson (1986) reports similar developments at U.K. Military Survey, while the Royal Australian Survey Corps have included similar requirements (in internal documents) for its mapping systems development.

Some of the applications of digital data will have *decision-making* characteristics. For example, new products will assists managers in terrain evaluation, site selection, route optimization, and navigation. In fact, two hundred years ago cartographers provided similar advice!

4.6 Trends back to decision-making

Historically, cartographers have provided their countries with planning information and explicitly given *decision-making* advice. Early explorers/cartographers are notable examples (Figure 12). In recent years this aspect has almost vanished from the cartographer's products. The trend has been to provide base information and thematic overlays leaving other 'planning authorities' to make all decisions [rather than selecting

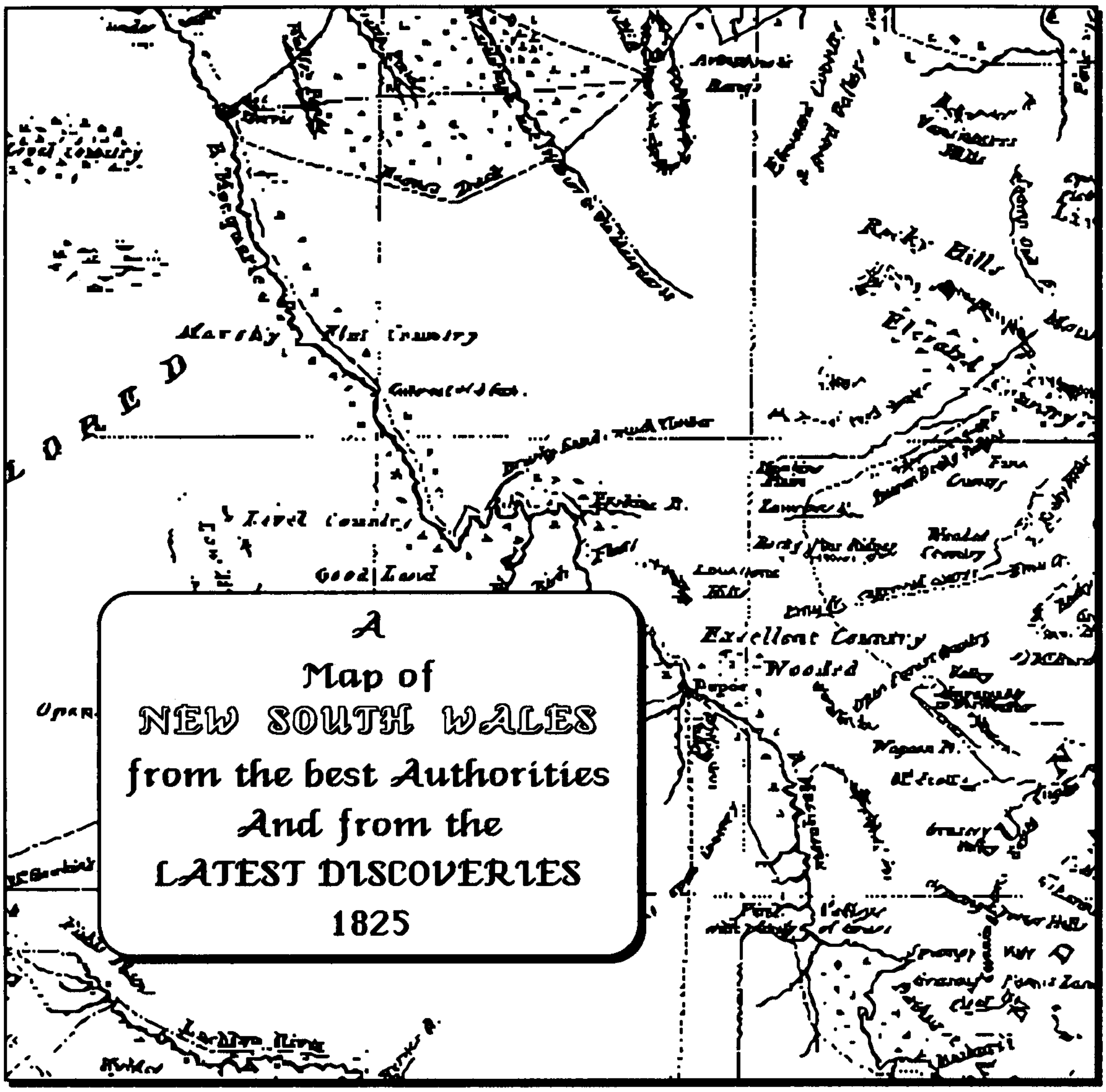


Figure 12: A map of New South Wales - 1825

(copied from a map reprinted by the Central Mapping Authority (CMA) of New South Wales from an original supplied to CMA by the Mitchell Library, Sydney) management organization' into a number of land management organizations resulting in conflicts of interest as to what information ought to be gathered, how it ought to be gathered, and to what standards it ought to be gathered. The outcome has been that different organizations collect their 'theme' and other 'base map' data. Consequently, in the exchange of data, other organizations consider the 'base map' data to be inadequate for their purposes and so modify or recollect the same data. The result is institutional and data quality chaos.

An alternative to this 'product specific' mode of geographic analysis, is to structure data independent of any one application and in a structure that best replicates its *real-world* structure and then to design rules to access that data for many applications.

4.7 Intelligent systems

The major trend in research is to structure data suitable for multiple purposes and using *real-world* relationships (Grady, 1986). Bouillé (1986) asserts that "contrary of what is generally taught, we must emphasize the fact that the structure [of geographic data] is completely independent of the problem we want actually to solve. Moreover, a structure built correctly, and with no 'a priori' idea, always contains a substructure which immediately answers our problem..." But, in order to achieve these desirable characteristics, far more intelligence has to applied to data than in the past. The theory for these developments will come from the field of artificial intelligence, specifically the area known as *expert systems* (Williams, 1987).

Intelligence can be achieved via two fundamental, but integrated sources. These sources are those of:

a. data relationships and structure; and

b. techniques and procedures for manipulating and analyzing the data relationships.

These sources can be considered as forming *expertise*. *Expertise* consists of *knowledge* about a particular domain (*real-world* geographic structures), understanding of the domain problems, and *skill* at solving some of these problems. *Knowledge* (in any speciality) is usually of two sorts: *public* and *private*. *Public knowledge* includes the published definition, facts, and theories of which textbooks and references in the domain of study are typically composed. But *expertise* usually involves more that just this *public knowledge*. Human experts generally possess *private knowledge* that has not found its way into the published literature. This *private knowledge* consists largely of rules of thumb that have come to be called *heuristics*. *Heuristics* enable the human expert to make educated guesses when necessary, to recognize promising approaches to problems, and to check effectively with errorful or incomplete data. Elucidating and reproducing such *knowledge* is the central task in building *expert systems* (Hayes-Roth *et al*, 1983).

Hayes-Roth *et al* write that "the ideas that underlie an approach to intelligent problem solving (Figure 13), motivate and help explain the primary knowledge in expert systems. Since, in most cases, experts face problems that do not have easily formalized or algorithmic solutions, heuristic methods must be used; and effective solutions depend on the timely use of knowledge to identify potential decisions that are promising and rule out unpromising ones. The central notion of intelligent problem-solving is that a system must construct its solution selectively and efficiently from a space of alternatives. When resource-limited, the expert needs to search this space selectively, with as little unfruitful activity as possible. An expert's knowledge helps spot useful data early, suggests promising ways to exploit them, and helps avoid low-payoff by pruning blind alleys as early as possible. An expert system achieves high performance by using knowledge to make the best use of its time".

1. Knowledge = Facts + Beliefs + Heuristics

2. Success = Finding a good-enough answer with the resources available

3. Search efficiency directly affects success

4. Aids to efficiency:
   (a) Applicable, correct and discriminating knowledge
   (b) Rapid elimination of 'blind' alleys
   (c) Elimination of redundant computation
   (d) Increased speed of computer operation
   (e) Multiple cooperative sources of knowledge
   (f) Reasoning at varying levels of abstraction

5. Sources of increased problem difficulty:
   (a) Errorful data or knowledge
   (b) Dynamically changing data
   (c) The number of possibilities to evaluate
   (d) Complex procedures for ruling out possibilities

Figure 13: Basic ideas of intelligent problem-solving

Chapter 5
ASPECTS OF PHENOMENOLOGY

5.1 Phenomena of the real world and notions of cognition

The *phenomena of the real world* (or data relationships and structure) can be described by an abstraction defined within functional categories, related via topological properties and spatially referenced. Data abstracted in such a way could be considered as being in a *geographic knowledge base*. The uses of this geographic data are affected by the requirements of a user's purpose, while the products for this purpose can be static reports, such as map overlays of categorized and symbolized geographic data, or as a result of analyses or desired view of various aspects of the data. In a sense, these products result from processes by which information is selected and encoded, reduced or elaborated, stored and recovered, and decoded and used. Such products can be considered as having *cognitive* properties. Moore and Golledge (1976) suggest that "environmental cognition refers to awareness, attitudes, impressions, information, images, and beliefs that people have about environments. These environments may be directly experienced, learned about, or imagined. Environmental cognition refers to essentially large scale-environments, from nation and geographic regions down to cities and spaces between buildings, to both built and natural environments, and to the entire range of physical, social, cultural, political, and economic aspects of man's world. Cognition of these environments implies not only what individuals and groups have information and images about the existence of these environments and their constituent elements, but also that they have impressions about their character, function, dynamics and structural interrelatedness, and that they imbue them with meaning, significance and symbolic properties".

In summary, the *phenomena of the real world* are those abstractions which describe the earth's surface, its form and physical features, its natural and political divisions, the climate, the productions and the populations, whereas the *cognition* is the interpretation and analyses of relations between the phenomenological objects.

5.2 The phenomena of our data reality

Several researchers have developed and itemized "levels of data abstraction". Notable, within the field of geographic data description, there are contributions by Nyerges (1980) who identifies six levels of data abstraction (Figure 14) and, more recently, work by Guptill et al (1987) who identify five levels of abstraction (Figure 15). The important component within both schemes is the stated importance of the *data model* (or Nyerges' information and canonical structures).

5.3 Spatial Data Model

The phenomena of data reality are considered, in totality, as *entities*. An entity and its digital representation is termed a *feature*. A feature is a set of phenomena with common attributes and relationships. All of the elements of this set of phenomena are homogeneous with respect to the set of selected common attributes and relationships used to define a feature. All geographic features implicitly have location as a defining attribute.

The concept of *feature* encompasses both entities and objects. The common attributes and relationships used to define the feature also apply to the corresponding entities and objects. An *entity* is a real world phenomenon that is not subdivided into phenomena of the same kind. This 'real world phenomenon' is defined by the attributes and relationships used to define the feature. An *object* is the representation of all or part of an entity. The concept *object* encompasses both *feature object* and *spatial object*. A *feature object* is an element used to represent the non-spatial aspects of an entity. A *spatial object* is an element used to represent the position of an element (Figure 16 and Moellering, 1987; Guptill et al, 1987; Rossmeissl et al, 1987).

Data Reality	The data existing as ideas about geographical entities and their relationships which knowledgeable persons would communicate with each other using any medium for communication
Information Structure *[Operational data view]*	A formal model that specifies the information organization of a particular phenomenon. This structure acts as a skeleton to the canonical structure and includes entity sets plus the types of relationships which exist between those entity sets
Canonical Structure *[Subject data view]*	A model of data which represents the inherent structure of that data and hence is independent of individual applications of the data and also of the hardware and software mechanisms which are employed in representing and using the data
Data Structure	A description elucidating the logical structure of data accessibility in the canonical structure. There are access paths which are dependent on explicit links and others which are independent of links
Storage Structure	An explicit statement of the nature of links expressed interms of diagrams which represent cells, linked and contiguous lists, levels of storage medium, etc
Machine Encoding	A machine representation of data including the specification of addressing, data compression and machine code

Figure 14: Nyerges' levels of data abstraction

Reality	The total phenomena as they actually exist
Data Reality	An abstraction of reality which includes only those entities thought to be relevant to anticipated needs. It is a definition of the scope of the data
Data Model	The sets of components and the relationships among the components pertaining to the specific phenomena defined by the data reality. A data model is independent of specific systems or data structures that organize and manage the data
Data Structure	The logical organization of the components of a data model and the manner in which relationships among components are to be explicitly defined
File Structure	A physical implementation of a data structure (format) in a computing system environment

Figure 15: Guptill's levels of data abstraction

The term 'data model' has been used in two contexts in computer science literature - as a model of a database and as a model of a database management system. Guptill has adopted the first. This is a practical use, while the other is more theoretical.

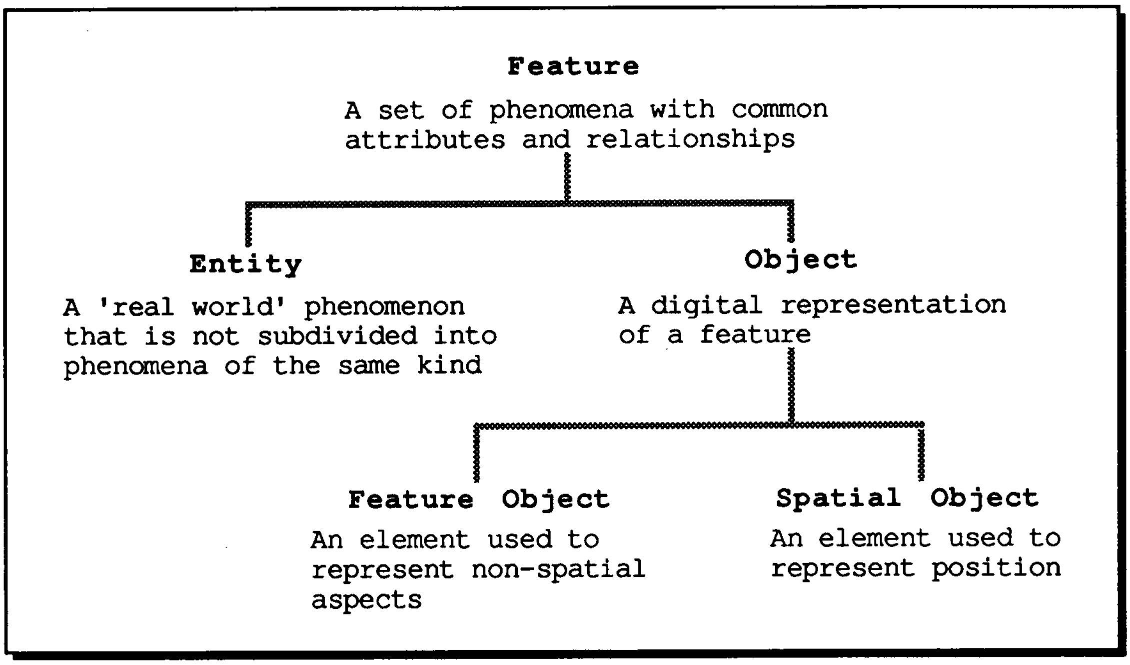


Figure 16: Concepts of feature, entity and object

(from NCDCDS,1987)

An attribute is a characteristic of a feature, or of an attribute value. The characteristics of a feature include such concepts of shape, size, material composition, form and function of a feature. The attributes assigned to a feature include those inherent in the definition of the feature and additional attributes which further describe the feature. An attribute value is a measurement assigned to an attribute for a feature instance, or for another feature value.

Further, Guptill suggests that three major groups of rules can be used to formulate the description of feature instance. These groups are rules for defining feature instances, composition rules for representing feature instances, and rules for aggregating feature instances (Figure 17). In separate and independent research, McKeown (1983, 1987) suggests that complex features (spatial entities) can be represented using *schemas*. Each entity is a *concept map* and can be represented by one *concept* schema and at least one *role* schema. McKeown notes that using such an approach facilitates hierarchical decomposition of features, say, using natural hierarchies such as political boundaries, neighbourhoods, commercial and industrial areas, and so on (Figure 18). These concepts of compositing and aggregating features are applications of *set theory*. Bouillé (1978) combines two fundamental concepts - the *set* and the *graph* - in his Hypergraph-Based Data Structure (HBDS). The *set* consists of elements which are capable of possessing certain properties and of having certain relations between themselves or with elements of different sets. A *hypergraph* is defined to be a family of hyperedges which are sets of vertices of cardinality not necessarily two. Thus, a hyperedge may link more than two vertices. The concept of the set allows for the grouping and relating of objects; the concept of the hypergraph allows a method of representing these groupings and relations (Domaratz and Moellering, 1986; Nyerges, 1980; Rugg, 1983; and Figure 19).

5.4 World Views

Rossmeissl et al (1987) suggest that a methodology to define the domain of features is to use a concept of *world views* of spatial entities. Rossmeissl's proposed views are

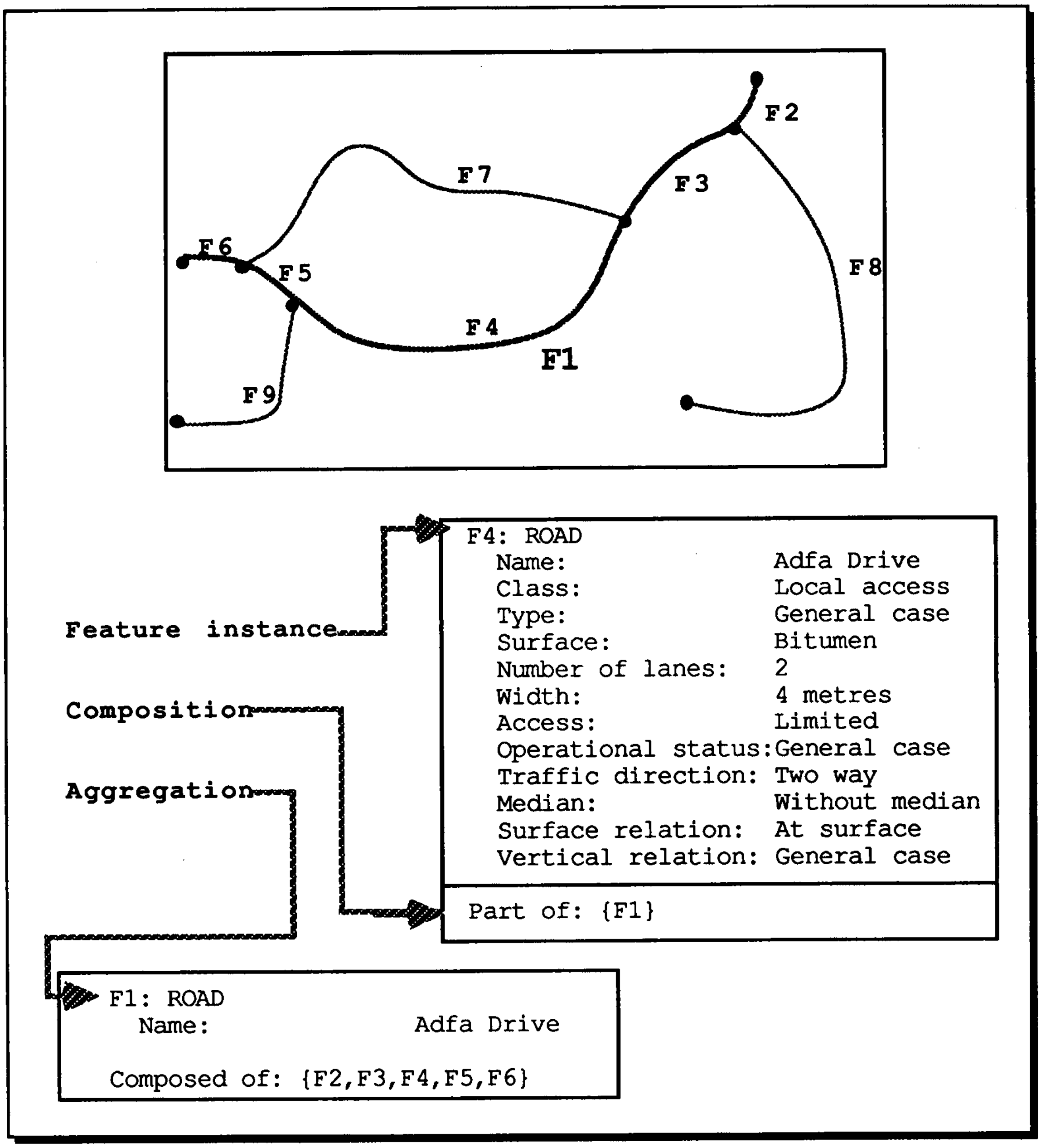


Figure 17: Representation of features

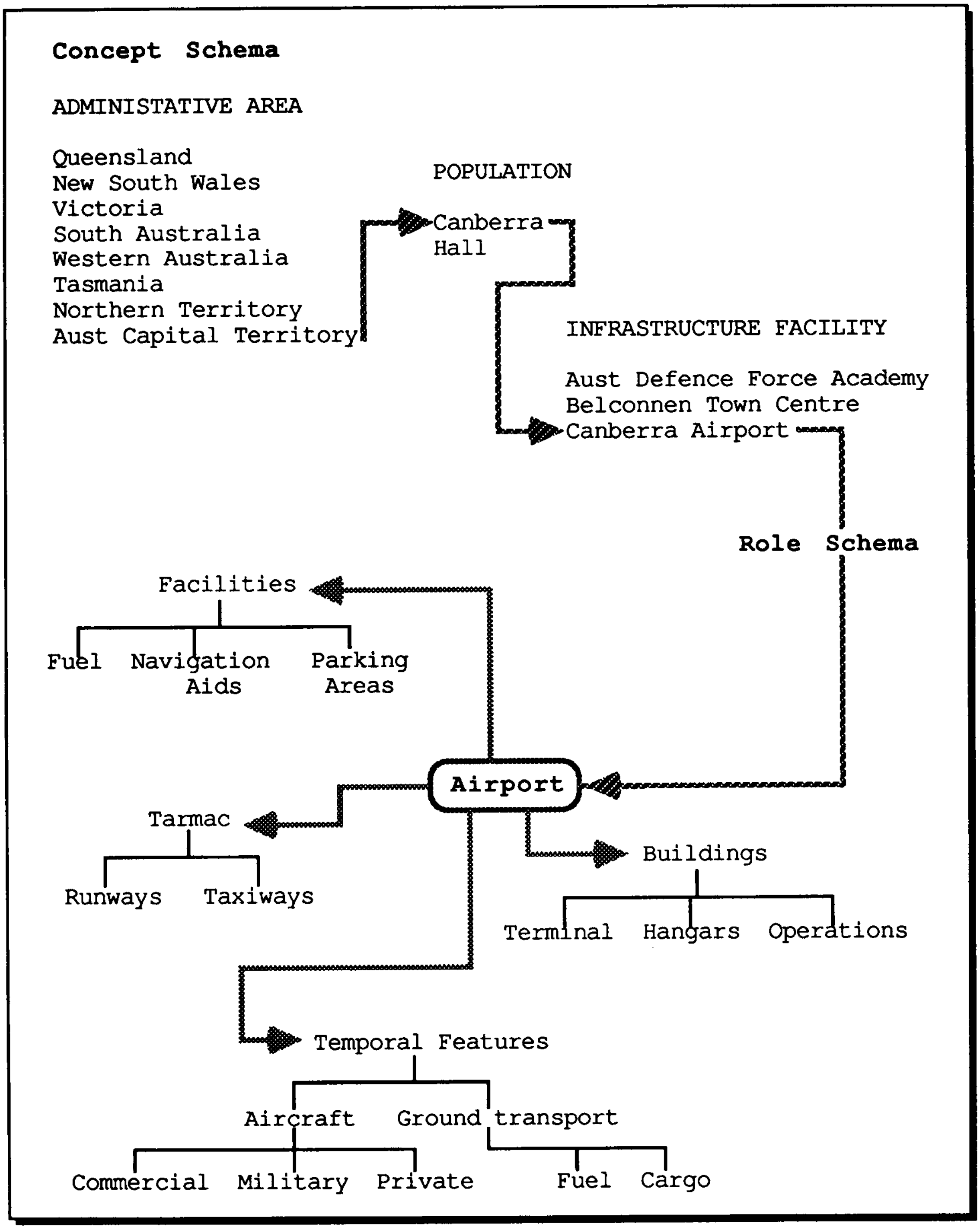


Figure 18: Concept and role schemas

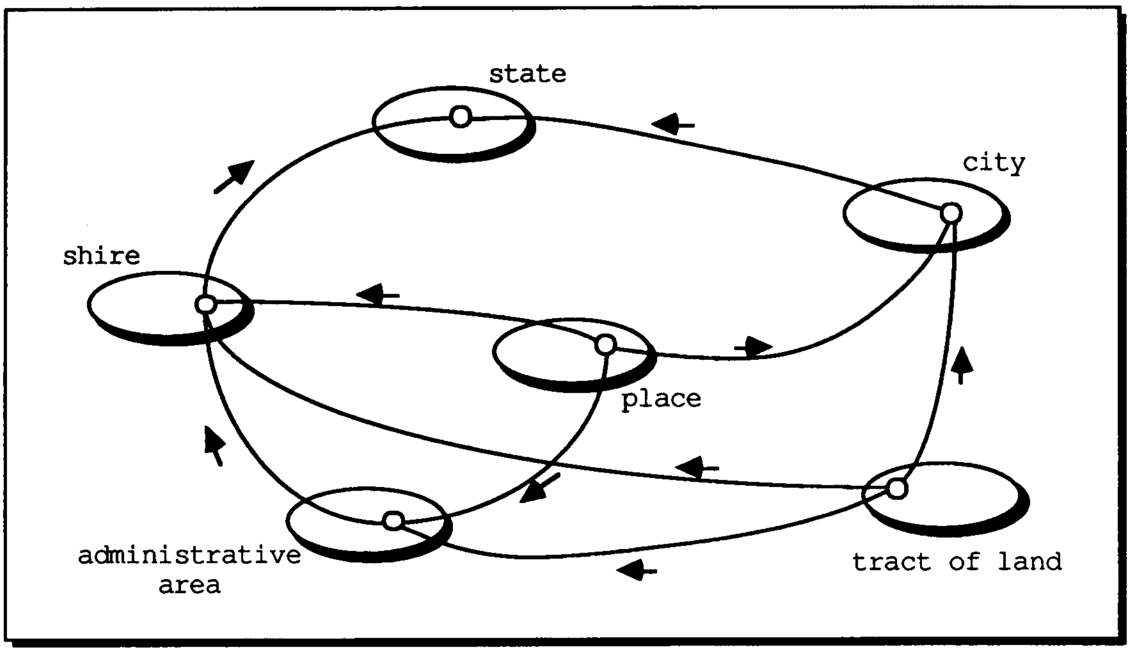
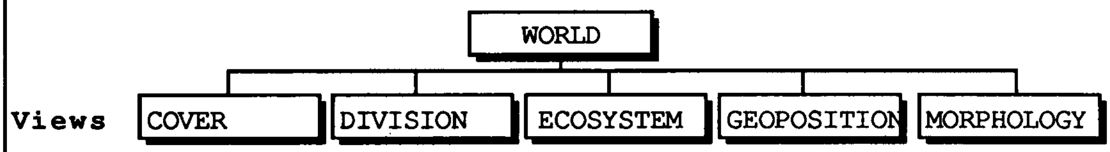


Figure 19: Relationships between administrative units

'cover', 'division', 'ecosystem', 'geoposition', and 'morphology' (Figure 20). The domain was established after extensive identification of features from topographic maps. The methodology uses 'world views' as a means of examining individual entities from a single perspective. For example, a road is an entity which covers part of the earth's surface. It can be classified in a world view called "cover", a view with a defining characteristic of material at a location on or near the surface of the earth. Other features in the view "cover" include "building", "bridge", "railroad", "forest", "rangeland", etc. A "country" cannot be a feature in the view "cover" because it is not covering material on the earth's surface. It is an example of a political entity and thus can be viewed as one of many divisions of the earth's surface independent of the actual material on or near the earth's surface. Other examples of features in the view "division" include "state", "city", "reservation", "census block", etc. Each view can be subdivided into subviews (Figure 21).

While the methodology is innovative, it clearly reflects the structure of graphic map products. An alternate approach would be to have *world views* related to functional categories as shown in Figure 22. The alternative approach is more applicable to *real-world* feature categories and corresponds to grouping commonly used in land inventories. These *views* will be analysed and discussed in the following chapter.

Apart from categorizing the domain of features, aspects of perception (scale relevance) seem to be inadequately addressed by researchers. Rhind (1988) notes that 'existing computer geographic information systems (apart from Domesday) are entirely or very substantially based upon digital storage of coordinate data and their attributes - essentially low level conceptualizations of the objects under consideration". He observes that "human beings evidently store multiple levels of conceptualization of objects, sometimes in a 'soft' or 'fuzzy' fashion". It seems that aspects of this conceptualization can be defined using adaptions of Rossmeissl's 'views' and McKeown's 'concepts' to manage data from 'scale related' views. This topic will also be discussed in the following chapter.



Cover This world view reflects physical or material features at a location on or near the surface of the earth.

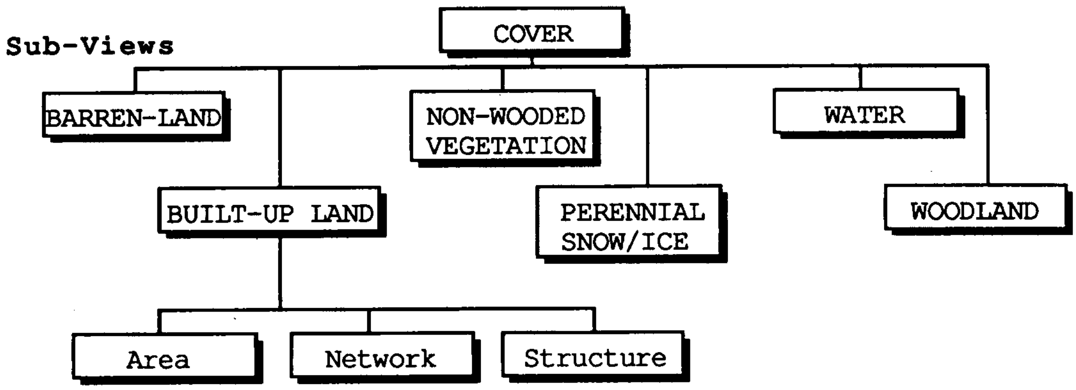
Division This world view reflects cultural demarcations of the earth's surface for a particular purpose or separations resulting from human activity.

Ecosystem This world view is based on the climate, vegetation, soils, and other controlling environmental factors which result in unique ecological units.

Geo-position This world view reflects measurement data about the earth's surface and contains points or lines on the earth or its representation for which location, relative to a particular datum, is well known.

Morphology This world view is based on the form of the land. The features are those landform features which are named, labeled, or symbolized on maps.

Figure 20: Rossmeissl *et al* ' 'world views'



Barren land	Cover composed of bare rock, sand, silt, gravel, or other earthen materials with little or no vegetation.
Built-up land	Structures and areas associated with intensive land use.
Area	Cover of intensive use with much of the land covered by constructions.
Network	An interconnected set of constructions used for transportation or communication.
Structure	A construction used for a special purpose.
Non-wooded vegetation	Cover composed of a natural or cultivated plant cover of grasses, brush, shrubs, or other non-wooded vegetation.
Perennial snow/ice	Cover composed of snow or ice
Water	Cover composed of flowing or standing water, impounded or naturally occurring, with channels or basins that are naturally occurring.
Woodland	Cover composed of a natural or cultivated plant cover of trees.

Figure 21: Rossmeissl *et al*' 'world sub-views'

Regional Administration	Includes political, administrative, institutional, statistical facilities and regions; as well as reservations, parks, monuments, etc.
Population	Includes places of human habitation and occupation eq residential, commercial, religious,cultural,entertainment, recreational,educational,etc.
Road Infrastructure	Includes roads, junctions, bridges, overpasses, and related features,etc.
Rail Infrastructure	Includes lines, marshalling yards,bridges, and all related features, etc.
Air Infrastructure	Includes airfields, facilities, navigations aids, etc.
Sea Infrastructure	Includes port facilities, jetties, piers, sea control features, channels,canals,etc.
Telecommunications	Includes communication faclities, structures, networks, etc.
Electricity / Fuel	Includes power plants, facilities, and networks for generation and distribution of power and fuel.
Water Resources	Includes facilities and networks for storage and distribution of water resources.
Industry	Includes manufacturing, mining, agricultural facilities; extraction and disposal complexes; etc.
Health / Medical	Includes hospitals, research institutions, aid posts
Physiography	Description of terrain
Oceanography	Includes environments of the oceans
Vegetation	Includes natural and cultivation plant life
Climatology	Climatic phenomena

Figure 22: World view categories

5.5 Geographic location

The distinguishing attribute of geographic phenomena is location on the earth's surface. That is, all geographic features can be located and referenced by a coordinate system.

5.5.1 The shape of the earth. Unfortunately, the earth is not a simple shape. In reality, the earth is a complex geometric figure. The figure of the earth is unique and can only be described as being geoidal, meaning earthlike. It can be defined by an equipotential surface corresponding to undisturbed mean sea level in both the sea and in hypothetical frictionless channels criss-crossing the land masses. Because of the variations in the density of the earth's constituents and because the constituents are irregularly distributed, the geoid generally rises over the continents and is depressed in the oceanic areas. It also shows various other bumps and hollows that depart from the "average smoothness" by as much as sixty metres. The determination of the precise figure of the earth is part of the responsibility of the science of geodesy (Robinson et al, 1978; Clark, 1969; Bomford, 1971).

The geoid is deformed from approximating a sphere by the rotation of the earth. Because it spins on an axis, the earth is bulged in the equatorial area and flattened in the polar regions. The actual amount of flattening is about 21.5 km difference between the polar and equatorial radii. For precise positioning, a regular geometric figure must be used. The figure used in geodesy and mapping is an ellipsoid. The determination of the size of the ellipsoid of revolution has long been a problem for geodesists. Until the advent of satellites, the size was determined by analysing networks of control points based on ground and astronomical observations. The resultant mathematical figures were optimized for localized portions of the earth's surface. For example, the figure used for Australia is known as the Australian National Spheroid (ANS) and has an Equatorial semiaxis (a) of

6,375,608.74 metres and a Polar semiaxis (**b**) of 6,364,924.86 metres (1966 adjustment).

The first use of satellites for surveying occurred in 1960s, however it is only in recent years that global positioning systems have been used in national surveying programs. As the technique implies, this method results in global location with the shape of the ellipsoid determined to provide an optimum figure for the earth as a whole. For example, the spheroid known as World Geodetic System 1972 (WGS72) has an Equatorial semiaxis (**a**) of 6,380,687.23 metres and a Polar semiaxis (**b**) of 6,364,900.27 metres.

These differences (refer to Figure 23 for a comparison of difference for the Australian continent) in geometric size of the earth need to be considered by developers of geographic information systems. Clearly location on one spheroid can be transformed to any other spheroid, but the selection (by an organization) of a default option in datums might be influenced not only by technical issues but institutional issues, particularly when, say, land ownership and control is based on a particular coordinate reference system.

5.5.2 Coordinate systems. Coordinates are a convenient method of recording position in space. They may be used to locate position in two (or three) dimensions, such as a point on a graph. An extension of this method to map use allows the location of a place by its *grid reference*. Coordinates can also be used as a convenient way of solving certain geometrical problems.

One such problem is that of delimiting the current status of property ownership. The cadastral parcel is an unambiguously defined unit of land within which unique property interests are recognized. While local monumentation constitutes the legal basis to the measurements, cadastral surveys are usually referred to the geodetic reference framework. The coordinates are obtained by land surveying techniques with accuracy specifications expressed in terms of traverse misclosures or boundary tolerances (National Research Council, 1983).

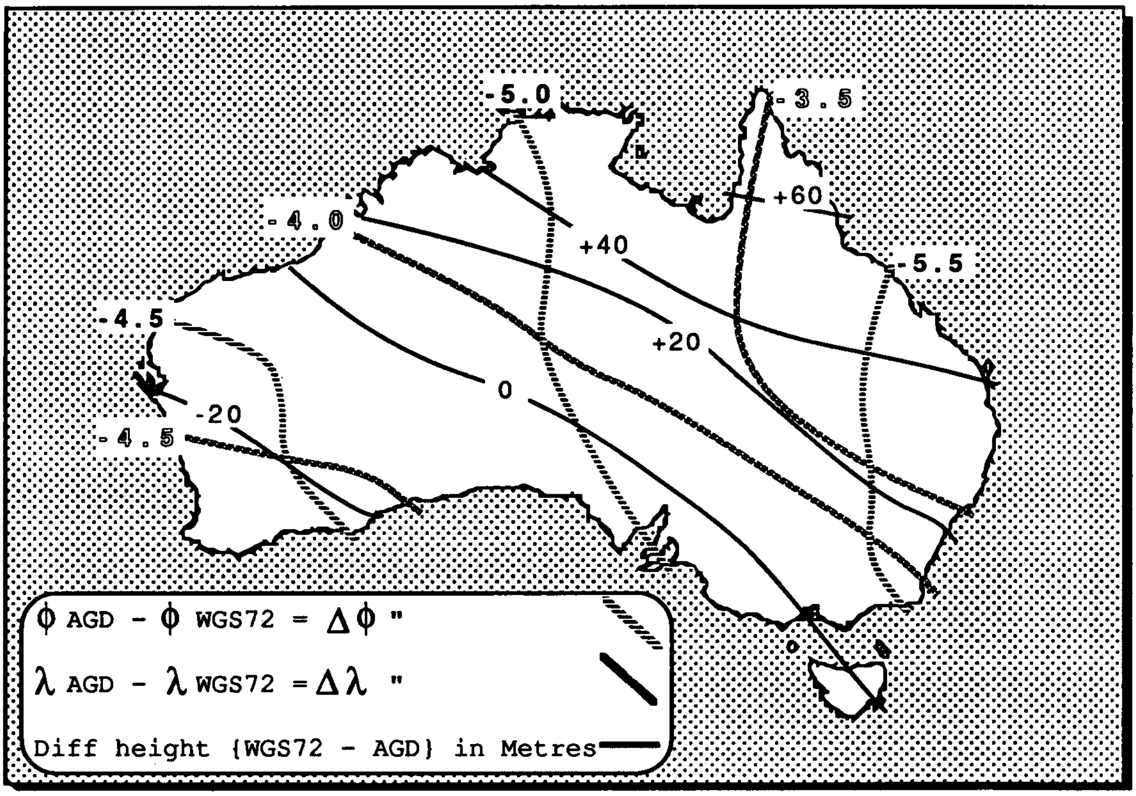


Figure 23: Differences between the Australian National Spheroid (Australian Geodetic Datum) and World Geodetic System 1972

However, the management of land and analysis of the terrain involve a balance between diverse factors of the natural environment and competing human interests and the use of such data must integrate data from diverse sources. These topics have been the subject of development in **geographic information systems** and **land information systems** for over a decade. In general, *topographic* maps have been used as *base maps* for these systems and a number of researchers have investigated aspects of accuracy for map overlay processes (National Research Council,1983; Chrisman,1982; Chrisman,1983; Chrisman, 1987b; Goodchild, 1978; NCDCDS, 1987; Vonderhoe and Chrisman, 1985).

These notions of *accuracy* and *error* are of concern to all organizations that process and disseminate geographic data, but in particular, to those that merge data from different data sources. The dominant trend amongst developers of *geographic information systems* and *land information systems* is to use existing maps for source data. Recent articles (Lynch and Saalfeld, 1985; Rosen and Saalfeld, 1985; Lupien and Moreland, 1987) describe techniques for merging different data sets. The technique is known as *conflation* and is defined as "combining of two digital maps to produce a third map file which is 'better' than each of the component sources" (Lynch and Saalfeld, 1985). Whilst such a 'rubber-sheeting' technique might solve a short term problem of establishing digital data bases, and, perhaps, improve attribute information, the problem of *error* and the definition of *quality* remain. This is so because each map merged has its own *lineage* and *locational* qualities. Without careful control it is possible that the combined product could be worse than any of the individual maps. It seems, however, that *topographic maps* (produced by the major mapping organizations) would have the best geometric accuracy because of production procedures and coordinate systems used [22].

Most large-scale topographic maps show one or more systems of rectangular coordinates. One system that has become widely used is the Universal Transverse Mercator

---

22 Technical aspects of map grids and projections are only superficially covered in this thesis. For further details refer to Robinson, Sale and Morrison, 1978; Maling, 1973; Richardus and Adler, 1972; Snyder, 1983; ASP, 1980.

Projection (UTM) grid system. The grid system and the projection on which it is based have been widely adopted for topographic maps, referencing satellite imagery, and other applications that require precise positioning.

Even though standard series topographic maps are produced according to prescribed procedures and conform to documented standards, the data has variations in quality and accuracy. Content and attribute quality depends on the age of source mapping photography and field verification for which dates are generally published in legend panels. (When digitized these dates are not necessarily recorded onto the digital files.) Positional accuracy is less clearly definable and varies across any map sheet. Because topographic maps are produced to prescribed standards, this positional accuracy is often stated as an average, e.g. "Horizontal map accuracy of 90% of well defined detail is within +/-14 metres of true position" and "Vertical accuracy of 90% of well defined detail is within +/-4 metres of true elevation" (which fall within the defined standards). These errors (as schematically shown in Figure 24) are composed of errors due to:

a. survey control error;
b. photogrammetric transfer and identification errors;
c. aerotriangulation errors (refer to ASP,1980);
d. photogrammetric, or manual, data acquisition (digitizing) errors;
e. output (plotting) errors; and
f. map platemaking and printing errors.

Each of these sources of error are subject of research and are not addressed in detail in this thesis. Nevertheless, the real quality of data cannot be quantified using simple descriptive labels. In addition, accuracy requirements are different for specific applications and the recording of *quality* is best defined under the concept of *truth-in-labelling*. The goal of this concept is to communicate information on *fitness for use*, rather than fixing

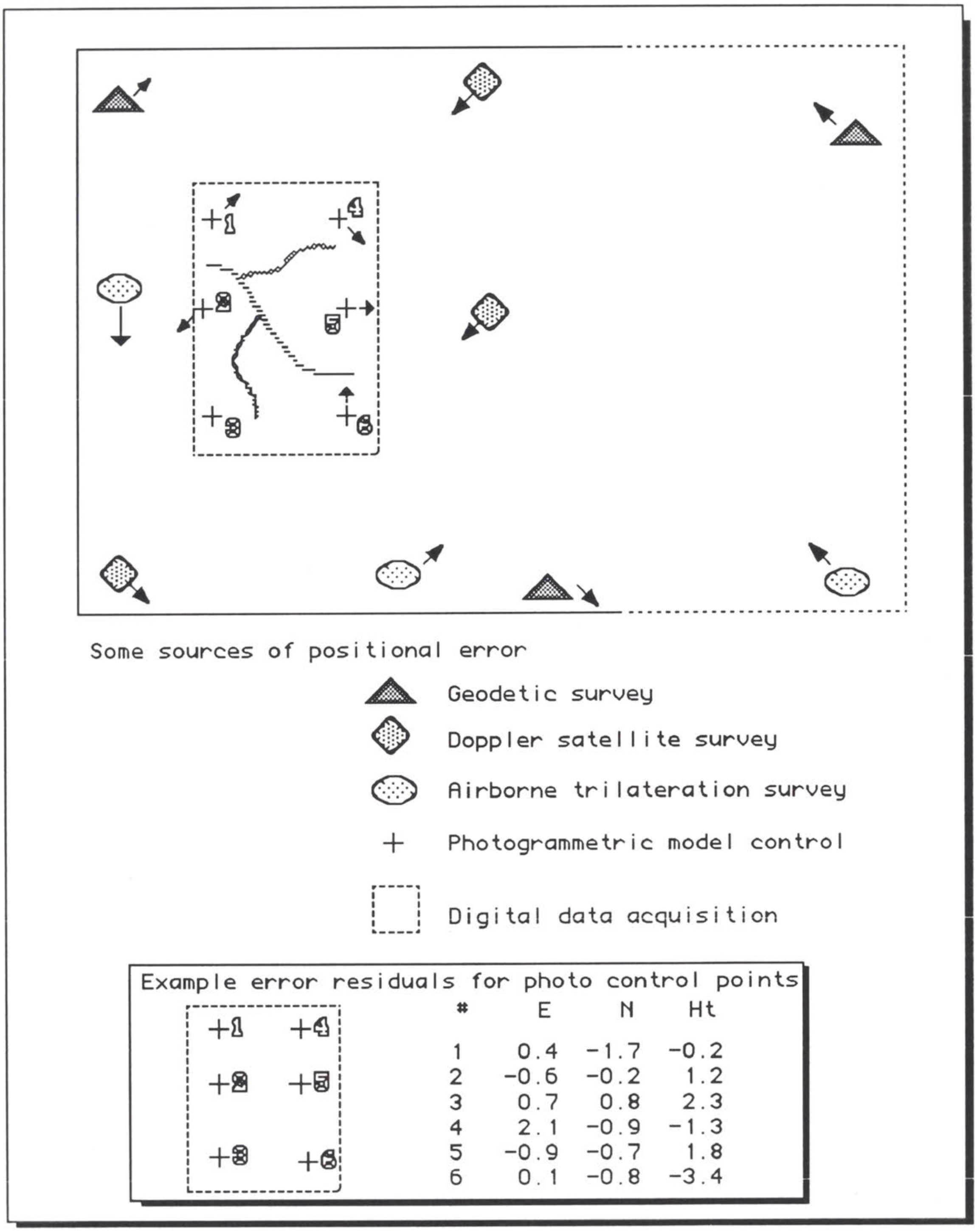


Figure 24: Positional errors as accrued in data acquisition

arbitrary thresholds of quality (NCDCDS 2 in Moellering, 1986; Moellering, 1987; Williams, 1987; Figure 25).

Geographic location is not, however, a static measure. Our planet is a *living and dynamic* entity. Geographic location can be affected to varying degrees by geophysical factors such as meteorological conditions and the very movement of the earth's surface.

5.6 Geophysical considerations

Smith (1972) suggests that the majority of geologists accept as a fact that the present distribution of the continents results from the breakup and joining together of previous distributions of the continents. This process, known as *continental drift*, has probably acted for a very long time, perhaps ever since the Earth first had a crust. Oxburgh (1972) suggests that continental drift along with the concepts of *sea-floor spreading, crustal structures* and world patterns of seismic and volcanic activity are part of a unified concept of *plate tectonics* [23].

5.6.1. Plate tectonics. While it is not within the scope of this thesis to analyse fully the concept of plate tectonics, the topic is mentioned in that it recognizes that the "entire surface of the Earth comprises a series of internally rigid, but relatively thin (100-150 km) plates. Although the size of the plates is variable, much of the Earth's present surface is occupied by half a dozen or so large plates. These plates are continuously in motion both with respect to each other and to the Earth's axis of rotation. Virtually all seismicity, volcanicity and tectonic activity is localized around plate margins and is

----

23 The term *plate tectonics* was first coined in 1967 by W.Jason Morgan of Princeton University. Morgan developed ideas of J.Tuzo Wilson of Toronto concerned with the relationship between oceanic ridges and transform faults, and suggested how the shape of plates could be determined and their movement predicted. In the meanwhile, D.P.McKenzie of Cambridge and R.L.Parker of the Scripps Oceanographic Institution arrived independently at similar concepts by the study of earthquake first motions in the north Pacific Ocean (Smith, 1972).

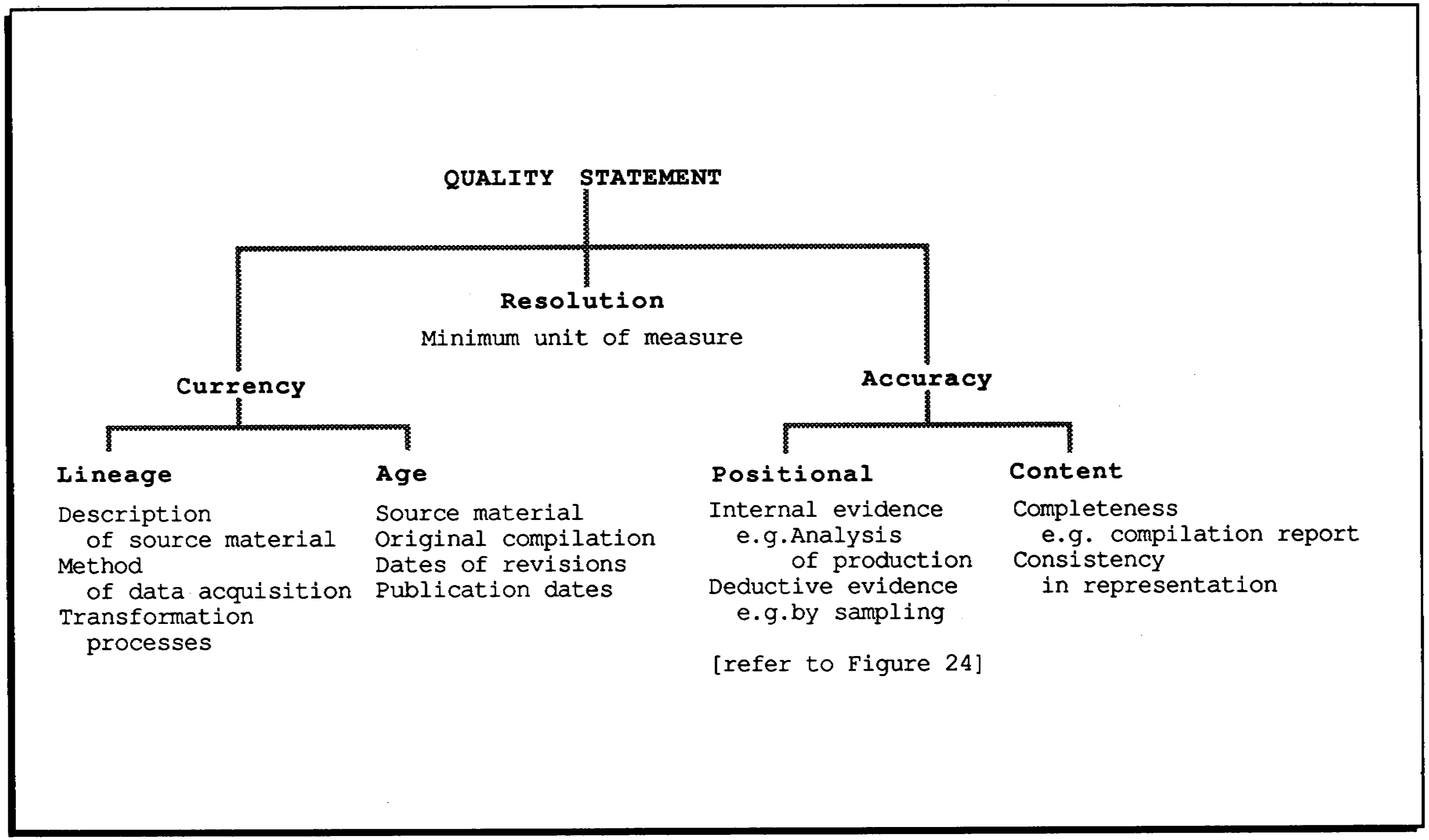


Figure 25: Data quality statement

associated with differential motion between adjacent plates. Spreading occurs symmetrically at ridges at rates ranging from between 1 cm and 6 cm per year and at ocean trenches crust is consumed at rates of from 50 to 150 mm per year" (Oxburgh, 1972). It is estimated that the plate on which Australia lies is drifting north at the rate of approximately 130 mm per year.

While this order of measure may seem to be trivial, it may or may not, have significance, depending on the use required of geographic data. Such an application might be the siting of a sensitive transmitter. Nevertheless, this tectonic plate movement provides just one more factor in the assessment of errors. Apart from plate movement, there are other geophysical factors that have significant bearing on geographic location.

5.6.2. Volcanic activity and earthquake activity. Volcanicity is the process by which matter is transferred from the Earth's interior and erupted onto its surface. The oldest rocks exposed on the surface of the Earth were produced by volcanic activity. So, volcanoes were active 3500 million years ago and, although the intensity of activity has waxed and waned through geological time, their products form, at the present time, most of the oceanic and part of the continental crust. Volcanoes are undoubtedly one of the greatest natural hazards to life on this planet. It is therefore a strange natural quirk that, without them, the water brought from the Earth's interior by volcanic activity has allowed the creation of the hydrosphere and atmosphere (Gass, Smith and Wilson, 1972). Wright (1972) further notes that there is good correlation between earthquake activity and volcanic activity and points to the distribution around the Pacific margin. Such activity is ongoing and although some volcanoes are old, others are new as is the case of Surtsey, south of Iceland, which was not in existence before 1963. Wright notes that "we must realize that the islands formed by these volcanoes are merely the summit regions of great mountains rising from the ocean floors, which may exceed 10000 metres in total height".

Although the continent of Australia is not characterised by volcanic activity, the region to the north, namely Papua New Guinea and Indonesia is prone to both volcanic and earthquake activity.

Discussion in the preceding paragraphs supported the assertion that our planet is a mobile and dynamic body. Some of the movements mentioned may not necessarily affect operational geographic information systems, apart from changes in terrain due to volcanoes and earthquakes. Such activity might, however, result in landslides and avalanches that could affect habitation, whereby it would be desirable to know the relationships between man's infrastructure and these physiographic phenomena.

Consider, as an example, the siting of a communication tower in the Rabaul area of Papua New Guinea. It would be desirable to select a site that had vehicular access from Rabaul and from where visibility was maximized. But should the tower be placed on an active, or indeed, dormant volcano? Probably not, because communications would be critical if an eruption did occur (the last eruption in the Rabaul area was in the early 1970s). There would of course be other vital factors in the siting of such a facility. One such factor might be the direction of prevailing winds. These winds might carry ash over the communication facility thereby minimizing its effectiveness. Another factor might be the creation of tidal waves and their effect on low lying areas (e.g. the causeway to Matupit Island and airfield was cut by sea activity during the 1970s eruption) [24].

Temporal phenomena have generally been ignored to this point in time by GIS evolution. Other temporal phenomena receiving little research are aspects of weather and tidal change. Up until now meteorological characteristics and ocean currents have not been addressed in GIS literature, but each affects applications of geographic information significantly.

---

24 This example has been dramatized for purposes of demonstrating the scenario. Volcanoes in the Rabaul area last erupted in the 1930s. However, an offshore earthquake did occur in 1973 and this gave rise to a *tsunami* which damaged low lying areas and cut the Matupit Island from the main island of New Britain.

5.6.3. Meteorological effects and tides. Man's life is affected greatly by the physical elements such as rains, floods, fire, the ocean, and so on. The use of the land can be modified greatly by such events. This aspect can be demonstrated by observing the terrain in northern areas of Australia with respect to vehicle movement. The equatorial monsoons create the two seasons known locally as the 'Wet' and the 'Dry'. Huge expanses of the country, including constructed roads are not trafficable in the 'Wet' whereas, the savannah areas of the north are easily traversed in the 'Dry'. Similarly, the coastal regions of the northern coastline are in some areas characterised by tidal ranges of up to 10 metres; so, even, on a daily basis cross-country movement can range from easy to impossible. Few models exist for these types of phenomena, and even fewer, if any, have been incorporated into geographic information systems.

5.6.4. Isogonic information. One further geophysical phenomenon that has yet to be considered for inclusion is that of the Earth's magnetic field. The Earth acts like a giant magnet with its magnetic field running approximately north and south. The angular difference between true north and magnetic north is called *magnetic declination*. Lines of constant angular difference between true north and magnetic north are known as *isogonic lines*. Magnetic declination can be predicted for any point on the Earth's surface even though the magnetic declination for any given point is always changing. This change is due to the magnetic *poles wandering* but this movement is in a predictable manner. Knowledge of isogonic information is essential for navigation which uses a magnetic compass.

The preceding discussion related to temporal aspects with respect to natural phenomena. But the description of geographic phenomena is also characterised by temporal aspects relevant to cultural or made made phenomena.

5.7 Temporal aspects

Time can be defined only in reference to some ongoing process. Environmental features change over time in two ways. First, the *state* of features is always changing. The soil erodes, in some regions lakes freeze while in other regions lakes dry up, and living things grow old and die. Secondly, the spatial *position* of some features also changes over time. Some things are self mobile, some disseminate offspring, and others are moved by external forces. The result of this diffusion of objects and ideas through space is continual environmental change (Muehrcke, 1978).

Change is not unique to the natural environment. The cultural environment is also in a continual state of change. The population of the Earth is ever increasing and along with movements in population, the result is that towns and cities are continually being modified. New subdivisions are constructed; older parts of cities are constantly being redeveloped; new towns are planned and constructed; and other towns and communities decay and die. In addition, man's infrastructure - administration, institutional, commerce, industry, road network, rail network, air network, sea facilities, power and fuel facilities, and health and medical services - is continually being modified. The establishment of procedures and techniques by mapmakers and geographic information system developers to adequately monitor these changes is still a matter of concern.

Muehrcke (1978) observes that "considering the significance of time, it seems incredible that it is rarely treated as an essential component in mapping. Map makers have treated time casually (if at all) simply for the sake of convenience, not because time is an inconsequential concern for the map user. In fact, time is probably the most important facet of our environment - even more crucial than space. We can learn to cope with spatial problems, but there is nothing we can do to stop time. Like it or not, we and everything around us are changing, second by second."

5.8 Summary

This chapter commenced with a general discussion of real-world phenomena and noted that an understanding of environmental cognition is necessary to properly describe the real world. Discussion followed on contemporary issues in research related to spatial data models and schemas for categorizing and describing real world phenomena. As little emphasis is being placed on geographic location (except for geometric relationships) in the literature, characteristics of the Earth's surface and issues in establishing reference systems were analysed. This discussion lead onto issues of *quality* and then geophysical considerations not yet incorporated into geographic information systems. These characteristics include plate tectonics, volcanic activity and earthquake activity, meteorological effects and tides, isogonic information, and temporal aspects.

Under the *expert system* approach, the aspects of *data reality* discussed in this section correspond to a formal definition of *public knowledge* and constitute a 'geographic knowledge base'. Modelling such a geographic knowledge base and formalization of structures will be investigated in Chapter 7, GEOGRAPHIC KNOWLEDGE-BASES. Having established this geographic knowledge base, it should be possible to extract information according to different interpretations (or cognitive views) aligned to the use of the information such as that alluded to in paragraph 5.6.2.

Chapter 6

ASPECTS OF COGNITION

"What do you consider the largest *map that would be really useful?'*

'About six inches to the mile.'

'Only six inches!' explained Mein Herr. 'We very soon got to six yards to the mile. Then we tried a hundred yards to the mile. And then came the grandest idea of all! We actually made a map of the country, on a scale of a mile to the mile!'

'Have you used it much?' I enquired.

'It has never been spread out, yet', said Mein Herr: 'the farmers objected. They said it would cover the whole country, and shut out the sunlight! So we now use the country itself, as its own map, and I assure you it does nearly as well.'

6.1 Introduction

This extract from Lewis Carroll's *Sylvie and Bruno Concluded* demonstrates the problem of interpreting the environment. Not only do users of geographic information perceive features differently, but also perceive scale related representations differently. The presentation of geographic data and awareness of geographic phenomena are influenced by a user's theme or interest and the resolution or level of detail required for a particular purpose or by a particular analysis.

Moore and Golledge (1976) suggest that "cognition refers to awareness, attitudes, impressions, information, images, and beliefs that people have about their environments. These environments may be directly experienced, learned about, or imagined. Environmental cognition refers to essentially large scale environments, from national and geographic regions down to cities and spaces between buildings, to both built and natural environments, and to the entire range of physical, social, cultural, political, and economic aspects of man's world. Cognition of these environments implies not only that individuals and groups have information and images about the existence of these environments and their constituent elements, but also that they have impressions about their character, function, dynamics and structural interrelatedness, and that they imbue them with meaning, significance and symbolic properties".

Muehrcke (1978) defines a map as *'any geographical image of the environment'.* He suggests that the definition has the advantage that within one definition we can encompass such diverse types of maps that we hang on walls or hold in our hands and, at the other extreme, those which are held solely in our mind. Muehrcke comments that "the maps in our minds, known as *cognitive* or *mental* maps, are often sighted in definitions. Yet they are really the ultimate maps, because they are the ones we use to make decisions about the environment. Thus, our mental images are the most important maps of all".

Mental maps can range from something highly structured and precise to something very general and impressionistic. Geographic knowledge extracted from these images may be detailed and applicable to such applications as the building of a road, a flood control system, or almost any other constructive endeavour. In some instances a less detailed interpretation of the geographic domain is applicable. Such instances might include the assessment of flood plain hazards, soil erosion, land use, population character, and so on. An even less detailed knowledge, or merely an overview, might suffice where broad earth patterns or relationships are required.

Mental maps are used by everybody on a daily basis. The simple process of travelling to work or school involves an evaluation of the environment and interpretation and analysis of the environment. But these mental maps are as Robinson *et al* (1978) suggest "unique to each individual. If one person were to describe a mental map to someone else, we may assume that the description would evoke a more or less similar image if all conditions were favourable. It would obviously be much easier, however, to substitute a drawing of the mental map for a word description in order to take advantage of the more efficient method of visual communication."

6.2 Traditional cartography

Traditionally, *cartography* has been accepted as *the art, science and technology of making maps of the earth and other celestial bodies* (Robinson *et al,* 1978). Cartography has developed a body of theory and practice that includes a series of processes common to the making of all maps. Maps are representations of parts of geographic reality and, as such, processes are required for *scaling, generalization, symbolization* and *transformation.* Scale is important because it sets a limit on the information that can be included in the map and on the degree of reality with which it can be delineated. Generalization is concerned with the elimination of nonessential detail of particular features, while retaining the characteristics of the features. Symbolization includes the use of symbolic items, icons, and notation to communicate key features not able to be represented in a plan form. Transformations are required to convert data from spherical surfaces to planar surface and to achieve properties related to direction, distance, area and shape.

Cartography is usually thought to consist of two classes of operations. One is concerned with the preparation of a variety of general maps used for basic reference and operational purposes. This category includes large scale topographic maps of the land, hydrographic charts, and aeronautical charts. The other division includes general reference and educational products as well as thematic maps of all kinds and atlas maps, road maps, resource management maps, regional planning maps, utilities maps, etc. All of these map products are, however, subject to compromise since they have been produced by a cartographer's interpretation of the geographic reality.

Technological advances in computer systems over the past twenty years have provided mapmakers and land resource managers with capabilities to perform increasingly sophisticated mapping and geographic analysis functions. For much of this period development has followed two distinct streams - one concerned with automated mapping and the other with land and natural resource management (refer to Chapter 2). Automated mapping systems (or computer-assisted mapping systems) are those that employ computer technology with an emphasis on computer graphics and with map production and with only limited capability for processing non-graphic attributes. These systems have been used, in the main, by organizations involved with the production of topographic maps and general reference maps. These automated mapping systems are differentiated from *geographic information systems* and *land information systems* that combine linkages allowing complex query, map overlay, polygon processing, and spatial modeling operations.

6.3 Geographic information systems

Geographic information systems have evolved as a means of assembling and analyzing diverse data pertaining to specific geographic areas, using spatial locations of the data as the basis for the information system. In the broadest context, geographic information systems identify a user's data needs, and channel the data to the intelligence level at which decision-making takes place. Geographic information systems have been used for such diverse tasks as territorial control, natural resource exploitation, taxation and ownership monitoring, land use and infrastructure planning, land use zoning, land use and infrastructure design and construction, construction facility record keeping and management, development measurement, census of statistics, event monitoring, natural resource management, and monitoring of the environment (Dangermond, 1982).

Both streams - *geographic information systems* and *computer-assisted mapping* - have been evolving for two decades and until recently often viewed as non-compatible approaches designed for different markets. But today's mapping market is seeing a major shift toward decision support and operations management. Consequently, there is now a trend in research to integrate these two streams of development. This integration requires that geographic data be structured and organized such that it will be useful for multiple purposes ranging from the production of standard series maps through to use in 'decision support systems'.

In addition to series mapping capabilities [developed to a high level of cartographic quality in computer-assisted mapping systems (Gilbert and Rooke, 1987)] and facilities for land records management, service and utilities management, and resource management common to many geographic information systems, new generation systems are including advanced analytical tools. These additional capablilities include tools for overlaying different terrain views as well as analytical tools suitable for slope and viewshed assessment, route and corridor determination and terrain analysis (Figure 26).

6.4 Future directions

Although the capabilities of existing commercially available systems appear to be improving almost daily, there are still deficiencies in the systems. There are a number of points of concern. Many systems are still only ***toolboxes***. System developers are still leaving operational configuration of the systems to the users. How many users would know which algorithms to use and where, even if they did know which algorithms and techniques were available to them? Most users simply do not have the time to experiment and fine-tune systems after they have been installed. Many systems are still designed for specific, fairly narrowly defined projects (including area of coverage). This means that expansion of the original project is difficult to achieve and exchange of data still remains a problem.

Fundamental changes are required in design philosophy. Current design is influenced by the 'so-called' user needs. This approach creates almost as many 'one off' systems as there are users. Even though individual systems may perform certain functions - be they for urban planning, public works or lands records management - economically and efficiently, they may not necessarily serve the greater community at large. In many systems the specialist theme is organized well but other data is often grouped into 'base map data' or 'background' information, so the value of this data for other users or

- **Standard Products**
  - Series Mapping
  - Thematic Mapping
- **Management and Control**
  - Land Records Maintenance
  - Service and Utilities Management
  - Resource management
  - 'World Views' Integration
- **Planning and Modeling**
  - Slope and Viewshed Assessment
  - Environment Simulation
  - Route and Corridor Determination
  - Terrain analysis and evaluation
  - Geographic Searching
  - Proximity Determination

Figure 26: Some views of geographic information

purposes is limited. Future design philosophy should reflect the need to use data for a multitude of applications.

For example, public awareness of environmental issues has strengthened in recent times. This awareness will force certain proposed changes to the landscape to be publicly assessed for environmental impact. A component of this environmental audit is a statement on the visual intrusion of proposed landscape changes. As a consequence, projects such as road and railway construction, transmission line routing and mining as well as more dynamic phenomena as forestry will need to be environmentally judged prior to implementation. In fact, almost all environmental impact studies are applicants for geographic information processing technology.

The environmental issues are becoming more diverse. Incidents such as the 'Exxon Valdez' oil spill are making the public more aware of the need for environmental monitoring. Although the actual route of the Alaskan pipeline was a subject of geographic information system application, obviously the offshore route to the open ocean was not. Of course the environment is not restricted to 'land' or 'ocean'. The Lawrence Livermore National Laboratory's Atmospheric Release Advisory Capability is an emergency response system capable of addressing accidents in which radioactive material is released into the atmosphere. The system has responded to such real-world events as the Three Mile Island and Chernobyl reactor accidents, as well as satellite re-entries (Walker, 1989). A more conventional emergency response might result from some form of military activity.

Ball (1988) suggests that "there are many important ways in which geographic information system technology can contribute to defence planning and operations. There are in fact no other approaches which can provide any similar capabilities with respect to the efficient collection, storage, manipulation and retrieval of geographic data across the whole of north Australia and down to tactical requirements. The specific applications which relate to defence planning and operations are myriad and include the following:

a. the provision of comprehensive regional, continental, hydrographic and oceanographic databases to assist decision-making, such as cost-effectiveness evaluations of alternative projects;

b. the provision of terrain, infrastructure and environmental information for use in evaluating and selecting sites for new defence training areas, bases and facilities and other defence infrastructure development;

c. assessment of the environmental and socioeconomic impact of terrorist attacks on defence installations or catastrophes such as explosions of ammunition dumps and ignition of fuel depots;

d. informing the development of strategic plans for the defence of Australia, including the location and characteristics of major port and airfield facilities and major terrain features such as escarpments, rivers, and vegetation;

e. informing the design or selection of defence equipment (e.g. the use of terrain analysis to determine requirements for cross-country vehicles);

f. operational intelligence relating to movement (e.g. information on road surfaces, bridge construction and capacity, and cross-country trafficability); siting of communication, radar and electronic warfare systems; placement of weapons such as artillery, mortars and surface-to-air missiles; and battlefield operations (e.g. information on cover and concealment, fields of fire, and terrain and vegetation features suitable for ambush and envelopment);

g. support for coastal surveillance operations;

h. support for naval operations in Australian waters and possible areas of engagement".

The examples highlight and demonstrate aspects of geographic information introduced earlier in this paper and show that current systems are only being designed for a small subset of the geographic phenomena.

In addition to the analytical functions required by these applications, communication of geographic knowledge needs to be addressed in more innovative ways. Rhind (1988) suggests that "existing computer Geographic Information Systems (apart from Domesday [25]) are entirely or very substantially based upon digital storage of coordinate data and their attributes - essentially low level conceptualizations of the objects under consideration. Human beings evidently store multiple levels of conceptualization of objects, sometimes in a 'soft' or 'fuzzy' fashion. Experience often enables, say, a geologist to deduce provably correct conclusions from such 'soft data'. In the longer term, it seems essential that we extract such knowledge and analytical and modeling experience from human individuals, at least before they retire and the unpublished benefits of their lifetime's work are lost to posterity".

6.5 Communication of geographic images

Images and themes play an important role in people's perception of their world. For me *Darwin* is a modern, multicultural city of mid-size located at the northern approaches to our country. *Darwin* is also remembered for the event of 24 December 1974 - the night *Cyclone Tracy* devastated the city. This event reminds me of the climate and the impact that weather patterns have on northern Australia in general. The event also reminds me of the importance of knowledge of the infrastructure - details of hospitals, water resources, power and fuel, and air facilities. *Darwin Airport* is located about a quarter of an hour

---

25 The Domesday Project was conceived and developed by the British Broadcasting Corporation (BBC) as a commemoration of the 900th anniversary of the Domesdays Book: in 1086, King William 1 ("The Conqueror") completed a survey of England, recording, in some detail, land ownership, usage and value. The results of this survey were recorded in a book, still in existance in the Public Records Office in London; not only does it provide a valuable insight into life in 11th century England, but it also represents one of the earliest and most complete land surveys in the world. 900 years later, this exercise has been repeated in a collaborative project, led by the BBC; information covering a much wider range of topics over an increased geographical area has been compiled onto two interactive videodisks. The first of these disks, the so called 'community' disk, was compiled by nearly 1 million individuals and holds a wide range of information on different areas of the country. The second disk, or 'national' disk was compiled by a smaller team of people and contains pictures, data and text drawn from a range of official sources and accessible by topic (Mounsey, 1988).

out of Darwin on the Stuart Highway. However, my knowledge of the layout of the City of Darwin (situated on a peninsula extending into *Port Darwin*) reminds me that the airport is about 10 kilometres *north-east* of the city. My knowledge of *Darwin Airport* tells me that it is on designated air routes for both civilian and military aircraft; has the capability to handle the largest of aircraft; and has extensive ground services. Unfortunately, my knowledge of runway construction details and navigation aids is limited. In addition, my knowledge of the air infrastructure of the *Northern Territory* (or the *Top End* - a geographically recognizable concept) tells me that should Darwin Airport be non-operational, airports such as *Tindal* (approximately 300 kilometres to the south) might be used in an emergency. *Tindal* is accessed by road from *Darwin* via the *Stuart Highway*. This highway is a part of the national highway network. Along this section there are a number of low-level bridges and, of course, the ubiquitous 'road train' (the transportation characteristic of northern and western Australia).

The images and knowledge highlighted in this dialogue might seem to be abstract. However, it should be the aim of designers of the next generation of cartographic systems to formulate and organize their geographic information in a logical *concept and theme oriented* manner; having the structural and relational characteristics of the individual features defined. Issues of multiple levels of conceptualization of concepts and features, descriptions expressed and managed in a *fuzzy-topological* manner, and methods and techniques in conveying this knowledge, all need to be examined. In addition to the usual graphic displays and attribute presentation in the form of text and tables, today's technology is enabling us to impart knowledge in far more informative ways. *Pictures* of key features or general characteristics of the terrain can be stored in libraries (in much the same way as gazetteer information) and displayed digitally on monitors (Figure 27). Similarly, digital *sound* recordings of place names and area descriptions can be used to impart information far more effectively than screens of text (Figure 28).

Much information can be provided in a 'soft' or 'fuzzy' manner. Methods to

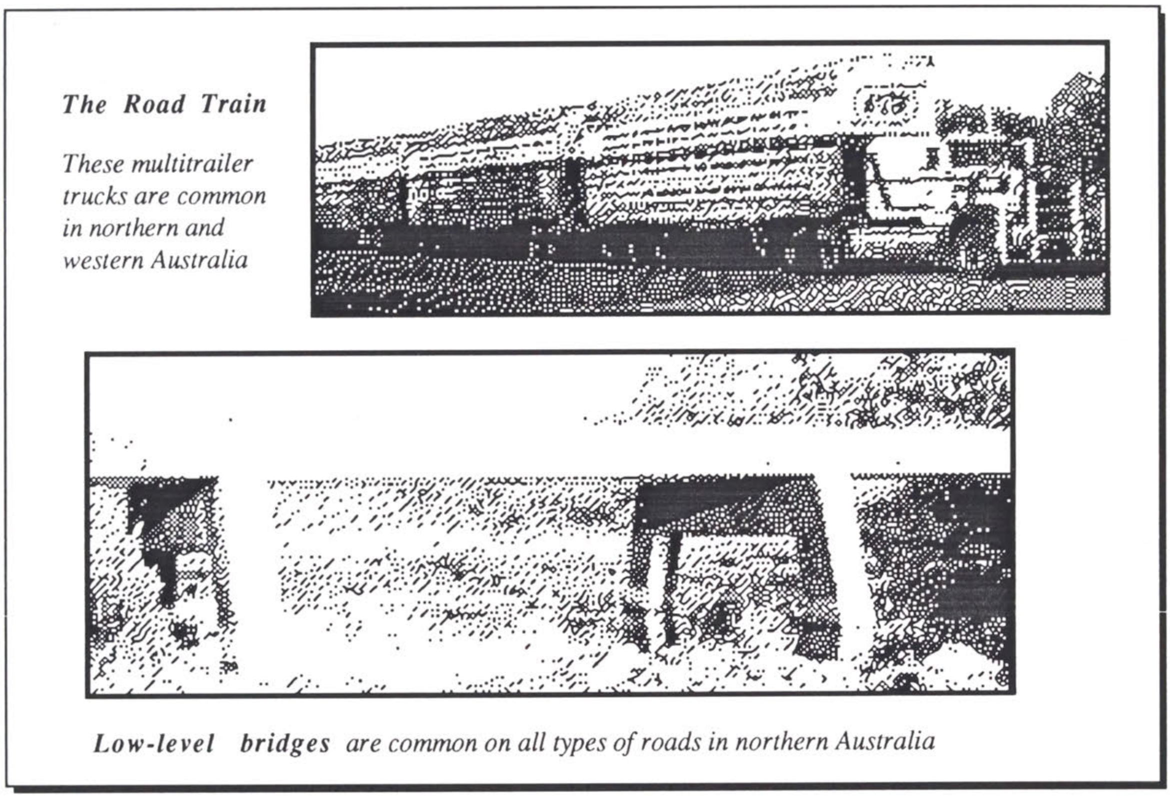


Figure 27: A photograph can 'be worth a thousand words'

Mataranka Homestead Resort *is located off the Stuart Highway some 10 kilometres east of the Mataranka township.*
The resort is principally known for its hot springs which have been developed for thermal bathing.

Figure 28: A sound recorded description can be more effective than text

communicate notions such as *near to, to the south of, just outside of* need investigation. In addition to the use of pictures, sound and 'fuzzy topology', *icons* - particularly of the style that are used on signposts - can impart important information. An example of the use of 'fuzzy topology' and icons can be seen in Figure 29.

Images also refer to levels of detail (Figure 30). But this level of detail may not necessarily be uniform across a particular region or through various themes of interest; in fact it is most unlikely that it will. Take, for example, the task of planning and communicating a trip from Darwin to Numbulwar. Initially one needs to assess administrative matters. In this case, Numbulwar lies within the Arnhem Land Aboriginal Reserve and so administrative information needs to be processed. Next, one would probably assess the approximate length of the trip and determine appropriate refueling places and points for enroute accommodation. Various levels of detail would be required for the road network. That is, it might only be necessary to provide an overview of the section between Darwin and the Roper Highway turnoff. The only ancillary information might be a general description of the terrain, such as "the section around Pine Creek is relatively rugged, the vegetation is moderately wooded while the section south from Katherine is flat with open savannah"; and details in specific places, such as the location and access to refueling points in Katherine and details of camping facilities at Mataranka Homestead Resort.

More detailed information would be required for the section east of the Stuart Highway to Ngukurr and even more between Ngukurr and Numbulwar. Firstly, the Roper Highway is a formed and maintained road throughout this first section but it does have some important low-level bridges and depending on the time of year, these and some sections of road may need to be analyzed. The second section is characterized by extensive areas of floodplain and so the actual route may vary depending on local conditions. Options might even include 'cross-country' travel whereby details of landform, hydrography, and vegetation would be essential.

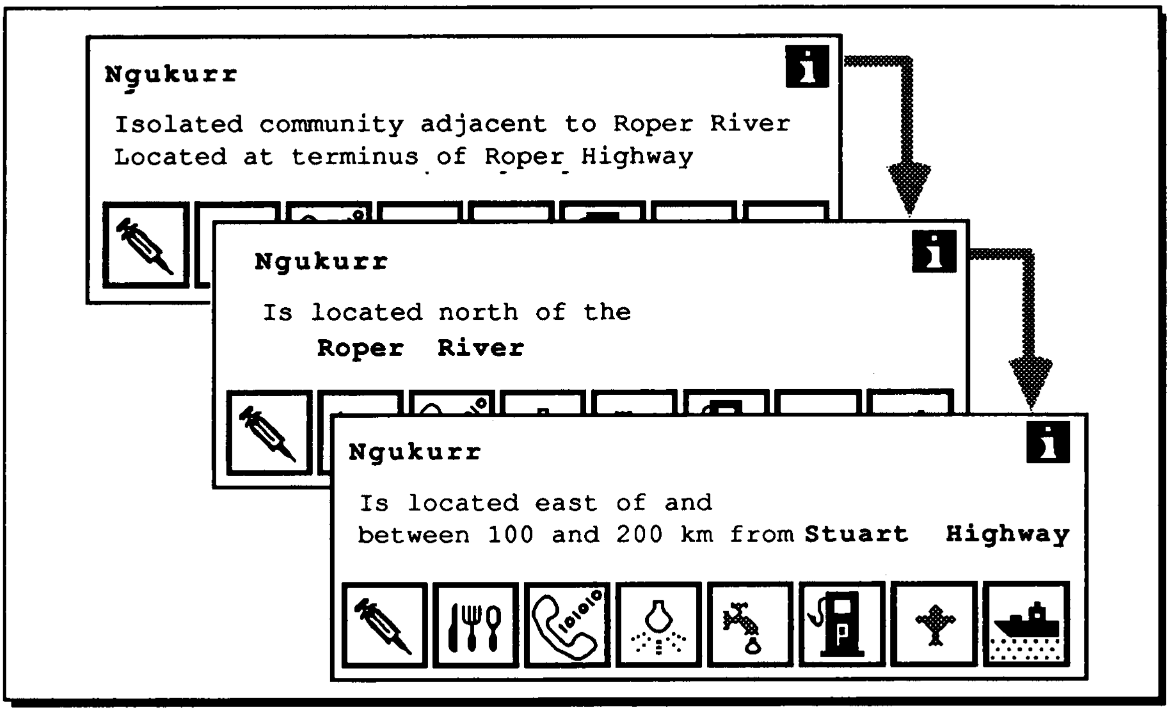


Figure 29: *Fuzzy* topology and icons

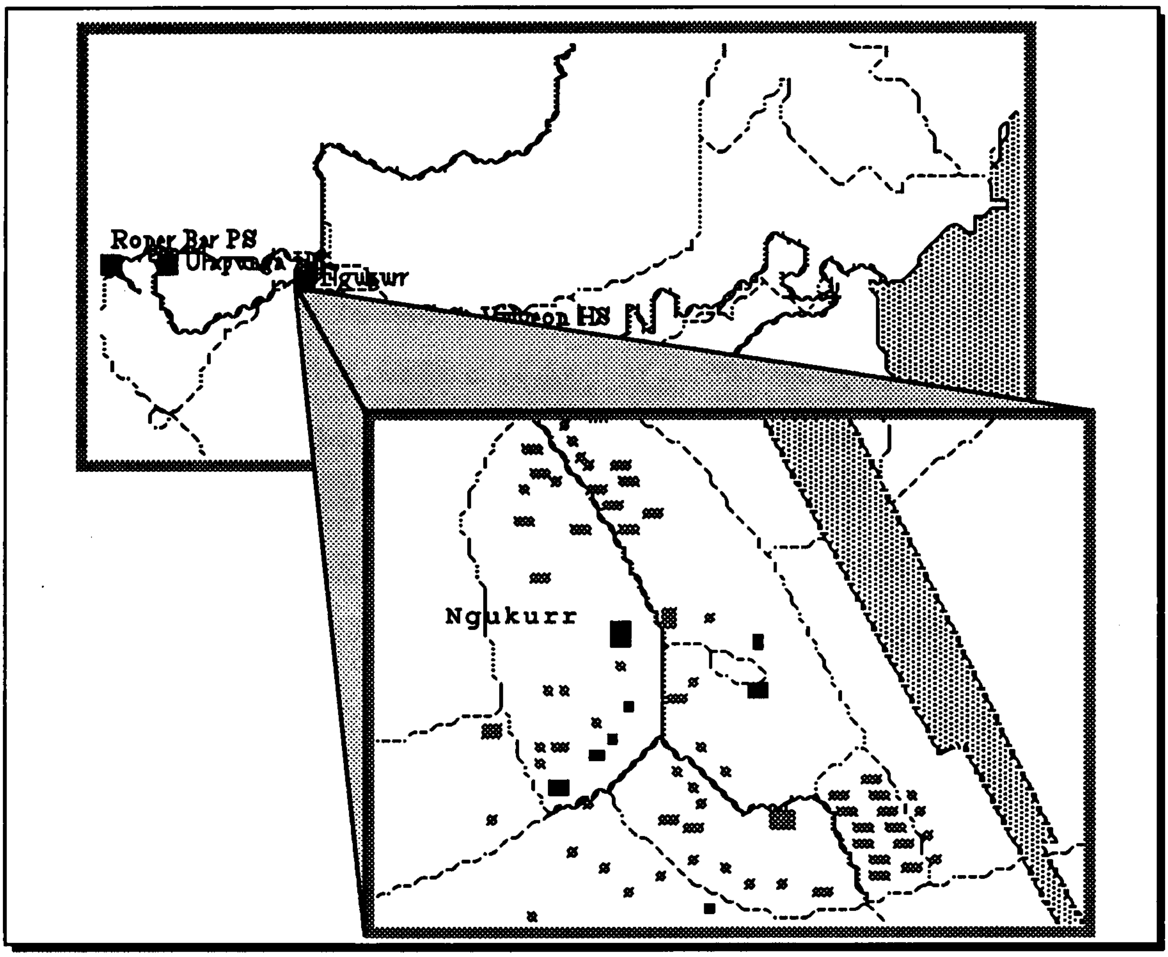


Figure 30: Multiple levels of conceptualization

In this dialogue, issues concerning variability in types and resolution of geographic information were raised. The over-riding point is that analysis of geographic information is not constrained to regular geographic units nor to fixed categories of scale. In response to this dilemma, Guptill (1989) conceives *seamless, scaleless cartographic data bases*. He suggests that "a seamless data base implies an ability to query, display, retrieve, or otherwise traverse the contents of a large spatial data base without limitations imposed by the spatial extent of the data. For example, a command to display the Mississippi River would yield the entire river, not just a portion of it. A scaleless data base implies an ability to make a transition from one level of detail to another appropriate to the scale of the display or precision of the data analysis. For example, select a feature, say Dulles Airport, and display its location with a point symbol at a scale of 1:2,000,000, zoom in on the airport, with runways appearing at a display scale of about 1:100,000, then, as the display scale increases, more detail, such as buildings, fuel tanks, and parking lots will appear".

6.6 Summary

This chapter commenced with somewhat abstract definitions of 'maps'. The theme of the chapter was concerned with *geographical images of the environment.* It was argued that conventional *cartography* and present *geographic information systems* were concerned only with a subset of geographic reality and that future systems should be more innovative by addressing more complex geographic problems and the communication of the results using a variety of methods, particularly as "public awareness of environmental issues has strengthened in recent times". The next chapter investigates the structure of geographic information that would permit *products to be constructed,* say using rules accessing geographic knowledge bases.

Chapter 7

GEOGRAPHIC KNOWLEDGE-BASES

7.1 Introduction

Chapter 4 outlined trends in digital cartography and geographic information system development. It was noted that development had been *evolutionary* and had been shaped by a rationalistic tradition. The chapter acknowledged changes in perception and definitions associated to the disciplines of geography and cartography. However, the theoretical aspects of cartography still replicate, in the most, standard and established procedures in the map production process, while the trends in data structures evolved from analysis of existing cartographic products.

Cartographic products are, however, derivatives of the representation of certain selected geographic phenomena. Subsequently, Chapter 5 examined the *phenomena of the real world.* The chapter outlined the most recent attempts to model *geographic reality* and then after observing that even the most recent research was formalizing cartographic (or derivative) structures, expanded on aspects of location and phenomena not yet addressed in detail. Chapter 6 discussed *cognitive views* of geographic phenomena and observed that the *hermeneutic* problem (or the problem of translation and interpretation) is a central problem of phenomenology.

This chapter discusses the structure of geographic information from a phenomenological viewpoint. That is, this component of the research is concerned with finding out **what** things are. Nyerges (1980) and Moellering (1983) observe that "it is only relatively recently that cartographers have come to realize that when one desires to work with cartographic information in the digital domain that the cartographic representation is only one fundamental aspect of the map information. Many other kinds of relationships have been recognized which are not necessarily graphic. Two distinct concepts of surface and deep structure exist in the cartographic domain. Surface structure of cartographic information is the graphic representation of the terminal elements which appear in the form of a map. However, there are many other explicit and implicit relationships between cartographic objects contained in the data that are not graphic. Deep structure relates to these relationships between cartographic objects that are not necessarily graphic. The relationships can be phenomenological, spatial, in some cases non-terminal graphic elements, or a combination of these. Such relationships are not evident from the surface structure". This notion of *deep structure* is fundamental to the creation of *knowledge-bases*. It is the aim of this chapter to extend this idea from cartographic data to geographic data. However, before endeavouring to describe **what** things are by using commonly used definitions of geography, cognitive views of geographic information, analysis of the domain of geographic features, interpretation of the domain, forms of representation and location, and sources of information, it is appropriate to examine knowledge representation concepts in general.

7.2 Knowledge representation

Several researchers have noted that artificial intelligence can play a role in the development of advanced geographic information systems. If we view geographic information systems as an application area for the use of artificial intelligence technology and approaches, there are several sub-areas of artificial intelligence that may hold promise such as knowledge representation and utilization, knowledge acquisition, and computer vision. McKeown (1987) suggests "tasks where artificial intelligence techniques may find utility are:

a. non-traditional representations of factual information based on semantic networks of information. Meta-knowledge about relationships of objects, normally reserved for application-specific systems, should be more closely linked with the topological properties and attributes of spatial objects and their relation to other spatial objects;

b. categorizing and unifying knowledge about multispectral classifications of specific types of remotely sensed imagery. Such knowledge is usually tightly coupled with systems that perform image analyses. A more general methodology would be to separate this knowledge from the data interpretation systems that use it. The spatial data base then becomes a repository for general knowledge that is accessible from a variety of applications;

c. integration of image analysis systems and other data with spatial databases so that the spatial database becomes a source of knowledge utilized during image analysis or classification as well as a repository of the partial and final results of the analysis."

Knowledge representation has long been a research issue in cartography with non-traditional representations and meta-knowledge being considered important. Global and local structures and multi-element characteristics have been discussed for more than a decade.

Nyerges (1980) points out that "many researchers contend that global data structures are impractical because large volumes of data are stored in main memory while checking topological relationships. In contrast, local processing of data, concerned only with sections of the model at any given time, proves to be beneficial because of reduced processing time and storage needs. Unfortunately, a local network data structure is not amenable to complex analytical operation at a global level. This requires global relationship specification". Nyerges further notes that "global network data structures are more suited for data base operation, especially operations undertaken in an interactive problem solving environment", and indicates that Brassel (1978) has proposed a global network data structure for multi-element map processing in which the 'node' is given the highest importance. These nodes (not necessarily topological) signify locations for phenomenologically important points.

Brassel (1978) illustrates desirable characteristics of multi-element map processing systems by examining the process of information retrieval from a traditional map via map reading. Brassel suggests that "in order to fully appreciate and interpret a map feature, the map user relates the feature to other map elements in its neighborhood and even to significant features at greater distances. Similarly, certain complex cartographic processes can only be performed in an appropriate manner if the global and local information is available to the cartographer. For example, quality hill-shading takes into consideration the local modulations of the terrain as well as the global characteristics of the overall mountain range; contour line generalization can only be satisfactorily performed in an appropriate manner if it is adjusted to the generalization of the nearby drainage pattern, road network, etc.; name placement requires adjustment to all map features in the neighborhood as well as some global considerations. An important requirement of such a structure is therefore its ability to provide for local links to other map elements as well as global references to significant features at larger distances". These characteristics demonstrate the problem of translation and interpretation, or the *hermeneutic* problem. Hermeneutics is a central problem of phenomenology. It is through an appreciation of the hermeneutic that we best come to see the importance of phenomenology for information system research.

Although the research by Brassel is over a decade old and that by Nyerges is just less that a decade old, the basic ideas are still current and still being speculated on, as in Guptill's (1989) 'Speculation on seamless, scaleless cartographic data bases', and other researchers investigating *micro* and *macro* interpretations of data. However, emphasis within the research community is still concerned with structuring and organizing map elements. Now, if we extend these fundamental ideas to the *real world* we first need to establish categories of features from the domain of geographic features.

7.3 The Domain of geographic features

Geography is concerned with the description of the earth's surface, treating of its form and physical features, its natural and political divisions, climate, productions, populations, etc. of the various countries (Haggett, 1972). Such descriptions are applicable from large scale environments, such as nations and regions down to cities and spaces between buildings, to both built and natural environments, and to the entire range of physical, social, cultural and economic aspects of man's world (Moore and Golledge, 1976). The representation of this description can be organized into a domain of features and this domain categorized into a set of **World Views** (as introduced in Chapter 5). These views should not be considered as authoritative or absolute but are suggested here as a first attempt to organize the domain of geographic features. It should be noted that phenomenology does not assert the existence of an absolute knowledge. For this research, these views are:

a. administration / institution;
b. population / habitation;
c. road infrastructure;
d. rail infrastructure;
e. air infrastructure;
f. sea infrastructure;
g. telecommunications;
h. power / fuel;
i. water resources;
j. industry / commerce;
k. health / medical;
l. tourism / recreation / entertainment ;

m. physiography ;

n. hydrography;

o. oceanography;

p. vegetation / cultivation;

q. climatology.

All views can be composed of regions, networks, complexes and features.

7.3.1. Administration / institution. This view contains information pertaining to:

a. political administration such as countries, states, counties, shires, city and township limits; as well as Economic Exclusion Zones and territorial claims;

b. government including facilities and regulated areas such as national parks, state forests, other legal jurisdiction features, and so on;

c. land management, property ownership and parcel records, census areas, zoning and planning areas, and so on;

d. minor administration and features of delineation such as fences and walls;

e. military including bases and facilities, ranges and controlled space;

f. public service facilities such as postal, fire and police;

g. education including schools, colleges and universities;

h. institutions such as training establishments, gaols and corrective institutes, museums and libraries, clubs and societies;

i. religion including churches, cathedrals, mosques, halls, and so on; and

j. memorials including shrines, monuments and cemeteries.

7.3.2. Population / habitation. This view contains information describing places of residence of both permanent and non-permanent status and includes such features

a. cities, towns, suburbs and communities;

b. residential complexes such as apartments, units, condominiums, flats, duplexes, dormitories and barrack blocks;

c. houses, dwellings, homesteads and huts;

d. demographic distribution such as those based on race, language, and socioeconomic status;

e. food and nutritional characteristics.

7.3.3. Road infrastructure. The road infrastructure view contains information describing the road transportation network from national and state levels of importance down to shire and local levels of importance and includes all related features. The view includes:

a. freeways, tollways, highways, distributive roads, local access roads, and cul-de-sacs;

b. tracks, driveways, foot paths and cycle paths;

c. bridges, elevated roads, overpasses, tunnels, and culverts;

d. cuttings, embankments, levees, causeways, curbs, ramps, and safety ramps;

e. junctions including interchanges, intersections and points of change of road status;

f. road and feature construction;

g. impedances including gates, grids, level crossings, toll plazas, rest areas, traffic lights, traffic signs, and so on.

7.3.4. Rail infrastructure. In addition to the network of railway lines, the rail infrastructure view consists of related features and facilities that are directly related to the rail network and structures constructed of rail of cable. Features included in this view are:

a. railway lines;
b. stations;
c. cargo loading facilities;
d. maintenance facilities;
e. marshaling yards, turntables and sidings;
f. signaling systems;
g. bridges, culverts, cuttings and embankments, levees and causeways;
h. tramways and trolley bus routes;
i. cable cars and chair lifts.

7.3.5. Air infrastructure. As a major departure from the current technique of representing airfields and aerodromes as primary features, this thesis proposes that such features form only a part, albeit an essential part, of an international and national regulated air network system. As such, this view includes:

a. regulated air space and corridors;
b. designated flight paths and controlled air space;
c. airports, aerodromes and landing grounds;
d. radio navigation beacons and devices;
e. heliports and helipads;
f. drop zones and parachute landing areas;
g. taxiways and tarmacs;
h. passenger terminals;
i. hangars;
j. fuel supply facilities;
k. carparks; and
l. critical elevations, obstacles and Maximum Elevation Figures / Lowest Safe Altitude.

7.3.6. Sea infrastructure. In a similar way that the air infrastructure view transited the land to air interface, the sea infrastructure transits the land to sea interface and includes features such as:

a. ports and harbours;
b. channels including buoys, beacons, and critical depths;
c. wharves, docks, jetties, and landings;
d. passenger terminals;
e. cargo handling facilities;
f. drydock and maintenance facilities;
g. navigable rivers and canals including locks;
h. marine navigation aids and lighthouses;
i. marinas and anchorages.

7.3.7 Telecommunications. The telecommunications view organizes information concerning transmittal and reception of communications and includes structures and networks. Features include:

a. television stations and transmitters;
b. radio stations and transmitters;
c. television and radio relay towers;
d. telephone networks;
e. data antennae and facilities.

7.3.8 Power / fuel. The power and fuel view is a transitional view, containing some features that link features within other views. Features include:

a. power stations;

b. dumps, storage piles and conveyor belts used by power stations;

c. penstocks and flumes used by power stations;

d. substations;

e. powerlines;

f. transformers;

g. distributive lines;

h. windpumps, solar collectors and other means of generating 'alternative' power;

i. fuel refineries and processing plants;

j. storage terminals and pipelines;

k. distributive pipelines;

l. outlet facilities and service stations.

Transitional characteristics can be demonstrated at one end by association with mines (industry/commerce theme) or dams (water resources theme) and at the other end with places of commerce (industry/commerce theme) or population (population/habitation theme).

7.3.9. Water resources. The water resources view contains some features that superimpose features in other views, as is the case when a reservoir/dam overlays the original stream (within the hydrography view). Features within the water resources theme include:

a. reservoirs;

b. dams and dam walls;

c. spillways;

d. water outlets;

e. elevated reservoirs, tanks, wells and bores;

f. distributive channels and pipelines;

g. valves and taps;

h. drains.

7.3.10. Industry / commerce. This theme covers all features related to industry (manufacturing, mining, agriculture) and commerce (financial, wholesale, retail) and includes features such as:

a. factories, plants and warehouses;

b. storage yards;

c. mines and processing plants;

d. conveyor belts and storage dumps;

e. salt evaporators;

g. oil and gas platforms and wells;

h. shearing sheds, livestock pens and yards, dairies, poultry farms, sheds and buildings;

i. greenhouses and nurseries;

j. financial districts, buildings and banks;

k. shopping complexes, malls, and districts;

l. stores, shops and financial and retail outlets.

7.3.11. Health / medical. The health and medical view consists of features such as:

a. hospitals;

b. health clinics, surgeries, and aid posts;

c. research institutions;

d. refuse disposal complexes and dumps;

e. sewage treatment works and drains.

7.3.12. Tourism / recreation / entertainment. This view includes features such as:

a. tourist resorts;
b. hotels, motels, and campgrounds;
c. tourist attractions and lookouts;
d. amusement parks;
e. swimming complexes and pools;
f. stadiums;
g. sportsgrounds, ovals and tennis courts;
h. racecourses and equestrian complexes;
i. motor racing circuits;
j. theatres and entertainment halls;
k. cable cars;
k. ski slopes.

7.3.13. Physiography. The physiography view is concerned with the description of the terrain. Part of the information for this view is determined from geo-referencing. For example, elevation models enable the description of elevation, slope, aspect, and so on. Features included within this view are:

a. regional physiographic descriptions including categorical areas as desert, floodplain, and tundra;
b. cliffs, gorges and escarpments;
c. sand dunes and ridges;
d. peaks, ranges, ridges, mountains, hills, karst, plains and valleys;
e. geology;
f; soils;
g. tectonics;

h. isogonic information.

7.3.14. Hydrography. The hydrography view is concerned with the description of natural drainage systems and includes such features as:

a. rivers, streams, creeks, and gullies;

b. falls and rapids;

c. sinkholes and springs;

d. lakes and waterholes;

e. swamplands and inundated areas;

f. floodplains;

g. braided watercourses, channel country and deltas.

7.3.15. Oceanography. As with the physiographic theme, the oceanography theme can be partially described using elevation data but from a sub-surface perspective. The theme includes features such as:

a. continental coastlines;

b. islands, islets and exposed rocks;

c. reefs and ledges;

d. submerged rocks and wrecks;

e. foreshore and marine flats and swamps;

f. straits, channels and passages;

g. tidal variation and currents.

7.3.16. Vegetation / cultivation. This view includes natural and cultivated plant life. Features and characteristics include:

a. jungles, forests, woodlands and scrublands;

b. savannah and grasslands;

c. plantations and orchards;

d. cultivated farmland.

7.3.17. Climate. A further major departure from current geographic information processing technology is to include a climate view. This view includes statistical data on rainfall and temperature.

Features listed in the thematic views above are not necessarily authoritive nor is it necessarily the total set of features in the geographic domain (Figure 31). The listing is produced as a first attempt to categorize the domain of geographic features into functional views or categories.

All of the information in the World views is interrelated in some way or another. The level of integration, association and detail of representation is influenced by perception and interpretation.

7.4 Hermeneutic aspects of the domain

As defined earlier *hermeneutics* is concerned with *translation* and *interpretation* . It is an appreciation of translation and interpretation that highlights the importance of structure of information (Boland, 1986). From a cartographic point of view, such interpretations can be broadly categorized into two concepts - a ***cognitive concept*** and a ***product concept***. The former corresponds to mental and dynamic interpretations of the domain of geographic features and the second corresponds to formalized and symbolized representations of the domain. This latter concept equates to *map* and *product-oriented* applications.

7.4.1. A cognitive, or identifiable, concept. Humans are able to interpret

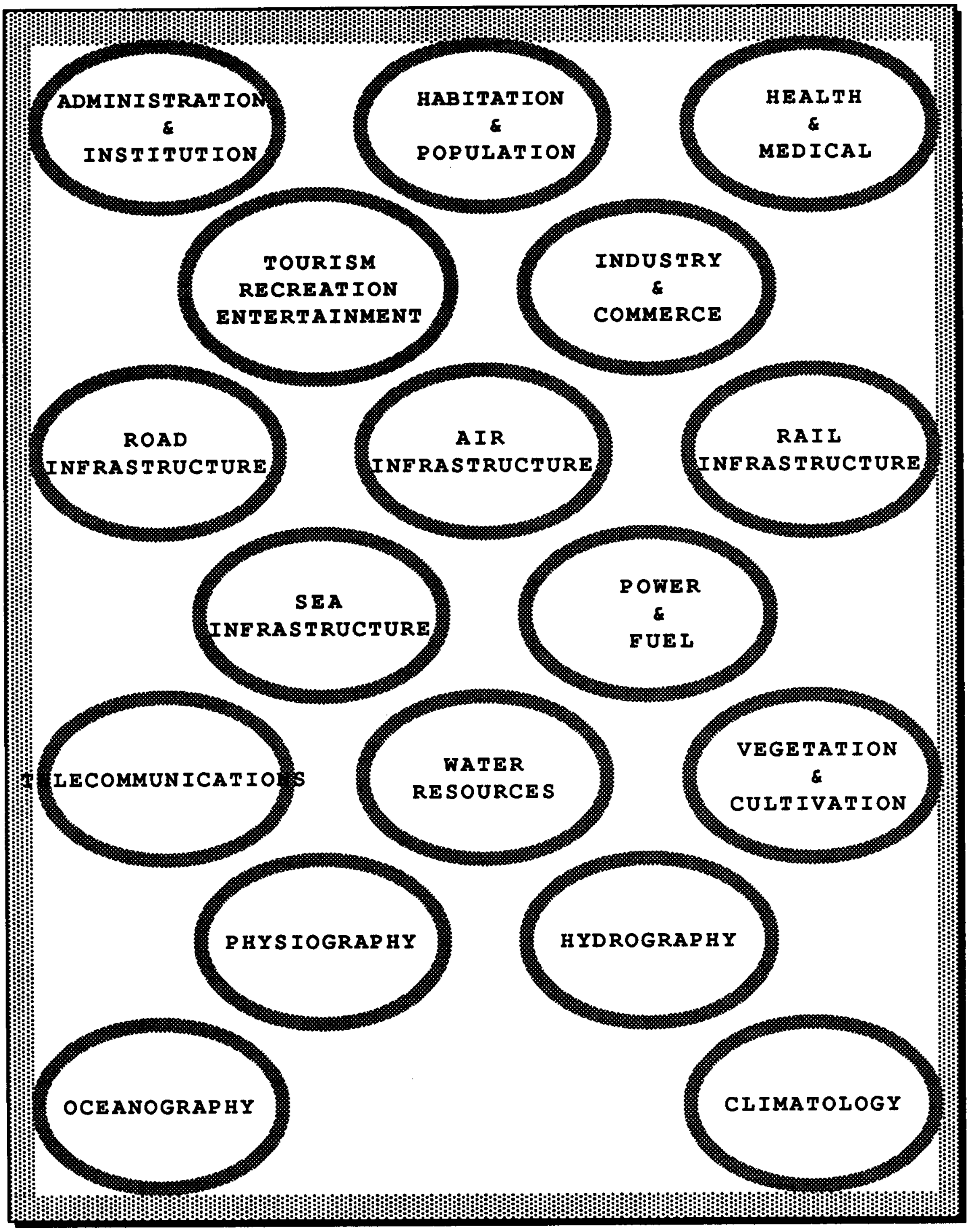


Figure 31: A domain of geographic themes

and conceive geographic information as ***identifiable concepts***. Notions such as the *Northern Territory*, the *Top End*, *Darwin*, the *Grampians*, the *Great Barrier Reef*, the *Hume Highway*, the *Upper Yarra Watershed*, the *Australian Defence Force Academy*, *Dreamworld*; all imbue meaning and signify some sort of geographic region (Figure 32). The precise boundary of the region may, or may not, be well defined; the interrelationships between different themes may, or may not, be correlated; and the level of detail of the information within the themes may, or may not, be similar. What is significant, however, is that with each of these *identifiable concepts* there is generally a *dominant theme* for the concept. For example, the Northern Territory is an administrative region; the Top End a physiographic or tourist region; Darwin a populated place; the Grampians a physiographic region;the Great Barrier Reef an oceanographic region; the Hume Highway a road transportation corridor; the Upper Yarra Watershed a water resources region; the Australian Defence Force Academy an institution; and Dreamworld a tourist attraction.

In addition to having a dominant theme, *identifiable concepts* may be conceived as having one or more *background themes*. For example, one may conceive the Northern Territory as having background information for ocean areas (delineated by its characteristically shaped coastline), key centres of population, its major road network, and, perhaps, major physiographic regions. The Top End, similarly, has an ocean area (the same as the Northern Territory), the city of Darwin, the town of Katherine and other important communities, and the road network. Background themes for the Great Barrier Reef might include the air and sea infrastructure, and tourist characteristics; while the Australian Defence Force Academy has as background themes to the dominant theme of institutional (both military and educational) themes such as population (accommodation blocks), recreational (sporting complex), road network, and commerce (cafeteria, book shop, and bank).

Identifiable concept	Description
Australia	Administrative - country
Canberra	Population - city
Yass	Population - town
Ngukurr	Population - community
Port Melbourne	Sea infrastructure - port
Tullamarine	Air infrastructure - airport
Hume Highway	Road infrastructure - highway
Murray Valley	Hydrography - river valley
Chichester Range	Physiography - mountain range
Upper Yarra Catchment	Water resources - natural hydrography
Australian EEZ	Administrative - economic zone
Designated Route A464	Air infrastructure - air route
Shoalwater Bay Trg Area	Administrative - Defence area

Figure 32: Some identifiable concepts

Identifiable concepts have the following characteristics:

a. recognition via a name or unique identifier;

b. description and categorization including the use of attributes and fuzzy relationships;

c. location via the use of a reference system in space and time;

d. size and composition; and

e. decomposition into other *identifiable concepts*.

The formalization and structure of these characteristics constitutes a *meta-knowledge* of the *identifiable concepts*. Meta-knowledge implies more than just object-oriented structures and simple relational aspects. Meta-knowledge, also, implies knowledge of descriptions of dominant and background themes; forms of representation and location; and statements of lineage and significance. But, before discussing these properties in greater detail, it should be noted that traditional cartographic products form logical and formalized concepts.

7.4.2. Product concept. Maps - both reference and thematic - are commonly accepted forms of representing geographic data. Interpretation is formalized within well established specifications and production methodologies. It should be noted that for limited scale range and limited series range products, knowledge representation needs only to be relatively simple. Computer-assisted mapping evolution has shown that unlinked vector or simple grid cell structures seem to be adequate for these types of products. In addition, the logical groupings of features is not overly critical and, in practice, groupings are often affected by symbolic representation.

However, due to various interpretations and applications by users, an extensive range of map products are required. In order to satisfy the ***multi-product*** requirements, knowledge representation has to be structured to facilitate *macro* and *micro* interpretations;

as is required by small scale and large scale maps. This implies that data needs to be organized for several representations, and structures have to be found that provide alternate representations of spatial objects (Bruegger and Frank, 1989). Again , *meta-knowledge* which has the advantage in an ability to apply appropriate data structures and usage rules to functionally logical groups of features in an efficient way, seems to be an appropriate technique, as for *cognitive*, or *identifiable*, *concepts.*

7.5 Meta-knowledge

Meta-knowledge is descriptive information about an *identifiable concept.* This knowledge consists of identification and general description; locational description, resolution, and geographic extent; role and functional descriptions; relationship within higher level features; and directories of available theme oriented information (Figures 33 and 34).

7.5.1. Identification. Concepts need to be uniquely identified by either a commonly accepted name, such as Australia, the Pilbara, Bendigo or the Australian Defence Force Academy, or a recognized identification code as in map numbering schemes such as SE 52-12 (a standard 1:250000 scale map) and 3663-II (the south-east quadrant of the standard 1:100000 scale map 3663 in the Australian topographic map series).

7.5.2. Dominant theme ID is selected from the list of world view categories such as road infrastructure.

7.5.3. Objects or feature types within theme. Aspects of geometric structuring, or cartographic structuring as it is commonly termed, can be organized into high level lists. Such types should not be constrained into currently accepted structures, but should be better correlated to the functionality of the objects concerned. For example, the road network is characterized by directional and bidirectional links, or segments; by

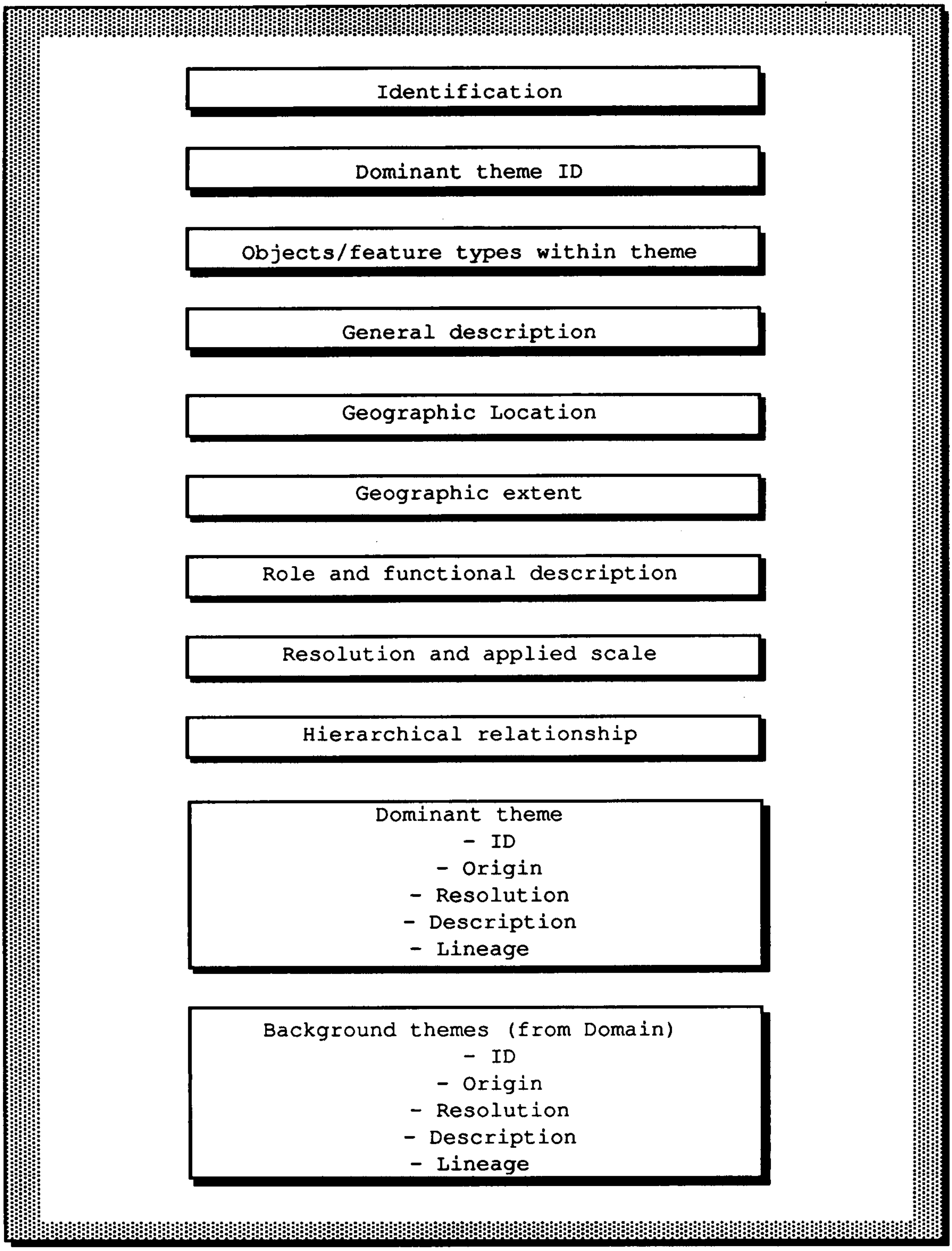


Figure 33: Meta-knowledge for an identifiable concept

Identification	**Roper Corridor**
Dominant theme ID	**Road infrastructure**
Object/feature type within theme	**Road network**
General description	**The Roper Corridor is a transportation corridor extending from the Stuart Highway in the west to the Gulf of Carpentaria in the east**
Geographic Location	**Band Mataranka - Numbulwar with width 100KM north and 100KM south**
Geographic extent	**Quadrangle 14.00S to 15.10S and 133.00E to 136.00E**
Role and functional description	**Regional level road network serving the Roper region**
Resolution and applied scale	**1000 metres for 1:1,000,000**
Hierarchical relationship	**Part of 'Top End' NT**
Dominant theme - Origin - Resolution - Description - Lineage	**Road infrastructure** **471000mE 8371000mN Zone 53** **1000 m on AMG** **Map - generalized** **RASVY 1:100000 topo maps**
Background themes (from Domain) - Origin - Resolution - Description - Lineage	**Habitation/Population** **471000mE 8371000mN Zone 53** **1000 m on AMG** **Map - generalized** **NT Lands town maps** **Sea infrastructure** **542000mE 8372000mN Zone 53** **Map - symbolized** **RAN hydrographic charts** *et cetera*

Figure 34: Example of meta-knowledge for the identifiable concept of Roper Corridor

complex nodes, or intersections; and contains relational features. Further, the road network, functionally, does not require explicit knowledge of bounding areas as is explicitly defined in polygon structures. As such, road networks should be defined using modified graphs.

7.5.4. General description. As an elaboration to the concept identification, a general description and comments can assist in conveying meaningful impressions of the concept, or identifiable area.

7.5.5. Geographic location. In 'real world' jargon, geographic location is normally expressed in terms of *fuzzy* relationships that can be translated, in most cases, into more formalized constructs. As an example, 'the band Mataranka to Numbulwar with widths of 100 km north and 100 km south of the centre line', can be translated into dimensions of an area on an oblique mercator projection centered about the line joining the two places. The coordinates for Mataranka and Numbulwar could be accessed from a gazetteer; an origin for the projection calculated; and 'false' latitude limits determined for the band (Williams, 1984). Location descriptions such as this example may be applicable to air routes and corridors.

Another example of geographic location might be to define a region as being enclosed by, or inclusive of, a list of places and other regions; whereby an aggregation of such objects defines the location.

7.5.6. Geographic extent. It is important that the actual geographic extent of the concept be known in geometric terms. This knowledge may be in terms of a simple quadrangle (either in geographic latitude and geographic longitude limits or Easting and Northing coordinates in a grid reference system); or other geometric constructs. Other constructs may be the formalization of those examples in paragraph 7.5.5 as well as, say, a centroid and radial limit; or an arbitrary scheme on a defined datum.

7.5.7. Role and functional description. As an extension to the general description, support documentation can be included to assist in a functional description of a concept.

7.5.8. Resolution and applied scale. A fundamental and obligatory component of meta-knowledge is the description of resolution and applied scale. Resolution refers to a unit of measure. An appropriate use of that characteristic would be to prohibit distance related operations to be performed at resolutions better than that appropriate to the quality of the original data. Associated with resolution is the notion of scale limits. A statement defining appropriate scale ranges, compatible with source data, is desirable.

7.5.9. Hierarchical relationship. As discussed earlier, identifiable concepts can be viewed from different levels of detail, and so each can be related to a simpler representation at a higher, or more generalized, representation. This hierarchical relationship needs to be included as a part of meta-knowledge.

7.5.10. Dominant theme. A summary of the coordinates of an origin, or principal object or feature, along with details of resolution and lineage details related to source, currency and completeness would provide information for 'fitness for use' for that theme selected to be the dominant theme for a concept.

7.5.11. Background themes. Similar summaries for all other themes would provide 'quality' statements on 'fitness for use'. Origin and resolution need not necessarily be the same as for a dominant theme, while the level of information would be influenced by the designated role of the concept.

Meta-knowledge, as McKeown (1987) suggests, is a "nontraditional representation of factual information based on semantic networks of information", and notes that "meta-knowledge is normally reserved for application-specific systems". This representation is expandable into progressively lower levels of structure. Initially, cognitive concepts and product concepts consist of interrelated information from the domain of themes; each theme being an aggregation of objects.

These objects can be identified, represented and can be assigned statements describing role, dependency, and lineage. The objects can in turn be decomposed into features. This research proposes that objects and features within the themes are unique and distinctive and require organization and structure to satisfy those unique 'real world' qualities. As such, discussion on these aspects of object and feature representation will be aligned to the domain of world views listed earlier. [26] There are, however, a number of data structures not yet discussed in preceding chapters.

7.6. Object structures

The characteristics of commonly used data structures such as polygon, grid cell, quad tree and triangulated irregular network are discussed in Chapter 3, as well as in Guptill *et al* (1987) and Morrison (1988). Not discussed previously, however, are a number of specialist structures that are well suited to 'real world' objects (Figure 35).

One such structure takes the form of a *graph.* A graph is an arbitrary collection of points called *nodes* and connections called *arcs* that go from one node to another. If we think of the nodes as representing locations in search space, then we naturally think of the arcs as connections from each location to its *successors*. Arcs may be one way or *directed*; two way or *bidirectional*; or *alternating* (Raphael, 1976). A graph structure is particularly

---

26 This analysis is not intended to be conclusive. Due to the complexity of the analysis, detailed studies of appropriate structures would best be pursued within a committee environment.

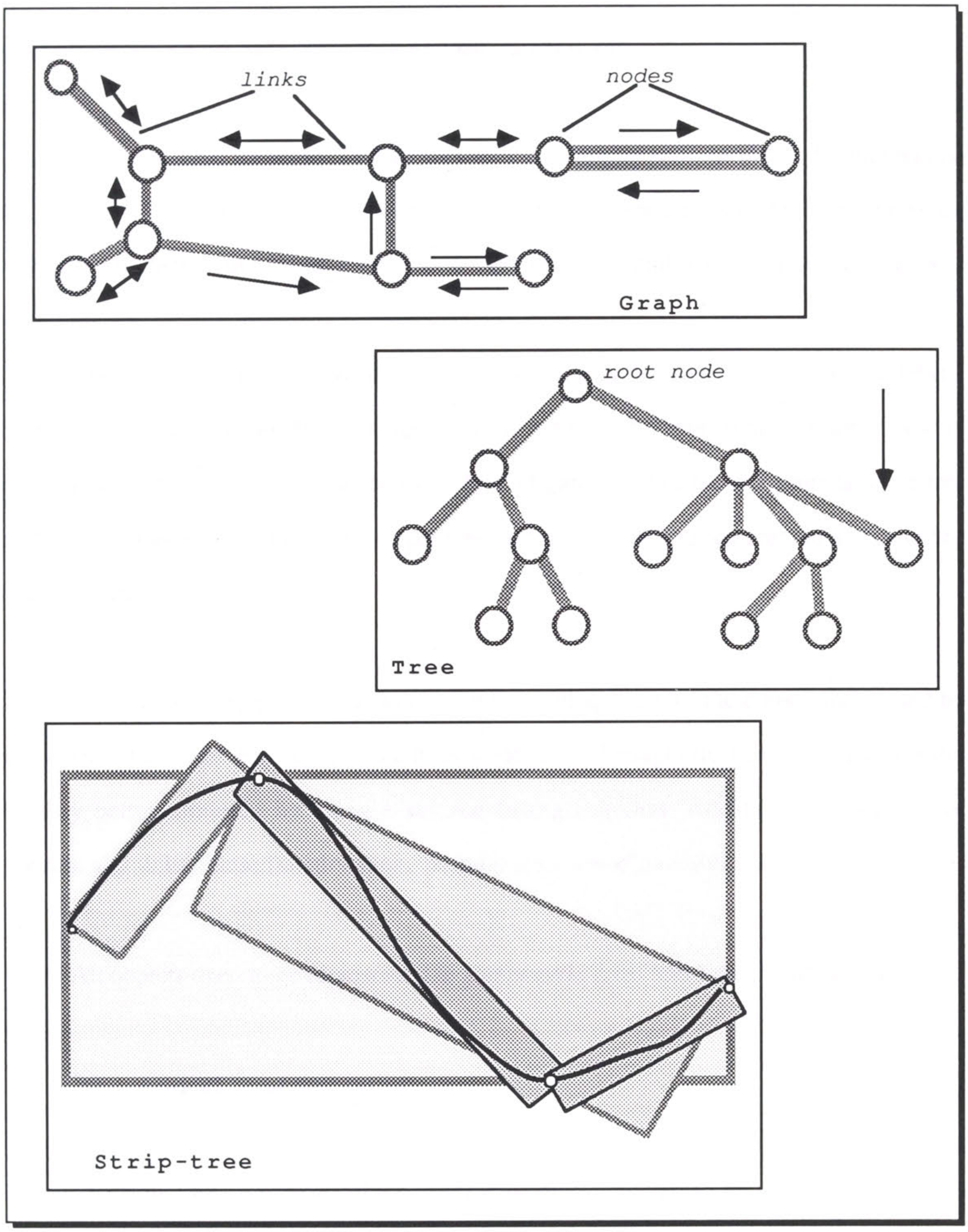


Figure 35: Miscellaneous object structures

suited to infrastructure networks, such as road, rail and air.

A special type of graph is a *tree*. A tree has a unique *root*, or top node, that has no predecessors. Every other node of the tree has exactly one predecessor. Tree structures are well suited to distributive systems such as sewerage drains, and water resource channels.

Another tree structure worthy of consideration is the strip tree (Ballard, 1981). Strip trees provide a powerful representation of curves. The representation defines strip segments as primitives to cover subsets of a line. Organization of these segments into a tree can be viewed as a particular case of a general strategy of dividing features up and covering them with arbitrary shapes.

Further, some types of data do not conform adequately to the constraints posed by geometric structures. Phenomena such as weather and magnetic field information are possibly better modeled by using a surface fitting function. Additionally, because of temporal variability these functions may be subject to periodic modification.

All objects need to be represented in a geometric form and functionally related.

7.7. Object representation

There are three fundamental forms for geometric representation:

a. plan;
b. generalization;
c. symbolization.

7.7.1. Plan. Plans are detailed maps showing buildings, roadways, railways, boundary lines and administrative boundaries. Cadastral maps which have the principal use as the basis for assessing tax are plans. In addition, any large-scale products that are required to be represented as accurately as possible, for example the layout of airfields, are best represented in plan form.

7.7.2. Generalization. The earth is so large that spatial relationships must be reduced to be comprehensible. Modifications to reduce data is called generalization and there are several operations available. There are four categories of processes - these being:

a. *simplification*, which is the determination of important characteristics of the data, the retention and possible exaggeration of these important characteristics and the elimination of unwanted detail;
b. *classification*, which is the ordering or scaling and grouping of data;
c. *representation*, which is the graphic coding of the scaled and grouped essential characteristics, comparative significances, and relative positions;
d. *induction*, which is the application in cartography of the logical process of inference (Robinson *et al*, 1978).

If linear or areal data conform to the tolerances of product specifications and are not in plan from then it is said to be generalized.

7.7.3. Symbolization. The next stage in representation occurs when data can be neither presented in plan form nor generalized. It this instance, if this object is significant then it may be symbolized. Robinson *et al* (1978) suggest that symbols may be classed as *pictorial*, *associative* or *geometric*. Pictorial symbols may be intricate or stylized and preferably they should communicate information without the necessity for a legend. Associative symbols employ a combination of geometric and pictorial characteristics to produce easily identifiable symbols. Associative symbology is used for bridges, churches, windpumps, exposed wrecks and so on. Geometric symbols most commonly used are circles, triangles, squares, diamonds and stars. Robinson suggests that "the categories (pictorial, associative, and geometric) can be thought of as occupying successive positions on a continuum of symbolization ranging from the analogic or mimetic at one end to the purely arbitrary at the other".

7.8. Object relationship

Explicit relationships achieved through topologically structured data have been discussed at length in Chapter 3 and, indeed, have been addressed extensively in the literature. However, aspects of object relationship that have received only scant attention concern dependency, and relative location.

7.8.1. Feature dependency

Feature dependency occurs via a reliance on a higher-order feature or as being a component of a higher-order feature. As an example of the 'reliance on a higher-order feature', bridges, cuttings and embankments cannot occur naturally without a road (or railway line or simpler type feature). An example of a 'component of a higher-order featuture' would be when individual buildings occur within a town or city boundary. In this latter example, the city *inherits* the buildings. Similarly, an airport inherits (or is *composed* of) runways, taxiways, tarmacs, terminals, and so on. Feature dependency implies that features may be primary or subordinate.

7.8.2. Relative location

Apart from feature dependency another characteristic of real world phenomena that has yet to be researched in detail concerns *fuzzy* locational properties. Fuzzy location refers to those common usage terms such as *around, is located near to, is located south of, is located north-east of, is located to the left of, is located to the right of, is located on* *the shore of, is located at the mouth of, is located within, crosses the, underpasses, lies on,* and so on. In addition to the direction, magnitude is often expressed within bands such as *within a kilometre of, between 1 and 2 kilometres of, greater than 1000 kilometres from,* and so on.

These notions of object structure, representation and relationship will be demonstrated in the following paragraphs addressing the *world view* themes.

7.9. Representation of objects within themes

7.9.1. Administration / institution. Information within the administration / institution theme is, in the main, polygonal or symbolic in nature. Administration, cadastral and census areas are polygon in form, while facilities such as government administration buildings, schools, churches, cemeteries and so on are in plan form (and therefore simple polygons) or symbolic depending on the resolution used in its definition.

Additionally, because of legal and administrative procedures, information within this theme is characterized by hierarchical qualities. A country is composed of states, federal planning areas, major census tracts and territorial claims. States are composed of cities, municipalities and shires as well as conservation parks and census tracts. Cities and municipalities are in turn composed of parishes, suburbs and the like, and, finally, subdivisions are composed of parcels (or sections and lots). It seems appropriate to maintain this hierarchical representation, firstly because it is quite possible that positional aspects of different components might well have been established according to different standards of accuracy and registration, and secondly as a technique to manage the enormous amount of information in a structured and organized way.

Further, information within this theme has relative location both within the theme as well to objects and features in other themes having similar relative importance. As examples, a building or facility would lie within a tract or parcel of land; buildings are related to electricity and water networks; and an administrative area may be located near a physiographic feature.

7.9.2. Population / habitation. Information in the population / habitation theme, as for the administration / institution theme is, in the main, polygonal or symbolic in nature. Area generalizations for populated places are in polygon form, as are demographic regions, while individual residences are in plan form (and therefore simple polygon) or symbolic, again depending upon the resolution used in definition.

Just as for the administration / institution theme, objects and features can be given location relative to other features both within the theme and from other themes and attribute information.

7.9.3. Road infrastructure. A road transportation network is a complex arrangement of roads having different functional uses, such as freeways, highways, arterial roads, distributive roads, and local access roads; and different construction details, such as surface, width and related features. Such features include bridges (in turn having constraints such as carrying capacity), overpasses and underpasses, level crossings, cuttings and embankments - all of which may have an impact on the use of the network when the use of the network concerns different vehicles types (Williams, 1988). Nyerges (1989) observes that "transportation organizations usually have a broader and deeper perspective on highway information than other organizations whose main interest is not with the details of maintenance, management and monitoring of a highway." Nyerges and Dueker (1988) further comment that urban applications often differ from state or federal applications. Because of detailed planning, management and engineering problems, metropolitan planning organizations interact with local governments and therefore data resolution, accuracy and detail should be commensurate with other facility information.

Some extensions to a basic topological model are required above what has normally been handled by GIS topological data structures. Transportation modeling requires a non-planar graph to represent directed, non-directed and alternating flows on networks, rather than a planar graph as in most polygonal applications. Non-planar graphs can also support the representation of highway overpasses and underpasses. Extensions to the basic topological model are also required to 'embed' networks of roads representing the various administrative levels. These extensions are achieved by the use of relationships for inter-level and intra-level connectivity (Figures 36 and 37; Williams, 1985 a; Williams, 1985 b).

7.9.4. Rail infrastructure. The rail transportation network, like the road transportation network, is a complex arrangement of routes having distributive and local service functional roles and, as the road network, contains relational and dependent features such as bridges, tunnels, level crossings, marshaling yards, sidings, and so on. The rail infrastructure theme includes tramways and cable cars. Being transportation models, the networks lend themselves to graph structures.

The rail infrastructure theme contains facilities that are well suited to representation by role schemas (as introduced in Chapter 5 and shown in Figure 18). These facilities include railway stations, maintenance facilities, and cargo handling facilities. Representation of these facilities is suited to the use of *identifiable concepts*, being decomposed from more generalized higher level representations.

7.9.5. Air infrastructure. The air infrastructure theme contains features whose control and management are highly structured and organized according to international regulations. As for the rail infrastructure theme, the air infrastructure theme contains facilities that are well suited to representation by role schemas (as introduced in Chapter 5 and shown in Figure 18). The air infrastructure theme consists of airways and route information, air traffic services and airspace, aerodromes, navigation aids, and

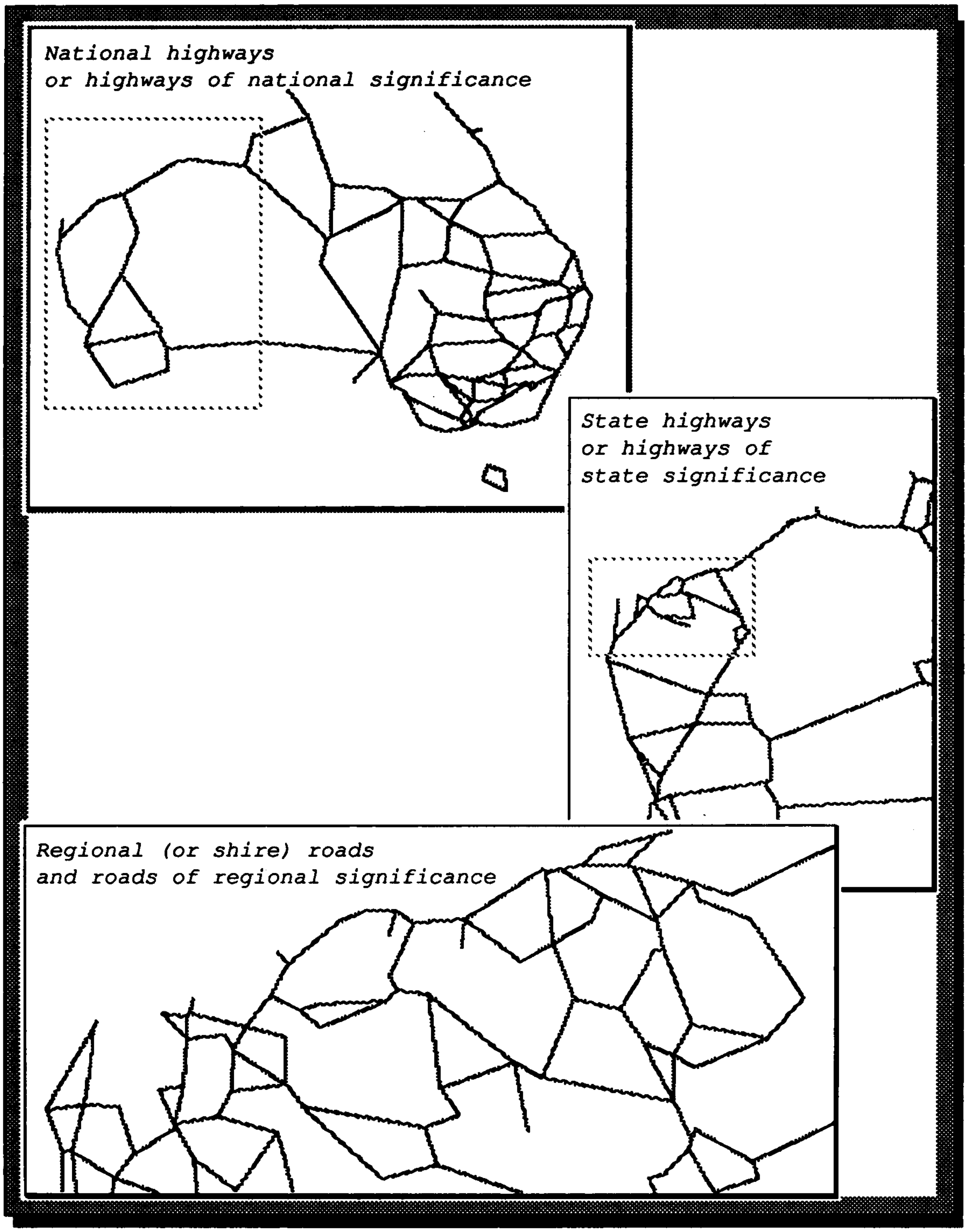
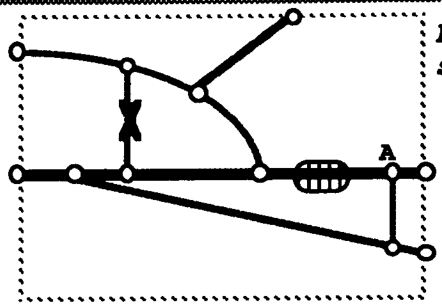
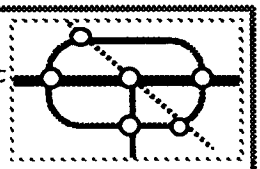


Figure 36: Hierarchical representation of road networks



Road Infrastructure is well suited to Graph structures

*Example of a Node Concept for Node **A***



Node Name
Identifier, if any
{geocode type}
coordinate pair, or triplet
Lineage details, if different from theme lineage
# of radiating links and link list
{Classification / Relation}
{Description}
{Spatial relationships}
Node concept, if any [eg Node A ::= links in + nodes]

where Geocode types may be (ϕ λ) E,N or UTM projection, etc.
Classification may be Simple, Transition between units, Relationship to higher level network, Relationship to lower level network, etc
Description may be a City, Locality, Cross roads, etc.
Spatial relationships via the use of fuzzy reference to features in other themes

Link nodeA to nodeB
Geocode type (as above)
{Coordinate list and format}
Lineage details, if different from theme lineage
{Classification} {Description}
{Surface} Width in metres
{Access} {Operational status}
Traffic direction {Median category}{Surface relationship}
Dependent feature list, e.g. bridges, cuttings, etc.
Spatial relationships (as above)

where Coordinate list and format may be coordinates, skeletal representation, strip trees, etc.
Classification may be National Hwy, State Hwy, etc.
Description may be Freeway, Clearway, Tourist road, etc.
Surface may be Concrete, Bitumen, Gravel, Unformed earth
Access may be General, Toll, Private, etc.
Operational status may be General, Closed (weather), Under construction, Under repair, etc.
Median category may Divided, Without median, etc.
Surface relationship may be At surface, elevated, etc.

Figure 37: Road network object structures

miscellaneous features.

The air routes can be represented by graphs while the terminal approaches are suited to the use of *identifiable concepts*. Air traffic services and air space is managed in designated areas and therefore suited to polygonal structures for representation. Aerodromes occur as either nodes within the air network or, if unregistered, as independent features. In the first case, these aerodromes are suited to representation at larger scale by the use of *identifiable concepts* and role schemas with the various dependent features interrelated to features within other themes. The lineage of these aerodromes is documented in flight information publications. Navigation aids, whose lineage is also documented in flight information publications, contain features dependent on other route information as well as independent features. Miscellaneous information includes isogonic information which, being a natural phenomena, can be considered as a component within the physiographic theme. Nevertheless, the use of air space and this type of information is related.

Because air infrastructure data is used in both above surface and ground applications, coordinate referencing needs to be in dual system, or at least able of being converted between systems. From the air operator point of view, elevations, such as Lowest Safe Altitude, are referenced in feet while distances are expressed in nautical miles and feet. Similar features, from ground based operations are often referenced in metres in a map grid reference system.

Figure 38 shows examples of some of the concepts discussed above. The small scale map in the upper left corner shows air infrastructure (aerodromes only) as the dominant theme with road infrastructure as a background theme. The *identifiable concept* 'Ngukurr Airport' is represented below at a larger scale and showing runway, airfield limits, navigation aid, and small terminal building. The attribute information (shown within the three boxes in the upper right) is presented in layout similar to that in publications and

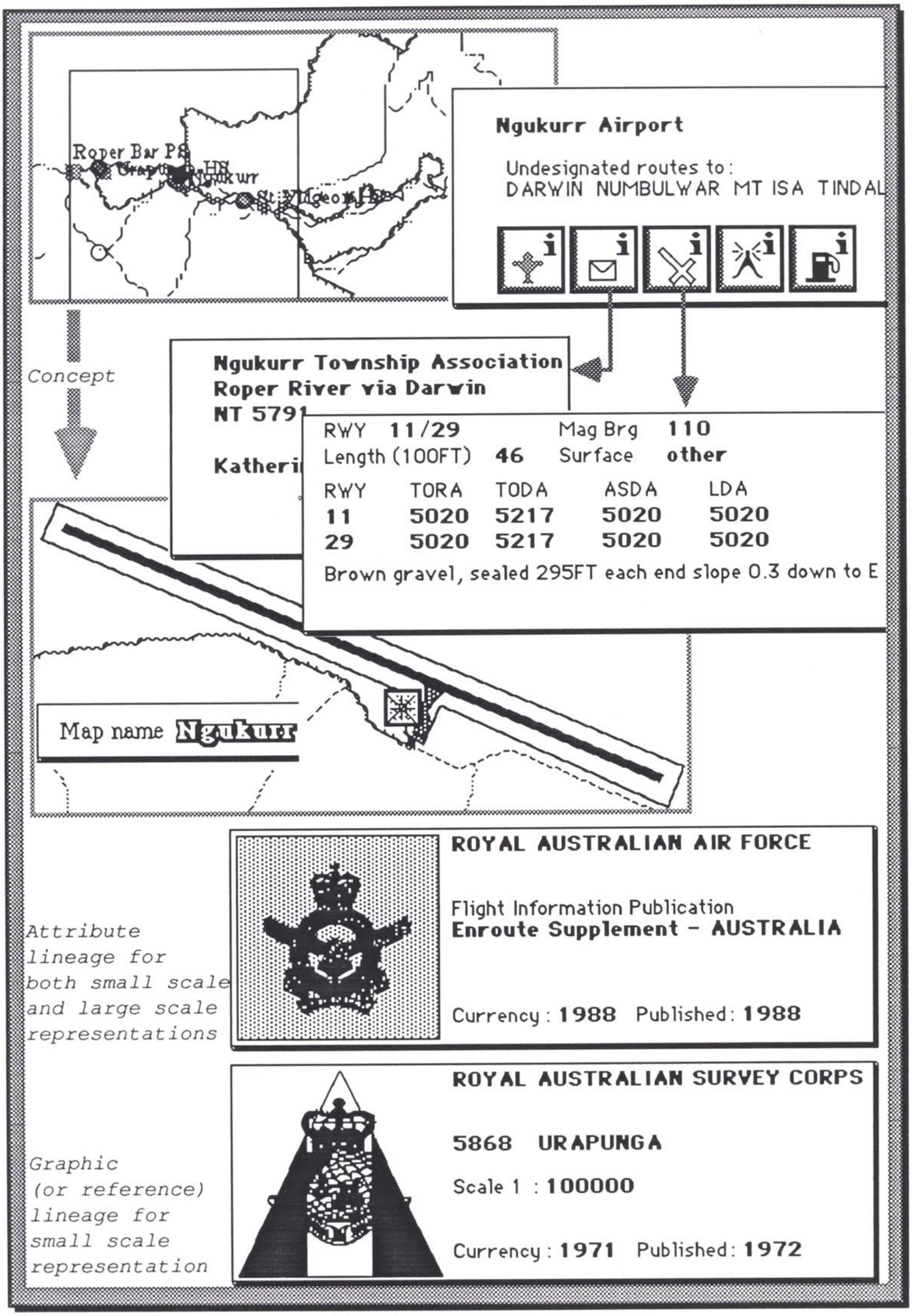


Figure 38: Air infrastructure information

whose lineage is detailed in the box second from bottom. The bottom box shows the lineage of the graphical information appearing in the square in the small scale map.

7.9.6. Sea infrastructure. Like air infrastructure, much information within the sea infrastructure theme has been managed according to strict guidelines developed by hydrographic organizations. Graphic information has traditionally been represented on conformal projections and has emphasized approaches to ports and harbours and shipping lanes. Additional attribute information has been published in tide tables, instructional charts, radio publications, handbooks, magnetic variation charts and meteorological charts; these latter examples indicating relationships within the physiographic and climatology themes.

In addition to the traditionally accepted information, sea infrastructure could also include such concepts as ports, maintenance facilities navigable rivers and canals, and beach landing sites. Ports could be defined as enclosing polygons which consist of features such as wharves, jetties, buildings, and the like, and linked to information in themes such as rail infrastructure, power and fuel, etc. Inland waterways and canals (with dependent features such as locks and weirs) are suited to graph structures.

7.9.7. Telecommunications. The telecommunications theme contains much information that is suited for graph and tree structures; telephone and cable television networks being typical examples. Not so obvious for this type of structuring is the television network. Relay towers clearly form networks although physical connections are not apparent. In addition, television and data transmitting stations are complexes and could be represented symbolically at one resolution and expanded by the concept approach for more detail.

7.9.8. Power / fuel. As with telephone networks, power and fuel supply are distributive systems and are suited to graph and tree structures. Such systems are generally managed by semi-government and private organizations and the area of coverage is dependent on the location of source materials and the distribution of customers. Rarely do these areas correlate with administrative units. Many relationships occur within this theme, for example, relationships between mining dumps being terminal features in industry and commerce theme and input to power supplies; between dams and penstocks, say in a water resources theme, and a power station; and to residences in the population theme as well as other buildings in the infrastructure themes.

7.9.9. Water resources. This theme, too, is a transitional theme, being related to all infrastructure themes as well as hydrography, physiography, and climatology themes. Features such as dams are polygonal whereas channels and pipelines are distributive networks. These types of features have direct relationships to features in the infrastructure themes.

The water resource theme also contains information about natural landforms and other components of the hydrologic cycle such as the atmosphere and sub-surface structure. Hydrologic analysis emphasizes the physical structure of a watershed in describing or predicting water and sediment yield. Land cover parameters are valuable in these studies by inferring the basin characteristics that include drainage density and type, stream length, sinuousity, and slope; and basin area, shape, width, length, slope and aspect. Multispectral imagery, obtained from satellite sensors and structured in a raster form, is useful in assessing and quantifying components within the hydrologic cycle (Salomonson, 1983).

7.9.10. Industry / commerce. Another of the infrastructure themes is the industry and commerce theme and, as with this group of themes, features are applicable to a range of structures. As well, features and complexes may be decomposed into identifiable concepts.

7.9.11. Health / medical. In addition to hospitals, health centres and the like, paragraph 7.3.11 included refuse disposal complexes and dumps and sewage treatment works and drains. Again, features are applicable to a range of structures with complexes able to be decomposed into identifiable concepts.

7.9.12. Tourism / recreation / entertainment. Paragraph 7.3.12 lists a range of features belonging to this theme. Figure 39 shows a sketch of 'Mataranka Homestead Resort' in the Northern Territory. Included in the figure are attributes for a campground and details of current weather (estimated). This figure is in sketch form (or symbolic) and would be an identifiable concept for a symbolic (point) representation at a higher level of representation.

7.9.13. Physiography. Terrain modeling to now has been performed using contouring and digital terrain models to depict the shape of the terrain with other elements of land cover and land use being considered as separate items. It seems appropriate that physiography, too, could be modeled and described according to *identifiable concepts*. Such an approach requires a methodology to organize physiographic and environmental regions. The most comprehensive study of this type undertaken in Australia was by the Division of Land Use Research, the Commonwealth Scientific and Industrial Research Organization (Laut *et al*, 1977) [27] (See page 134). Laut and his team organized the state of South Australia into a simple four level hierarchy of areal units to describe environmental conditions. These range from environmental units, the smallest areal unit through environmental associations to environmental regions.

The landform classification adopted in the study distinguished three major landform types on broad genetic criteria: erosional, depositional and volcanic. "Erosional landforms include all those which have been subject to erosional processes for a considerable time. They vary from severely eroded hills and mountains to structural plains, the latter resembling the original depositional surfaces. The duricrusted plains and tablelands are a

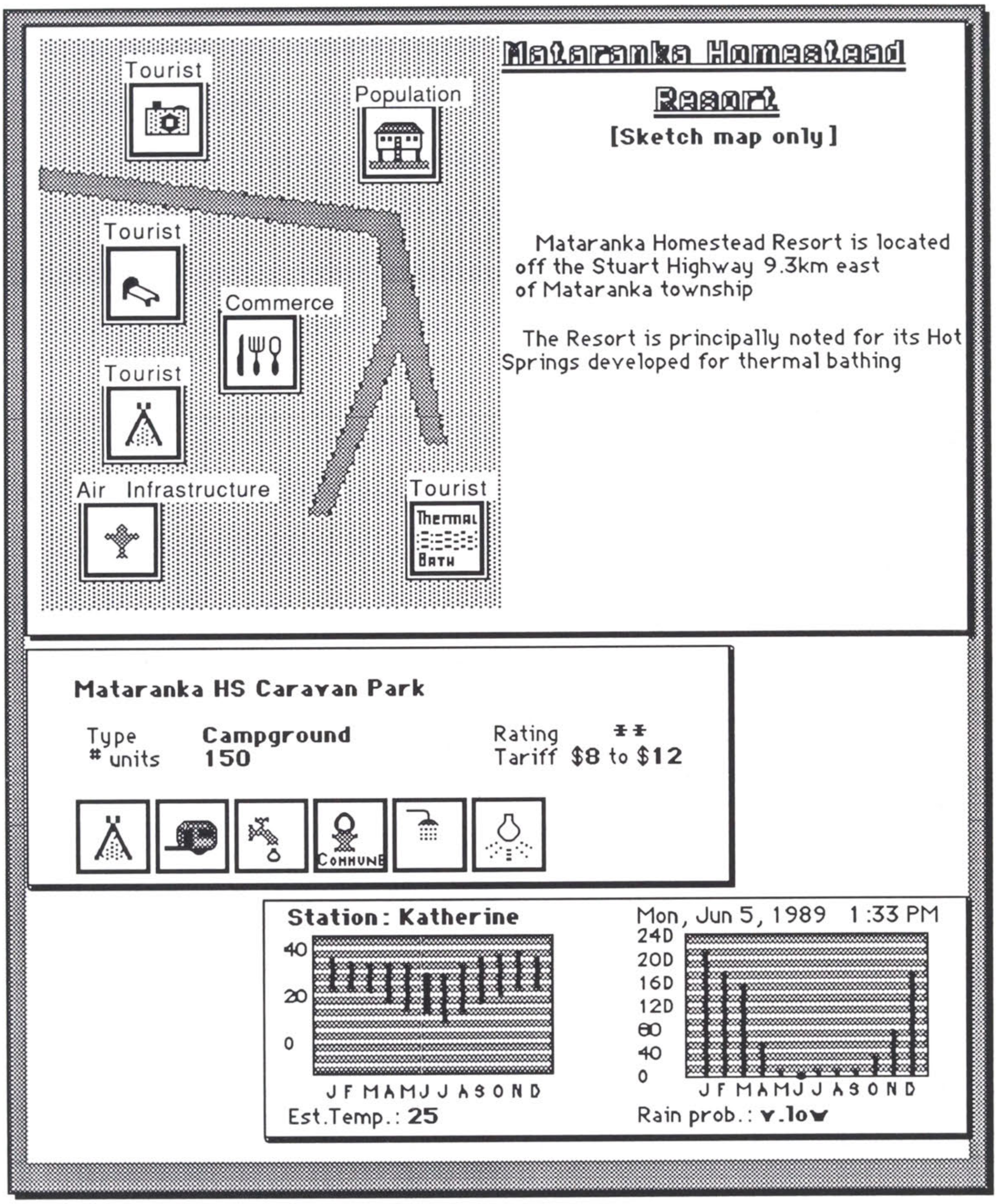


Figure 39: Concept sketch of a tourist resort

particular form of erosional surface which represent former land surfaces on which soil horizons have been indurated with either silica or iron. The silica or iron crusts are resistant to erosion and often form prominent escarpments. Depositional landforms are created by fluvial, littoral or aeolian deposition. Some of these are being actively developed at present whilst others are relict, that is, formed in the geological past but remaining clearly recognizable. The most common depositional landforms are active floodplains, alluvial plains, sand plains, and dunefields". The authors note that "volcanic landforms only occur in the south east corner of the state where there are some cone craters and associated ash plains". Details of landform types are shown in Figures 40, 41 and 42.

A model, such as that developed by the CSIRO, has a number of advantages. Firstly, it would enable decision making processes at a generalized description level such as describing the physiographic features around a particular feature within another theme. Secondly, it would provide a classification for physiographic areas, which would permit different representations for terrain to be used more effectively and efficiently. As an example, there are techniques to represent terrain as contours, as grid elevations and as triangulated irregular networks to name but three forms. This type of classification would permit the use of different structures for different terrain forms thereby taking advantage of algorithms suited to the particular representations.

----

27 The seven volumes of 'The environments of South Australia' contain the environmental information that was prepared for a study entitled "A feasibility study for an ecological study of Australia'. This study was commissioned by the Commonwealth Department of Environment and Conservation in 1975 and funded jointly by the Commonwealth Scientific and Industrial Research Organization (CSIRO) and that Department and its successor (Department of Environment, Housing and Community Development). It consisted of two tasks to be completed within two years:

a To devise and demonstrate a suitable methodology for mapping and describing major plant communities, wildlife habitats, present type and intensity of land use, ecosystems and landscape, using a test area of 410 000 km^2 of southern South Australia; and

b To assess the suitability of LANDSAT imagery for this purpose.

Although in 1977 the environmental mapping and description programme was extended to include all of South Australia, the final Australia-wide programme was never commenced.

Erosional plains

Plain
Undulating plain
Stony plain
Rise
Depression
Tor, inselberg, etc
Pediment
Footslope
Doline
Sinkhole
Cave
Breakaway
Cliff
Pan

Limestone plains

Plain
Undulating plain
Stony plain
Rise, ridge
Depression
Pediment
Footslope
Doline
Sinkhole
Cave
Breakaway
Cliff
Pan

Duricrusted plains

Plain
Undulating plain
Stony plain
Rise
Depression
Pediment
Footslope
Breakaway
Cliff
Pan

Structural plains

Plain
Undulating plain
Stony plain
Rise
Depression
Pediment
Footslope
Breakaway
Cliff
Pan

Duricrusted tablelands

Plateau surface
Escarpment
Hillslope/talus slope
Footslope

Structural tablelands

Plateau surface
Escarpment
Talus slope
Footslope

Ridges/ranges

Crest
Strike ridge
Escarpment
Hillslope
Dipslope
Footslope

Hills/mountains

Crest
Hillslope
Footslope
Escarpment
Cliff
Rock outcrop

Figure 40: Erosional landform types

Floodplains (active)

Channel
Bank
Levee
Bar
Terrace
Backplain
Oxbow
Scroll complex
Dune
Floodout
Terminal Lake
Sump

Tidal flats

Flat
Estuary
Channel

Beach plains/ridges

Dune
Consolidated dune
Cliff
Swale
Foredune
Beach

Sandplain with minor dunes

Dune
Plain surface
Rise
Depression
Pan

Sand plain

Plain surface
Sandy rise
Depression
Pan

Alluvial plains (inactive)

Plain
Stony plain
Sand plain
Clay plain
Rise
Depression
Pan

Alluvial fans

Fan surface
Depression
Gully
Stream

Relict coastal plains

Plain
Beach ridge
Swale
Lagoon
Consolidated dune
Dune

Continental dunefield

Dune
Interdune corridor
Interdune low
Pan

Playas/playa lakes

Lunette
Playa basin
Delta
Salt crust

Figure 41: Depositional landform types

Ash plain	Lava plain
Plain	Plain
Undulating plain	Undulating plain
Rise	Rise
Mound	Mound
Cone	Cone
Maar	Crater
Depression	Maar
Sinkhole	Tumulus
	Depression
	Sinkhole
	Flow feature

Figures 40, 41 and 42 are reproduced from Table 1 - Landform Types
(Laut *et al*, 1977)
Environments of South Australia Handbook

Figure 42: Volcanic landform types

The physiography theme also includes information on soils, as well as descriptions and models concerning tectonic plate movement and isogonic data. In discussion on soils, Laut (1977) includes descriptors of surface roughness, soil depth, soil drainage, soil reaction trend, and stoniness.

7.9.14. Hydrography. The methodology described in the preceding paragraphs are equally applicable to the hydrography theme, and in most instances would coincide with the those classifications. Laut *et al* (1977) have used four classes of drainage channel density: rare, common, frequent and very frequent.

Within current technology, the description for use in computer-assisted mapping and geographic information systems has been rather simplistic, mainly because this type of data has generally only been used as a background theme. Descriptive and attribute information could include details of physical characteristics such as direction flow, width, depth, velocity, banks heights for both high and low water, bank composition and slope, bottom composition and crossings, tidal effects and flood conditions.

7.9.15. Oceanography. Oceanography is concerned with the properties of sea water, marine and submarine topography, sea level variations, waves and tides, oceanic and atmospheric circulation, structure of the ocean floors, sediments, and ocean resources. Much information within the oceanography theme has been managed according to strict guidelines developed by hydrographic and bathymetric organizations. Graphic information has traditionally been represented on conformal projections and has emphasized approaches to ports and harbours and shipping lanes and graphic representation of submarine topography. Additional attribute information has been published in tide tables, instructional charts, radio publications, handbooks, magnetic variation charts and meteorological charts; these latter examples indicating relationships within the physiographic and climatology themes.

It seems that, as little development has gone into structuring information (from a geographic information system point of view) in this theme to date, at least submarine topography is well suited initially to subsurface digital terrain models. The dynamic nature of this theme is worthy of further investigation (which is beyond the scope of this thesis).

7.9.16. Vegetation / cultivation. The methodology described in the paragraphs on physiography and hydrography are also applicable to the vegetation and cultivation theme. Laut *et al* have categorized vegetation as 'native vegetation' and 'vegetation cover'. Classification of native vegetation is based on floristic and structural criteria. Structural criteria pertains to the types of plants, for example trees, shrubs, grasses, and their arrangement in the vegetation; whereas floristic criteria pertains to the grouping of similar plant communities. Cultural vegetation cover includes plantations, orchards, vineyards, parklands, croplands, and grasslands.

Within current technology, the description for use in computer-assisted mapping and geographic information systems has been rather simplistic, mainly because this type of data has generally only been used as a background theme and in simplistic analysis. So, although polygon structures are suitable for concept regions, the actual representation of natural vegetation, being spatially non-uniform in coverage, is well suited to image structures.

7.9.17. Climatology. Weather and climate have not, until now, been addressed in the literature as components within geographic information systems, and yet weather and climate are fundamental components within geography and impact on man's everyday life. Climate is concerned with the prevailing or average weather conditions of a place as determined by the temperature and meteorological changes over a period of years. This implies that regions can be defined, although boundaries would be indefinite in nature, and assigned to tables of statistical information thereby permitting estimates to be made as shown in Figure 39.

Weather, on the other hand, is the general condition of the atmosphere at a particular time and place, with regard to the temperature, moisture, cloudiness, etc. Meteorological satellites are rapid and efficient methods of collecting global weather. They provide accurate storm positions, storm sizes and intensities, cloud heights, upper air winds, precipitation estimates, numerical atmospheric sounding data, fog and stratus conditions, snow cover on the ground, haze and air pollution conditions, and a tropical storm tracking and monitoring capability (Weisnet and Matson, 1983). Weather information is produced in a variety of formats but could be integrated into geographic knowledge bases.

7.10 Identifiable concepts and 'world view' conflicts

Identifiable concepts have been characterized via recognition by using a name or unique identifier, description and categorization as in the use of attributes and fuzzy relationships, location using reference systems, and having size and composition. *World view* concepts, on the other hand, require that information be managed in a more structured and regulated manner. This implies that area delimitation conflicts will occur. As an example, the road infrastructure, in the 'real world' is managed, generally, by governments and the governmental areas are aligned to state, city, and shire administrative units. The same situation, however, does not occur for objects in the 'power and fuel' and 'water resources' themes in which facilities and networks are managed by quasi-government corporations or privately-owned companies. The area of influence for these objects is determined by the distribution of resources and clientele. This area conflict occurs between most themes with greatest incompatibility occurring between the 'cultural' themes and the 'natural' themes, such as physiography and climatology.

The dilemma arises through a conflict in the use of data and is little different to the long standing conflict posed by cartographers as to what they should show on their maps, which, of course, gave rise to *reference maps* and *thematic maps*. This dilemma has compounded in recent years due to the situation whereby the 'data gatherers' are also the 'data users'.

This problem can be alleviated by establishing *archival* or *'multi-purpose'* data bases or, as Nyerges and Dueker (1988) suggest, *subject* databases, to organize and manage data that is independent of any one application; and *application, project, product,* or *operational* data bases configured for specific specialist purposes. The *subject* databases would contain the geographic information and knowledge structures for theme-oriented features as discussed in this chapter. The *operational* and *product* databases would contain knowledge of interrelationships between themes for particular applications and groups of applications and would require knowledge rules for their creation.

These two databases, in time, can be modified and improved upon by the addition of results from previous analyses. One such example might be as a result of determining a route between two places on a network. If the analysis were likely to be used in the future then the results might be recorded in an *expertise database* (refer to discussion on *expert systems* in Chapter 4). Such a technique would enable *private knowledge* to be formally managed thereby establishing a 'learning system'.

The next chapter addresses some knowledge rules that might be applicable to the creation of *operational* and *product* data bases and a selection of rules applicable to analysis of the geographic information contained therein.

Chapter 8
GEOGRAPHIC KNOWLEDGE-RULES
Product Construction

8.1 Introduction

A survey of literature describing present day computer assisted mapping systems and geographic information systems reveals that there are almost as many variations of systems in terms of hardware and software configuration, types of data, and structures for data as there are established systems. This situation has occurred in the main due to weakness in conceptual theory for digital cartography and that automated cartography has been 'technology driven'. With respect to addressing these issues, this thesis has argued in favour of structuring data from a *phenomenological*, or real world, point of view and the creation of geographic knowledge bases.

The previous chapter concluded by observing that there was a dilemma in that the structuring and organization of 'world theme' information was incompatible with cognitive concepts and suggested that three types of geographic knowledge bases need to be constructed - one being a generic or *subject* type concerned with organizing information similar to the way it occurs and is managed in the 'real world'; another is a specialized *operational* or *product* type created by the use of 'product construction rules' from the former; and the third is an *expertise* database which was an evolving database containing the results of previous analyses.

This chapter expands on this notion of *product construction* and examines some rules, algorithms and analyses that might be applicable to *expert systems* and *decision support systems* using geographic information.

8.2 Expert and decision-support systems

An *expert system* seeks to replicate, hence replace the abilities of a human expert in a specific domain problem. Expert systems typically involve a closed-world assumption; the problem domain is circumscribed, and the systems performance is confined within those boundaries. d'Ydewalle and Delhaye (1988) suggest that "expert systems are computer programs capable of executing complex tasks that require a great deal of experience in a specialized area and that an expert system searches for the most plausible solution to a complex problem". They contend that "heuristics are methods that use information on the nature and structure of a problem to find a solution, but with no guarantee that a solution will always be found; and that algorithms, on the other hand, can be defined as sets of rules then, when used in a specific sequence, always produce a solution". d'Ydewalle and Delhaye note that the formalizations in algorithms and heuristics can lead to the development of an expert system. The production of standard series maps and standard products, such as operational data bases, are suitable for generation using an expert system approach.

A *knowledge-based decision support system* on the other hand seeks to assist a human (manager) by taking over the more structured parts of a larger, only partially formalizable, problem domain. In decision support system contexts, the world is open. A knowledge-based decision support system must be adaptable and extendible to meet the evolving needs of the user and changing conditions in the environment (Lee,1986). This approach is applicable to dynamic enquiry systems, predictive analysis and simulation, site and corridor assessment, and so on.

8.3 Standard map products - *product databases*

Reference maps are commonly accepted forms of representing geographic data, with map compilation being formalized within established specifications. Maps are composed of overlays of information that has been symbolized and enhanced with symbols, grid referencing, and selected nomenclature and descriptive notation. Maps are also generally bounded according to predetermined limits, often related to a geographic graticule.

8.3.1 Standard series map products. In order to produce standard series maps via 'product construction' techniques, processes need to be formalized by a set of rules or algorithms (Algorithm 1). These rules need to:

a. extract information from *subject databases*; whereby the meta-knowledge for 'world themes' is processed and compared to product specifications for applicability;

b. assess available information, by determining whether the information lies within or intersects the product area and whether the information is processable as a feature or whether it is decomposable as would be the case for concepts and complex objects;

c. transform and manipulate selected information, using map projection formulae and transformation formulae as required by the product specifications;

d. categorize, symbolize or generalize selected information. Categorization, and ultimately feature coding, is achieved via distinguishing features based on their intrinsic character (or nominal measurement) and differentiating within classes of data on the basis of rank according to some quantitative measure (or ordinal measurement). Symbolization is concerned with representing the information via the use of colour, pattern, line weight, and iconic techniques. A component of the symbolization is the use of generalization. Conditions for generalization include congestion, as is the case when too many features occur in a limited geographic space;

```
construct map product area boundary
generate and plot map grid
generate and plot map graticule
from the list of  <<world view>>  themes
if theme-oriented data is required by product specifications
then
   process all concepts and features within the theme
place nomenclature according to product specifications
place descriptive notation according to product specification
generate and plot map legend
```

Procedure process-a-concept

```
if concept is required by product specification
then
   if  concept is within or intersects product area
   then
       if  concept resolution is compatible with product scale
       then
           process features within the concept
       else
           if  concept resolution is coarser than product scale
           then
               symbolize the concept to product specifications
           else
               if concept resolution is finer than product scale
               then
                  Generalize features within the concept
       update nomenclature listing, if required
       update feature description listing, if required
       update lineage report for product
```

Procedure process-a-feature

```
if feature is required by product specification
then
   if  feature is within or intersects product area
   then
       plot the feature in plan form to product specification
```

Procedure generalize-features

```
if features are required by product specification
then
   if  all or some features are within the product area
   then
       use appropriate generalization tools for feature specification
       check interrelationships with features in other themes
       symbolize the generalized feature
```

Algorithm 1: Map product construction coalescence, for example when features will touch when symbolized; and conflict, or where features from different themes overlap when symbolized. Measures which indicate a need for generalization can be assessed by examining density, distribution, length and sinuousity, shape, and distance. Controls on how to apply generalization functionality include operator selection such as decisions based on the importance of individual features; algorithm selection [28]; and parameter selection. Feature symbolization would also include the production of contours and hill shading via the use of appropriate algorithms on a range of data structures representing relief;

e. add relevant nomenclature, accessed directly from gazetteers;

f. add relevant descriptive notation accessed from attributes to selected features;

g. plot grids and graticules according to product specifications; and

h. produce appropriate legend panels.

8.3.2 Derived standard series map products. In addition to the processes to produce standard series map products, extra rules are required to manipulate and generalize data to appropriate hierarchical levels. Shea and McMaster (1989) list twelve categories of generalization operators to effect the required data changes (Figure 43). These operators are:

---

28 As an example of the importance of algorithm selection Rhind (1988) comments that the selection of algorithms "is especially, but not exclusively, important in analog to digital conversion and involves taking into account the characteristics of the data. For instance, quite different algorithms are optimal for converting from raster to vector data when the former are derived from large-scale urban maps rather than from small-scale environmental ones; indeed, it seems intrinsically likely that different criteria will be appropriate in urban areas in different countries and, perhaps, even within one city. In essence, this all involves a process of adaptive recognition in which the *target's* characteristics are known only on a statistical basis and vary in space/time. Without such automated object recognition, coding of digital features and reorganization of data sets for different tasks can be immensely time-consuming".

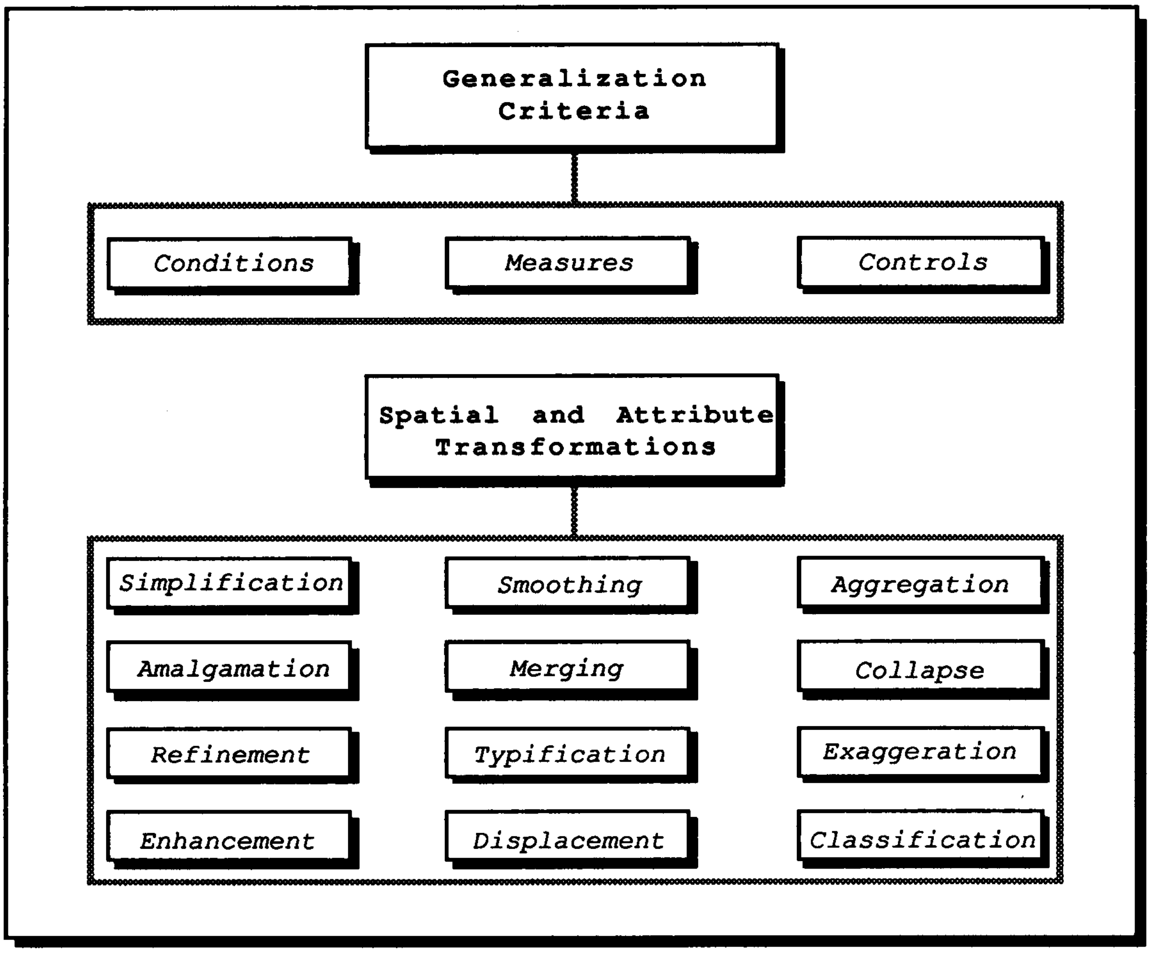


Figure 43: Cartographic generalization

from Shea and McMaster (1989)

a. *simplification*. Simplification operators produce a reduction in the number of derived data points which are unchanged in their *x,y* coordinate positions.

b. *smoothing*. These operators act on a line by relocating or shifting coordinate pairs in an attempt to plane away small perturbations and capture only the most significant trends of the line.

c. *aggregation*. When the number or density of like features within a region prohibits each from from being portrayed and symbolized individually, the features must be aggregated into an higher order class feature and symbolized as such.

d. *amalgamation*. Through amalgamation of individual features into larger elements it is often possible to retain the general characteristics of a region despite the scale change.

e. *merging*. For severe scale changes, some linear features (for example divided highways) can be merged into a single feature that still retains the character of the features.

f. *collapse*. As scale is reduced, many areal features must eventually be symbolized as points or lines. The decomposition of line and area features to point features, or area features to line feature, is a common generalization process. Settlements, airports, rivers, lakes, islands, and buildings, often portrayed as area features at large scale, can become point or line features at smaller scales.

g. *refinement*. A selective number and pattern of like features are depicted with the maintenance of the original pattern and distribution.

h. *typification*. The typification process uses a representative pattern of the symbols augmented by an appropriate explanatory note.

i. *exaggeration*. The shapes and sizes of features may need to be exaggerated to meet the specific requirements of a product.

j. *enhancement*. Enhancement deals primarily with the symbolization component and not with the spatial dimensions of the feature. This enhancement of the symbology applied is not to exaggerate its meaning, but merely to accommodate the associated symbology.

k. *displacement.* Feature displacement techniques are used to counteract the problems that arise when two or more features are in conflict either by proximity, overlap, or coincidence.

l. *classification.* Classification is concerned with the grouping together of objects into categories of features sharing identical or similar attribution.

8.3.3 Operational charts. A large group of maps designed to aid the navigator is given the general name of *chart.* There are various kinds of charts, such as those used by the mariner at sea, called *nautical charts*, and those used by the navigator of aircraft, called *aeronautical charts.* Because they are used for plotting positions and bearings and courses, charts must be prepared to a high level of accuracy and must be frequently revised so as to be nearly up to date as practicable. Charts range in scale from large-scale, such as air approach and mariner's harbour charts, to small-scale planning charts. Maling (1973) suggests that charts are "required to fulfill three requirements:

a. charts provide information about the nature and position of hazards to navigation. These include shallow water and submarine obstacles to be shown on the nautical chart and high ground and overhead obstacles to be shown on aeronautical charts.

b. charts provide information about the availability and identification of aids to navigation. These include marine lights and buoys on nautical charts and radio direction-finding aids like beacons and radio ranges on aeronautical charts. Where such aids are available, both marine and air charts may show lattice network denoting lines of constant instrumental readings which are used in various kinds of hyperbolic navigation systems to fix position.

c. a chart is the base upon which the graphical work of navigation is done."

These requirements impose two stringent additives to those generalization and representational properties of standard series maps. These are the emphasis on thematic information and the special symbology and positional requirements of those symbols; and the necessity for projections that optimize angular and distance measurement relevant to the specific chart (Maling, 1973, pp. 183-197).

8.4 Standardised database products - *operational databases*

Although product requirements for maps and charts are well defined and construction rules can be designed to mirror conventional cartographic techniques, products for digital data are not yet established as replicable and to recognized specifications. There are, however, developmental efforts by a number of governmental agencies to establish standard digital data bases and digital products. One such effort is that by the United States of America Defense Mapping Agency (DMA). Figure 44 shows a selection of data bases listed in 'Digitizing the Future' published by the US Defense Mapping Agency.

8.4.1 Aeronautical information. DMA has two prototype products for aeronautical information. One product provides details on air facilities such as airport facilities, support equipment, services, operations, navigation aids, communications, transportation and climate. The other product provides aeronautical flight information such as airport records, runway details, arresting gear records, enroute data (including way points), airspace boundaries, and navigation records. Both products are distributed according to pre-defined structures and formats.

8.4.2 Elevation and terrain matching data. DMA has a range of products designed for applications with terrain elevation. One such product is the Terrain Contour

Terrain elevation data

A uniform matrix of elevation values. For applications that require terrain evaluation, slope and surface roughness.

Feature analysis data

A data base consisting of selected natural and man-made features. Primary applications are radar return simulation, navigation, and terrain obstruction studies.

Air facilities information

Information on airport facilities, support equipment, services, operations, navigation aids and communications, transportation, and climatology.

Elevation data for Firefinder

Terrain elevation data derived from photogrammetric sources and based upon the UTM systems of coordinates. Data is transformed into a special format.

High speed digital chart

Selected coastal, and harbour and approach information developed to support high speed craft. Coordinated effort with NOS.

Terrain contour matching data base

Data base derived from photogrammetric or large scale map sources. Data is used by cruise missiles for navigational updating. There are four types of matrix data - landfall, enroute, mid-course and terminal. The missile uses radar altimeter to determine the terrain profile and compares this with matrices to determine its position.

Figure 44: DMA digital data products

scale cartographic source maps and is used by cruise missiles for navigational updating. The data are in matrix format consisting of reference maps of ground elevations at various spacings for enroute, mid-course and terminal applications.

DMA produces two bathymetric data bases. The Digital Bathymetric Data Base is a gridded bathymetric data base developed by the Naval Oceanographic Office and contains depths given in metres at five minute intervals of latitude and longitude worldwide. This product is suitable for small scale bathymetric contour charts, planning graphics, and digital display. A second product is known as the Bathymetric Data Base and is a collection of soundings obtained through the digitization of hydrographic surveys and random track data. The data is accessed by identifying a geographic area.

8.4.3 Weapons systems. Included in DMA's range of digital products are data sets having formats especially designed for intelligent weapon systems. This data is based on conformal referencing systems and is designed to strict accuracy requirements.

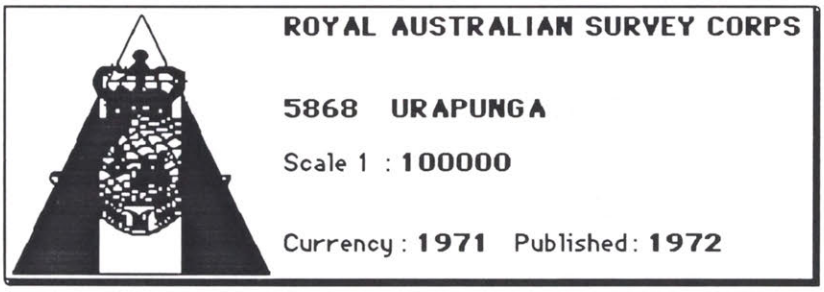
8.5 Phenomenon-based information systems

Whereas the 'product database' approach emphasized compromisation via selection and generalization processes, a phenomenon-based approach requires a comprehensive range of features within themes to be organized and related independently of any one application but related to 'real world' properties. To this end, phenomenon-based information systems can be established using *identifiable concepts* relevant to objects and features within a theme. Examples include the tourism region - the Top End; the road transportation corridor - the Roper Corridor; the populated community and locality - Ngukurr; and others as shown in Figure 32.

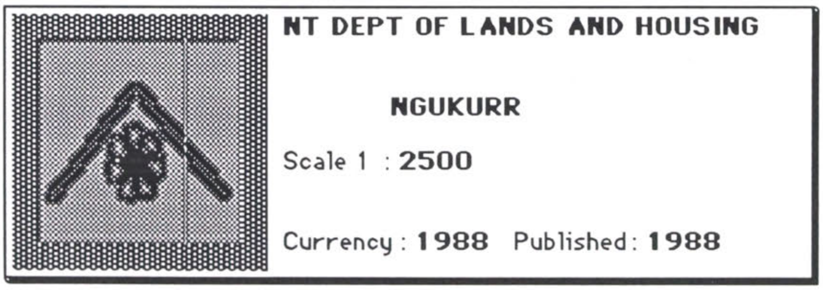
8.5.1 Theme-based analysis. Case study - the Roper Corridor. The Roper transportation corridor can be described as a region following the Roper Highway and the Roper River from the Stuart Highway in the west to the Gulf of Carpentaria in the east and being an *identifiable concept* within the Northern Territory road network. Figure 45 shows the *dominant* road infrastructure *theme* complete with symbolic representations for the dependent features (bridges and fords). Background information includes features from the population/habitation, air infrastructure, sea infrastructure, and oceanography themes. Features within the *dominant theme* can be considered as *identifiable concepts*. This property is demonstrated by Figure 46 which shows, in pictorial form, the ford at Policeman's Crossing. This technique enables representation by scale commensurate with that appropriate to the geographic extent of the feature.

Depending upon the purpose of the phenomenon-based information system, meta-knowledge can be held for the original background themes that would enable those themes to be selected as the dominant theme. Figure 30 is a composite figure showing the communities within the population theme for the Roper Corridor and the identifiable concept of Ngukurr. As discussed in previous chapters, meta-knowledge includes details concerning identification, geographic location and extent, resolution and applied scale, theme based information and objects, and features within both the dominant theme and background theme, general descriptions, as well as details of lineage as:

a. for the smaller scale representation -



b. for the larger scale representation -



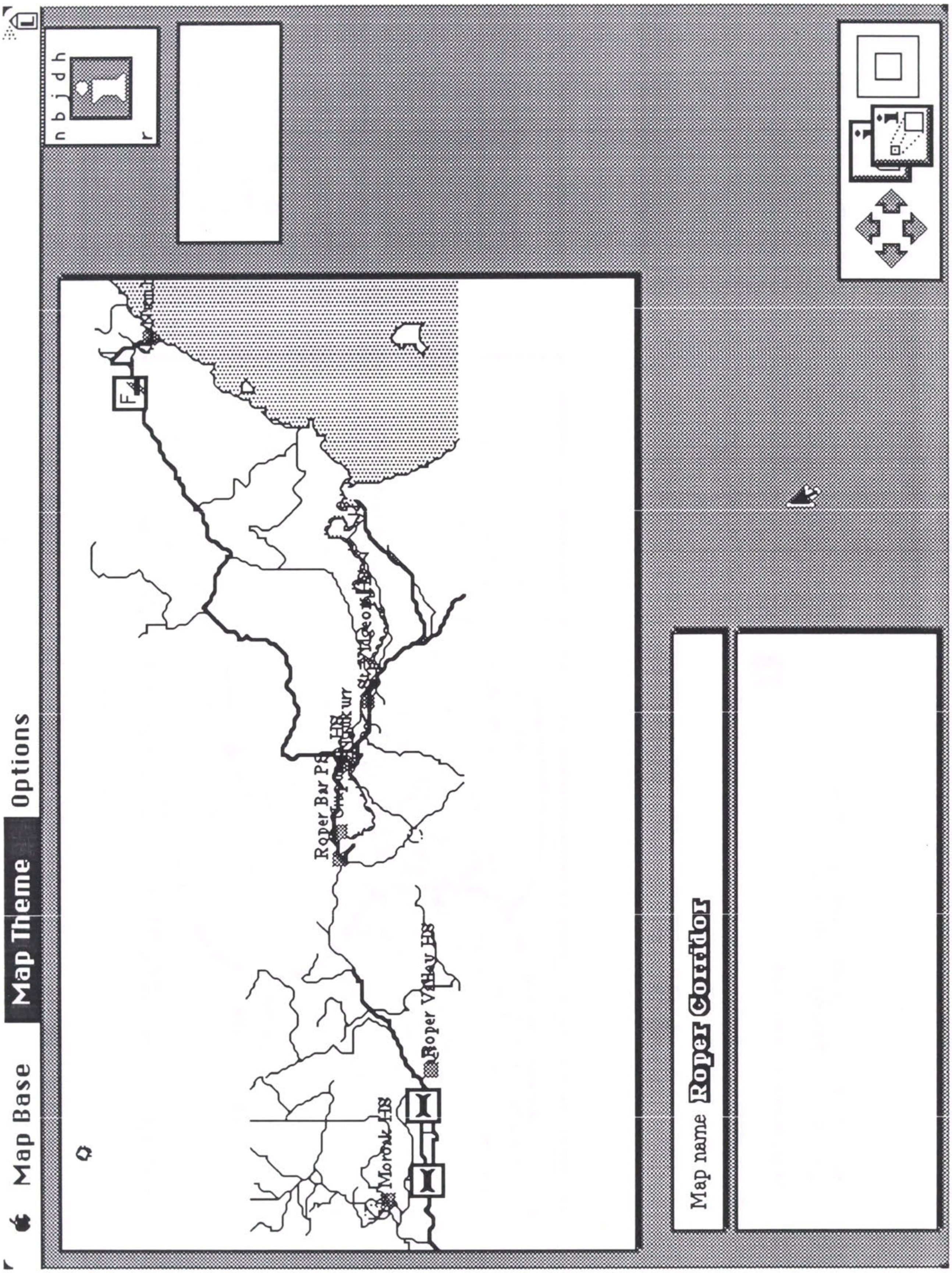


Figure 45: Roper Corridor road network

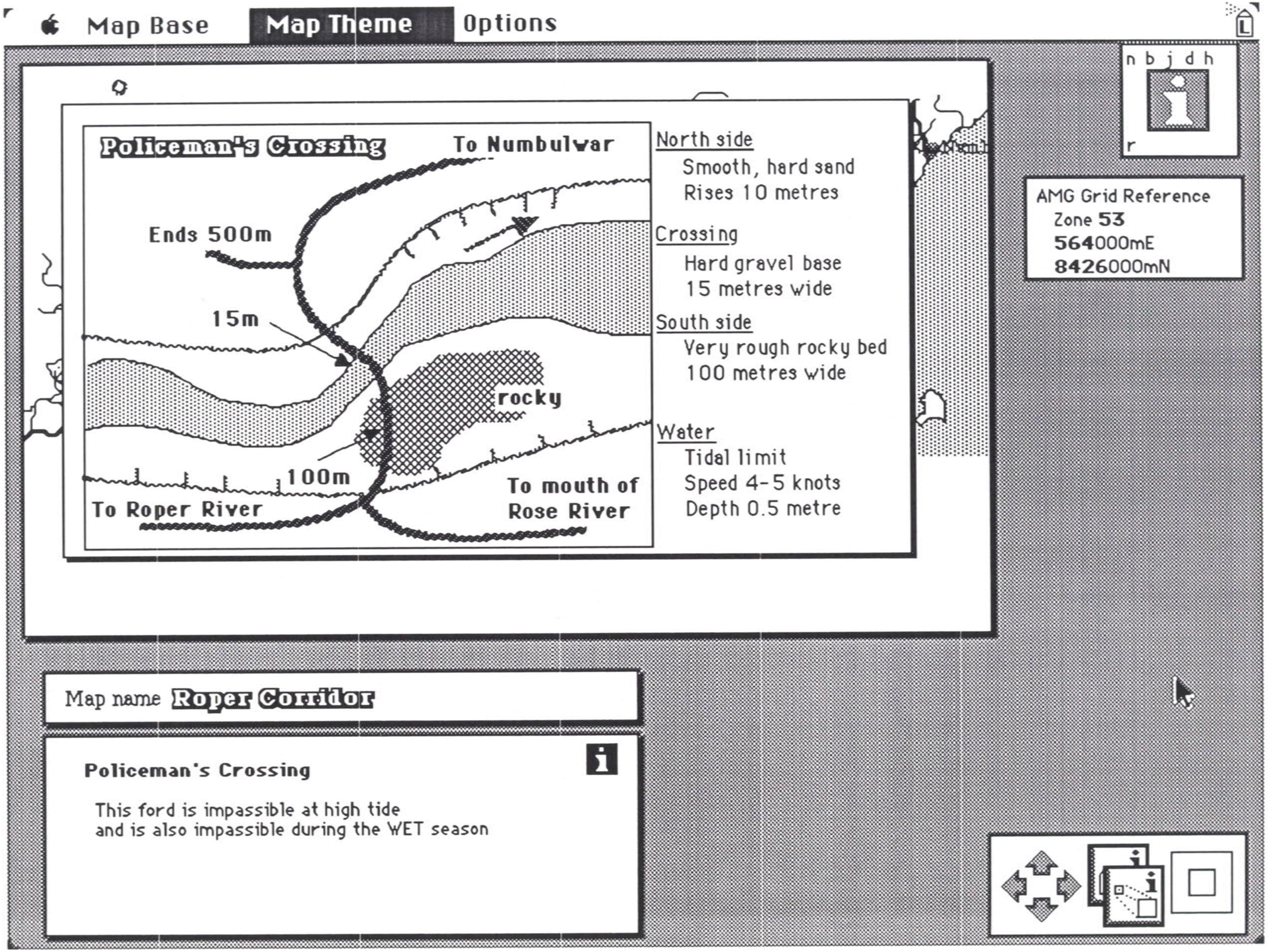


Figure 46: Policeman's Crossing

As for the parent concept, the new *identifiable concept* of Ngukurr can be processed by a variety of themes relevant to the concept. In this case study, the *identifiable concept* of Ngukurr includes the community and locality of Ngukurr. Ngukurr is an isolated community having a population of approximately four hundred and fifty persons lying adjacent to and just north of the Roper River. Ngukurr is located at the terminus of the Roper Highway and east of and between one hundred and two hundred kilometres from the Stuart Highway. Theme based information within the concept includes administration and institution, population and residential, road infrastructure, air infrastructure, sea infrastructure, power and fuel, water resources, industry and commerce, health and medical, hydrography and climate.

Figure 47 shows a part of Ngukurr with the dominant theme of 'water resources'. The water supply shown is represented as an object, or complex feature, and includes storage tanks and the water supply network. It should be noted that other objects, or complex features, having similar structures include electricity distribution within the power and fuel theme, and the sewerage network within the health and medical theme.

Within the Ngukurr locality, apart from the community (populated place), other features that have significance at the Roper Corridor level are the Ngukurr Landing (a feature within the Sea Infrastructure theme) and Ngukurr Aerodrome (a feature within the Air Infrastructure theme). The aerodrome is an object, or complex feature, at the Ngukurr level; consisting of a runway, airfield limits, a tarmac, a building and a navigation aid, whereas at the Roper Corridor level the aerodrome is a simple feature (refer to Figure 38). The relationships between these different features at both levels establish and highlight *multiple inheritance* (Egenhofer and Frank, 1989). Eginhofer and Frank (1989) note that "the structure of a strict hierarchy is an idealized model and fails frequently when applied to real world data. Most hierarchies have at least a few non-hierarchical exceptions in which one subclass has more than a single direct superclass. An example from geography shows how multiple inheritance combines often two distinct hierarchies. One hierarchy

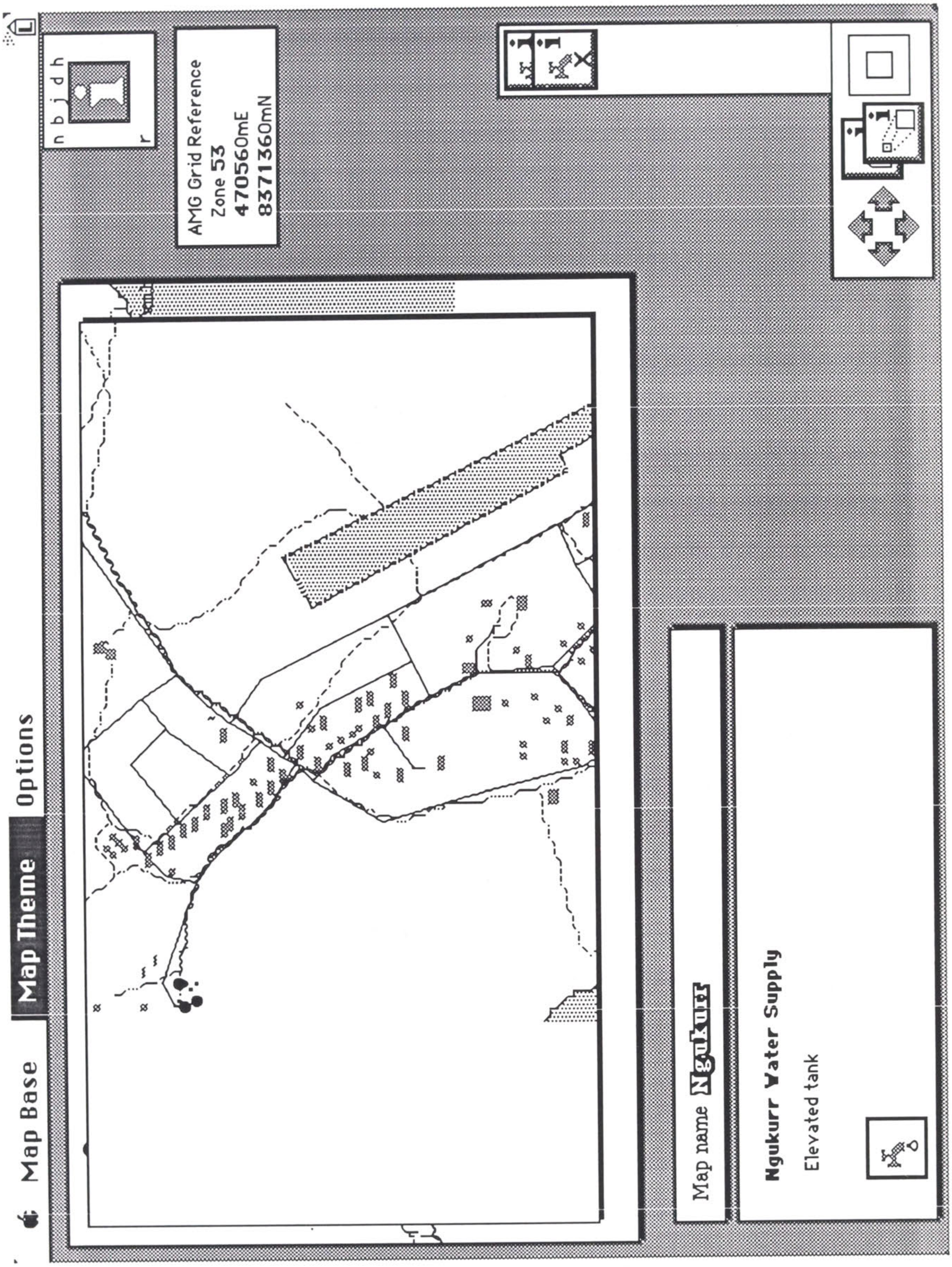


Figure 47: Ngukurr water supply network

determined by the separation of 'artificial' and 'natural' transportation links', whereas the other hierarchy distinguishes 'water bodies'. Classes with properties from both hierarchies are 'channels', that are 'artificial transportation links' and 'water bodies', and 'navigable rivers', that are 'rivers' and 'natural transportation links'."

As noted earlier in this case study, any of a number of background themes can be nominated as a dominant theme. The air infrastructure and sea infrastructure are two such themes. One other theme is the physiographic theme. This thesis has emphasized non-conventional representations of data and management of geographic information. The management of physiographic information is equally relevant to such an approach. Traditionally, relief data has been structured in the low level formats of contour strings for mapping, and grid cell and triangulated irregular networks for terrain analysis and engineering applications. Although this case study does not investigate the data structure aspects of physiography, it proposes the identification of terrain features. One such example is shown in Figure 48 - the Quirindi Gorge. This gorge lies along the southern escarpment of the Arnhem Plateau and on the Wilton River. The figure shows a stereoscopic pair of photographs and demonstrates an application of digital photography and point positioning data bases. Point positioning data bases contain the mathematical model and the rational function coefficients for stereographic pairs of photographs. Used in conjunction with analytical tools for determination of intervisibility and slope and aspect evaluation, digital photography and terrain modeling offer decision makers tools for site selection and the evaluation of key terrain.

This case study commenced with introducing the Roper Corridor as a transportation corridor. The next case study develops the structure of the road network system by discussing developments in route determination and vehicle navigation.

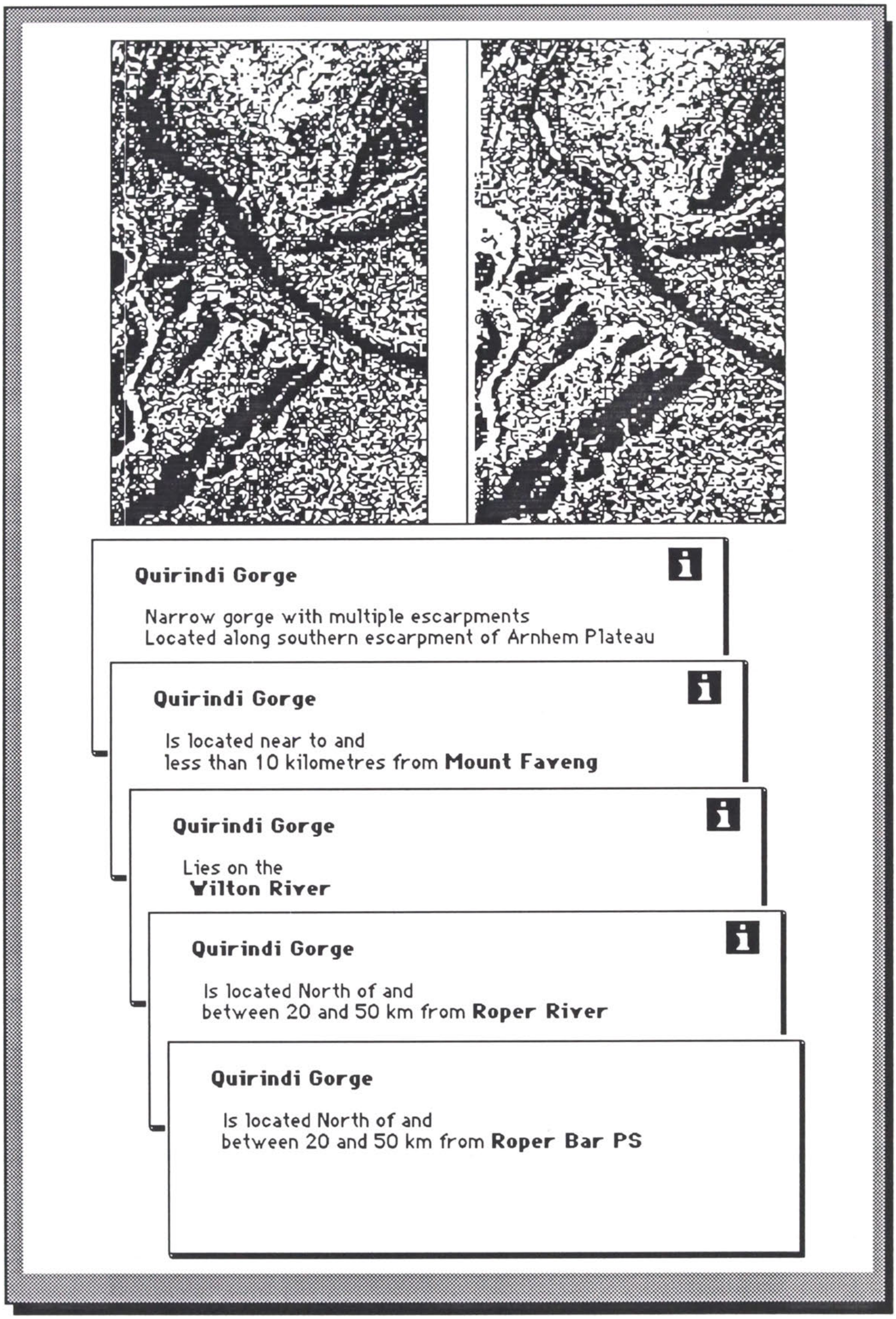


Figure 48: Stereoscopic view of Quirindi Gorge and *fuzzy* relations

8.5.2 Case Study - Road network analysis [29]. Generally, in the selection of a route between origin and destination points in a transportation network, it is an *optimal route* that is required. Optimal route determination is the computation of the "best" route between the origin point and the destination point. "Best" could mean shortest, fastest, least congested, and so on, depending upon some criteria related to an application. For example, for an emergency vehicle driver, "best" usually means the fastest route, whereas for a tourist, it might mean the most scenic route.

Mathematically, a network consists of a collection and arrangement of a set of nodes and a set of links. Algorithms have been developed using various techniques such as depth-first analysis and breadth-first analysis. However, algorithms that show the most promise are those using *heuristics*. Optimal (minimal cost) path analysis, characteristic of the A^* procedure (see Raphael, 1976, pp.82-86, and Algorithm 2), uses heuristic cost functions.

The power of such algorithms is that they use "rules of thumb" and knowledge relevant to the application. An example of such knowledge may be that it is desirable to head in the general direction of the destination. In the A^* algorithm, Raphael uses $h(n)$ (an estimator) to be the airline distance between an active node and the final destination. The estimated distance via the active node is the sum of the actual distance already traveled by road and $h(n)$. Such knowledge improves the efficiency of search algorithms.

In the road transportation network, the system is a complex arrangement of roads having different functional uses, such as freeways, highways, arterial roads, distributive roads, and local access roads; and different construction details, such as surface and width; and related features. Such features include bridges (in turn having constraints such as

---

29 Refer to paper presented to 7th AUSTRALIAN CARTOGRAPHIC CONFERENCE Sydney, Australia, 22-26 August 1988 titled "Analysis of the Road Transportation System".

Algorithm A*

1. Initially all nodes and *g, h,* and *f* values are unknown. Open the start node, set *g(start)* = 0, calculate *h(start)*, and set *f(start)* = *h(start)*.

2. Select the open node whose *f* value is smallest. Call it *N*. If *N* is a goal node, the path to *N* is the minimum cost path and its cost is *g(N)*. If no open node exists, there is no solution path in the graph. If two or more nodes have equally small values of *f*, then if any of them is a goal node, the path to it is the minimum cost solution, otherwise choose one arbitrarily to be *N*.

3. Close node *N*. For each successor *S* of *N* , calculate

   g'(S) = g(N) + (cost on link from N to S).

If *S* were previously opened and has a previous value *g(S)*<=*g'(S)* , then ignore *S*. Otherwise open *S* and set *g(S)* = *g'(S)* . Calculate *h(S)*, and *f(S)* = *g(S)* + *h(S)*.

4. Go back to step 2.

Algorithm 2: The A* algorithm

carrying capacity), overpasses and underpasses, level crossings, cuttings and embankments - all of which may have an impact on the use of the network when the use of the network concerns different vehicle types.

To include these aspects in to a search algorithm, the *estimator* can be modified depending upon the description of the link from an active node to a successor node. For example, a "rule of thumb" might be that highways are generally straighter and more direct than vehicle tracks (Williams, 1985a). Such a rule would favour higher order roads over lesser roads. In addition, if vehicle constraints inhibit certain road classes, bridge types, or underpass/overpass clearances, then such links can be rejected.

Further, the topological structure of the transportation network differs from the general polygon topology in that links may be *directional*. Such is the case for freeways, access ramps, and one-way streets. The use of this knowledge would exclude invalid use of these links (a factor that does not seem to have been addressed in literature to date).

Currently, only one commercially oriented vehicle navigation system is available - that being the Etak system (White, 1987). For non-vehicle applications of networks, the major suppliers of geographic information systems have network packages generally designed for use in utility (power, sewerage, water) applications. To date, most have concentrated on 'project' areas (e.g. Etak's San Francisco area), or planning regions. It seems that the complexity of processing networks over large geographic areas has resulted in only scant research.

Consider the task of planning a route from a suburban street intersection in a major city, say Melbourne, to a rural property a couple of thousand kilometres away, say in Queensland. To plan such a trip (assuming no prior knowledge of the route) a combination of street directories, city and environs arterial road maps, regional maps, and state-based maps would be required. A heuristic approach is to use a street directory to plan a route to an arterial road, an environs map to plan to the interstate highway system , a state map to plan to close proximity to the destination, and a regional map to plan near the destination. Of course, in evaluating these maps it is apparent that additional detailed knowledge from appropriate maps is needed for key cities and towns enroute.

Applying this concept of map usage to automated road network analysis requires the use of hierarchical, network, and relational structures. *Hierarchy* exists where data is required at different levels of resolution for the same geographic area. *Networking* exists, not only as a structure in a simple road network, but also in the connectivity of adjacent regions, such as might occur when segmenting metropolitan or geographic areas. *Relations* exist where symbolized locations on one level of application correspond to an entire network at a higher resolution, as is the case where a town may be symbolized on a state map but represented as a network on a town or environs map.

The topological structure of such a complex network needs additional objects to complement the *simple* node and link for the simple network. Connectivity between adjacent networks can be achieved by using *intra-level* nodes. Hierarchy can be implemented by using *inter-level* nodes for the translation of identical intersections from one level to another, as well as specially designed constructs (Williams, 1985b). For example, a *complex* node might consist of a simple node plus radiating links equating to terminal simple nodes on a network of higher resolution. As another example, a *special* node might be a simple node plus *directional* radiating links related to tables, say, defining the route through a freeway interchange (Figure 49).

In addition to the extended geometric structure of networks, path selection algorithms need to be modified to enable the use of heuristics as discussed in the preceding scenario (Algorithm 3).

Graphic maps have traditionally been the dominant form for representation of

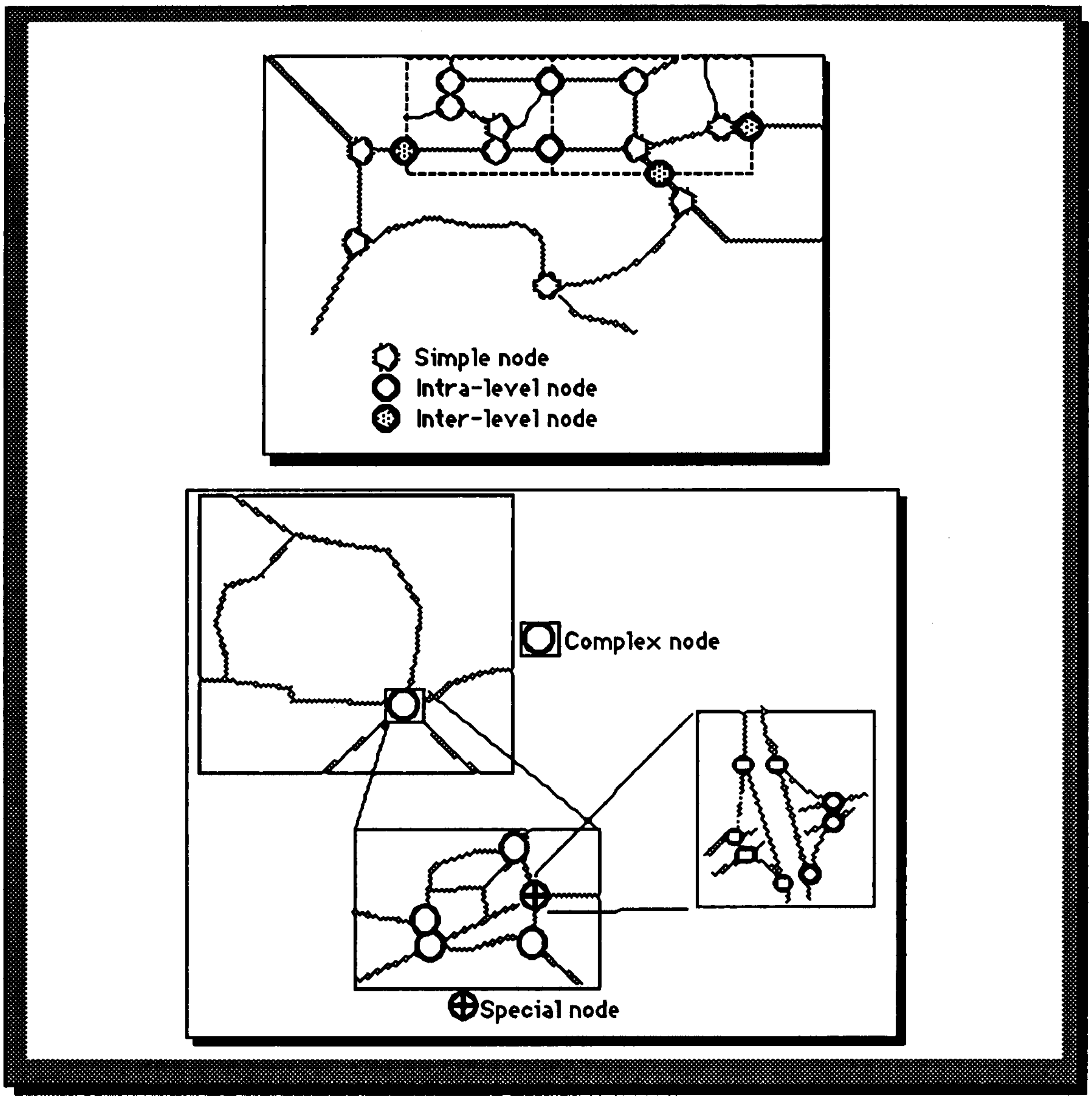


Figure 49: Diagrammatic representation of node types

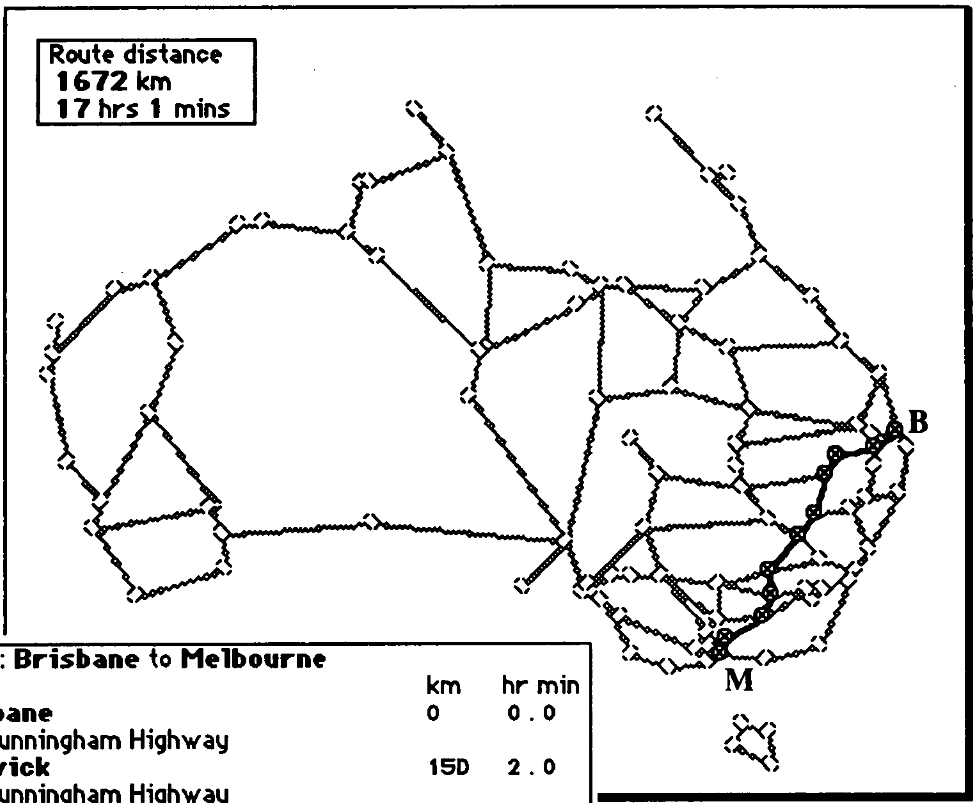
```
                Algorithm plan-path (origin,destination)

if same base map unit
then  process simple network
else
   if map units are on same hierarchical level
   then
       if on adjoining map units
       then
           calculate optimum intra-level nodes
           process simple network for each map
       else
           locate optimum exit inter-level node for each map unit
           process simple network for lower level map unit
           plan path (inter-level equivalent nodes at higher level)
   else
       if map units hierarchically related
       then
           locate optimum inter-level node
           process simple network for lower level map unit
           plan path (inter-level equivalent node, destination [or
                         origin] node)
       else
           locate optimum inter-level node for lower level map unit
           process simple network for lower level map unit
           plan path (inter-level equivalent node, destination [or
                         origin] node)
```

Algorithm 3: Path planning in multiple levels information in support of navigation. But there are at least two issues which may affect the final configuration in vehicle based systems. Firstly, studies (Mark, 1987) indicate that verbal directions are sometimes more effective than graphic representations, and, secondly, there is a safety issue when a driver is required to look at a visual display unit while driving.

Two basic types of graphic display are the use of a base map (be it vector based, image based, or some type of film image) with the route high-lighted or marked by a cursor; and purposely constructed graphic displays. White (1987) favours this second option suggesting that "not only is the resulting picture better than words, it is better than a printed map, by far. A new map is composed every few seconds, designed for the driver's current situation and displayed on the screen. It is a simple image, conveniently oriented with vast amounts of irrelevant data omitted. The information includes a star marking the destination which gets nearer to the car symbol as the vehicle approaches the destination. Also included are nearby streets. These are ways that digital maps are far superior to printed maps even for non-analytical uses."

Legal and safety issues are of concern and it seems that with respect to the use of graphic displays in vehicles, use may well be restricted to navigators. Figure 50 shows the route between Brisbane and Melbourne (determined using Algorithm 2). The graphic display is enhanced by providing a trip listing accessed from a gazetteer.

There are, however, instances where a graphic display is not required. These include cases where drivers (e.g., delivery or collection drivers) are familiar with the basic road structure and are merely seeking guidance on route optimization for a given circumstance or dynamic status of the road or its associated features. In instances where only descriptions of the road or associated features are required or where statements of advice are required then text displays (or audio) may serve the need. Such statements may take the form:



Route : **Brisbane** to **Melbourne**

	km	hr min
Brisbane	0	0 . 0
Cunningham Highway		
Warwick	150	2 . 0
Cunningham Highway		
Goondiwindi	340	4 . 0
Newell Highway		
Moree	465	5 . 0
Newell Highway		
Coonabarabran	677	7 . 0
Newell Highway		
Dubbo	847	9 . 0
Newell Highway		
West Wyalong	1102	11 . 0
Name not known		
Wagga Wagga	1257	13 . 0
Olympic Way		
Albury	1377	14 . 0
Hume Highway		
Seymour	1582	16 . 1
Hume Highway		
Melbourne	1672	17 . 1

Figure 50: Route Brisbane to Melbourne

From Sauk City travel along Highway 12 for 17 kilometres (13 minutes) to Springfield Corner. Proceed along Highway 19 through Waunakee for 12 kilometres (11 minutes) and then turn into Highway 113. Travel for 16 kilometres (14 minutes) to the interstate highway.

8.5.3 Case Study - Air infrastructure analysis. Air infrastructure consists of features whose control and management are highly structured according to international regulations (paragraphs 7.3.5 and 7.9.3). It is not within the scope of this research to investigate such rules and regulations and subsequently formalize 'product rules'. However, if formal structures are relaxed, as might be the case for emergencies such as natural disasters, then the air space with associated spatial array of aerodromes can be considered as an 'open network' (or a network of nodes having no clearly defined links).

There are a number of applications that are concerned with geographic searching and route determination that can be implemented by using spherical trigonometry. These applications include:

a. searching for the nearest feature (say an aerodrome) to a particular point;
b. searching for features (say aerodromes or towns) within a preset radius of a given point;
c. determining the great circle route distance and departure and arrival bearings between two, or more, places;
d. automatic construction of en-route charts based on terminal places and selected reporting points.

The first two applications can be implemented using sphere rotation formulae such as that shown in Formula 1 and demonstrated in Figure 51 (Williams, 1985b). The sphere rotation formula performs a rotation such that, placing the geographic coordinates of a place as an origin, other sets of coordinates are transformed so that the origin point becomes the 'false' north pole. Therefore distances from the 'false' pole are determined by a latitude test and converted into an arc distance. Figure 51 lists aerodromes that are

$$n_1 := \mathrm{COS}(\varphi) * \mathrm{COS}(\varphi_0) * \mathrm{COS}(\lambda_0-\lambda) + \mathrm{SIN}(\varphi) * \mathrm{SIN}(\varphi_0)$$

$$\varphi_n := \mathrm{ARCSIN}(n_1)$$

$$z_1 := \mathrm{COS}(\varphi) * \mathrm{SIN}(\varphi_0) * \mathrm{COS}(\lambda_0-\lambda) - \mathrm{SIN}(\varphi) * \mathrm{COS}(\varphi_0)$$

$$z_2 := \mathrm{COS}(\varphi) * \mathrm{SIN}(\lambda_0-\lambda)$$

$$\lambda_n := \mathrm{ARCTAN}(z_1/z_2)$$

where input parameters are

φ_0	latitude origin (*false* north pole)
λ_0	longitude origin (*false* north pole)
φ	latitude of selected place
λ	longitude of selected place

and output coordinates are

φ_n	latitude of selected place transformed to *new* sphere
λ_n	longitude of selected place transformed to *new* sphere

This formula is designed to produce geographic coordinates on a 'new' sphere whose 'north' pole coordinates are the actual geographic coordinates on the sphere in normal aspect.

Formula 1: Sphere rotation

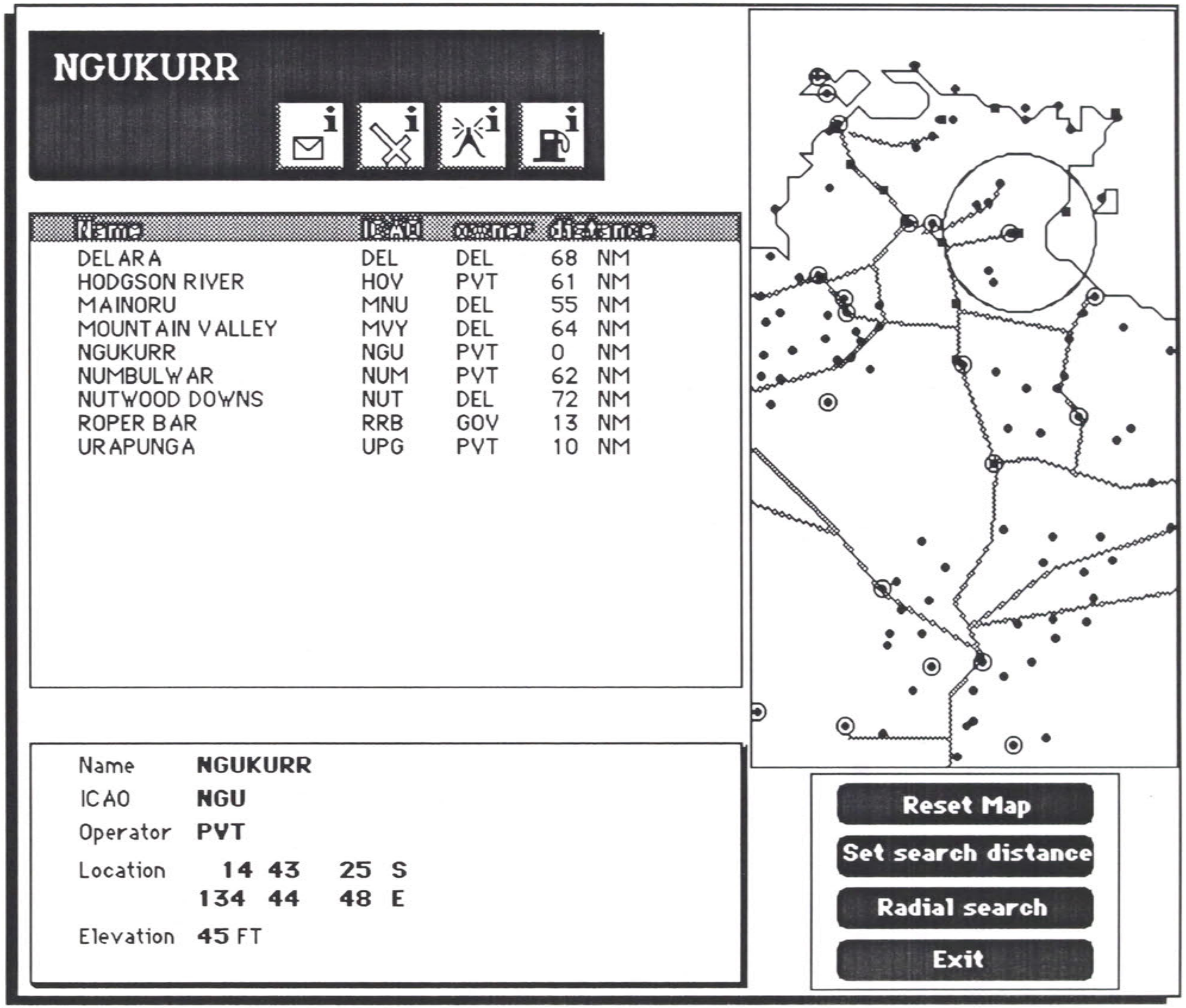


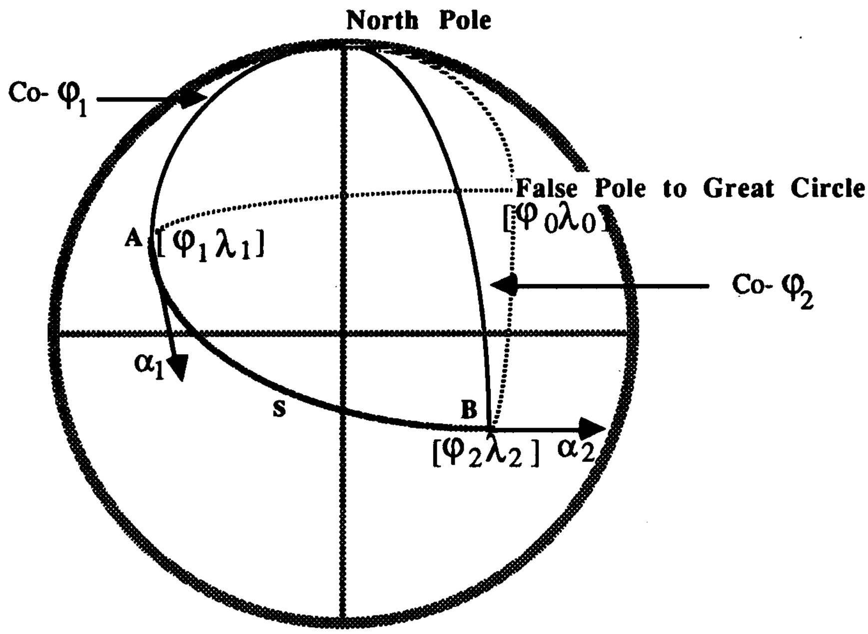
Figure 51: Radial search using spherical trigonometry

miles (100 minutes, or 1 degree 40 minutes of longitudinal arc) from Ngukurr aerodrome.

The third application can be resolved using half-angle spherical trigonometry as shown in Formula 2 and demonstrated in Figures 52 and 53. (Williams, 1985b). This formula accepts as input, the geographic coordinates of two terminal places and calculates the great circle distance between the two places, as well as the departure bearing and the arrival bearing. During the calculation, a by-product of the trigonometry is the calculation of the 'zenith point' to the great circle. This point can be used as the origin point in Formula 1, while the terminal points and, say, reporting points can be processed as data points to output a list of points referenced to the 'new' sphere. Then by selecting coordinates north and south of the 'false' equator results in a data band suitable for used with a conformal projection (e.g. Mercator) thereby constructing the framework for an en-route chart. By selecting features from the air infrastructure theme and applying appropriate specifications would result in the automatic construction of en-route charts.

Another use of the formula (Formula 2) could be to determine routes between distant places. For example by analyzing arcs of departure and range limits in conjunction with Formula 2, intermediate points can be determined. This procedure is defined in Algorithm 4 and discussed in Williams (1985b).

8.5.4 A partial definition for theme-based analysis. Although discussion (in the case studies) on theme based analysis has been relatively superficial and has only considered the road and air infrastructure theme, it is apparent that applications can be defined using forms such as the Backus-Naur notation or 'railroad' diagrams. Figure 54 (from Williams, 1980) defines possible infrastructure analysis products.




```
z1 := COS((λ2-λ1)/2) * COS(((coφ2)-(coφ1))/2)
z2 := COS((λ2-λ1)/2) * SIN(((coφ2)-(coφ1))/2)
n1 := SIN((λ2-λ1)/2) * COS(((coφ2)-(coφ1))/2)
n2 := SIN((λ2-λ1)/2) * SIN(((coφ2)-(coφ1))/2)
α1 := ARCTAN(z1/n1) - ARCTAN(z2/n2)
α2 := ARCTAN(z1/n1) + ARCTAN(z2/n2)
s := ARCTAN(√((z2*z2+n2*n2)/(z1*z1+n1*n1))) * 6378 kilometres
z1 := COS(α1/2-45) * COS(-φ1/2)
z2 := COS(α1/2-45) * SIN(-φ1/2)
n1 := SIN(α1/2-45) * COS(90-φ1/2)
n2 := SIN(α1/2-45) * SIN(90-φ1/2)
φ0 := 90 - 2 * ARCTAN(√((z2*z2+n2*n2)/(z1*z1+n1*n1)))
λ0 := λ1 + ARCTAN(z1/n1) - ARCTAN(z2/n2)

     where  coφ ::= 90-φ for northern latitudes
     and    coφ ::= 90+φ for southern latitudes
```

This rigorous half-angle spherical formula which is designed to produce the great circle distance between two points, the departure and arrival bearings, and the coordinates of the zenith point to the great circle, has been derived from general half-angle in Ehlert (1978)

Formula 2: Distance and bearings between two places on the Earth's surface based on a spherical earth

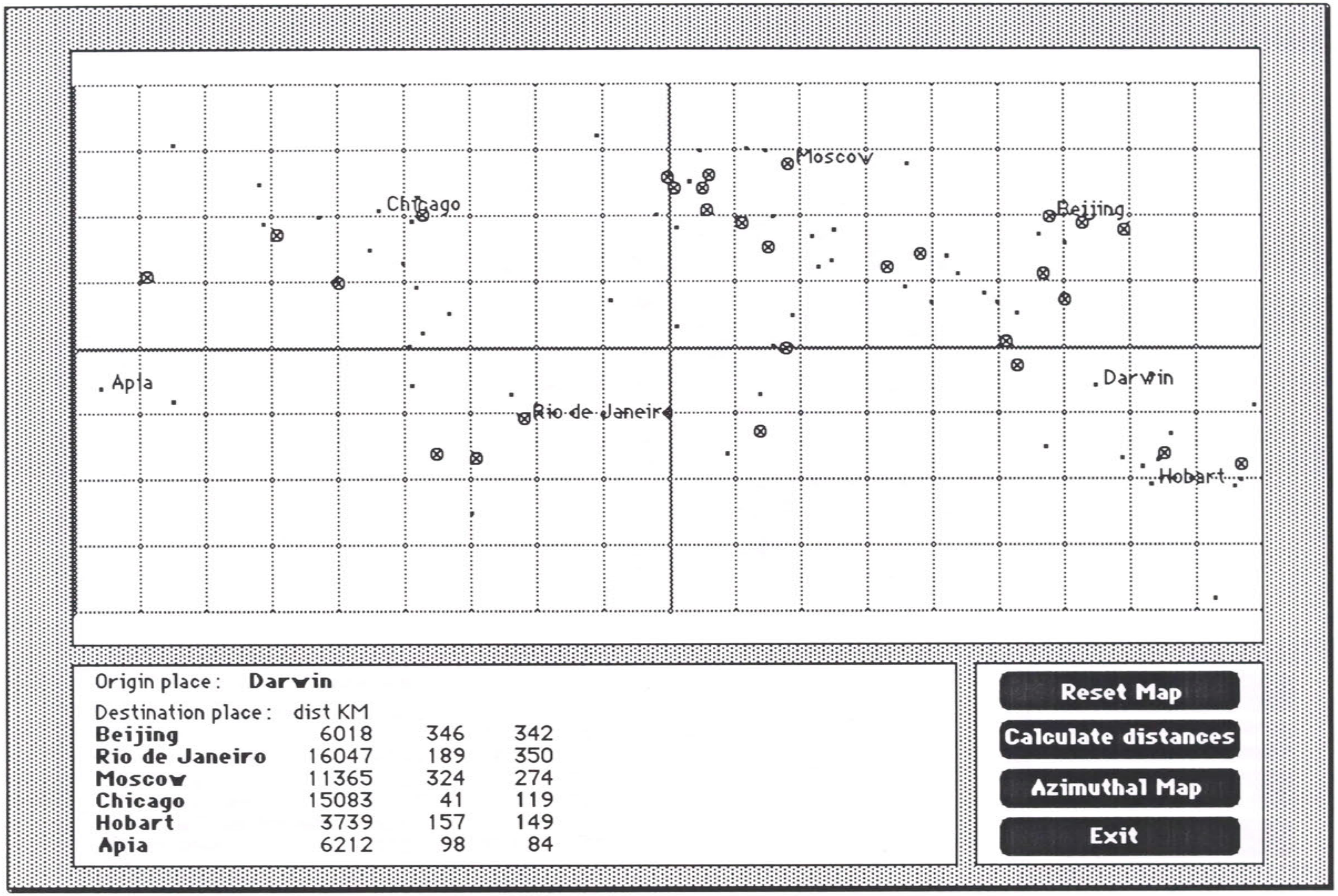


Figure 52: Great circle distance and bearings using spherical trigonometry

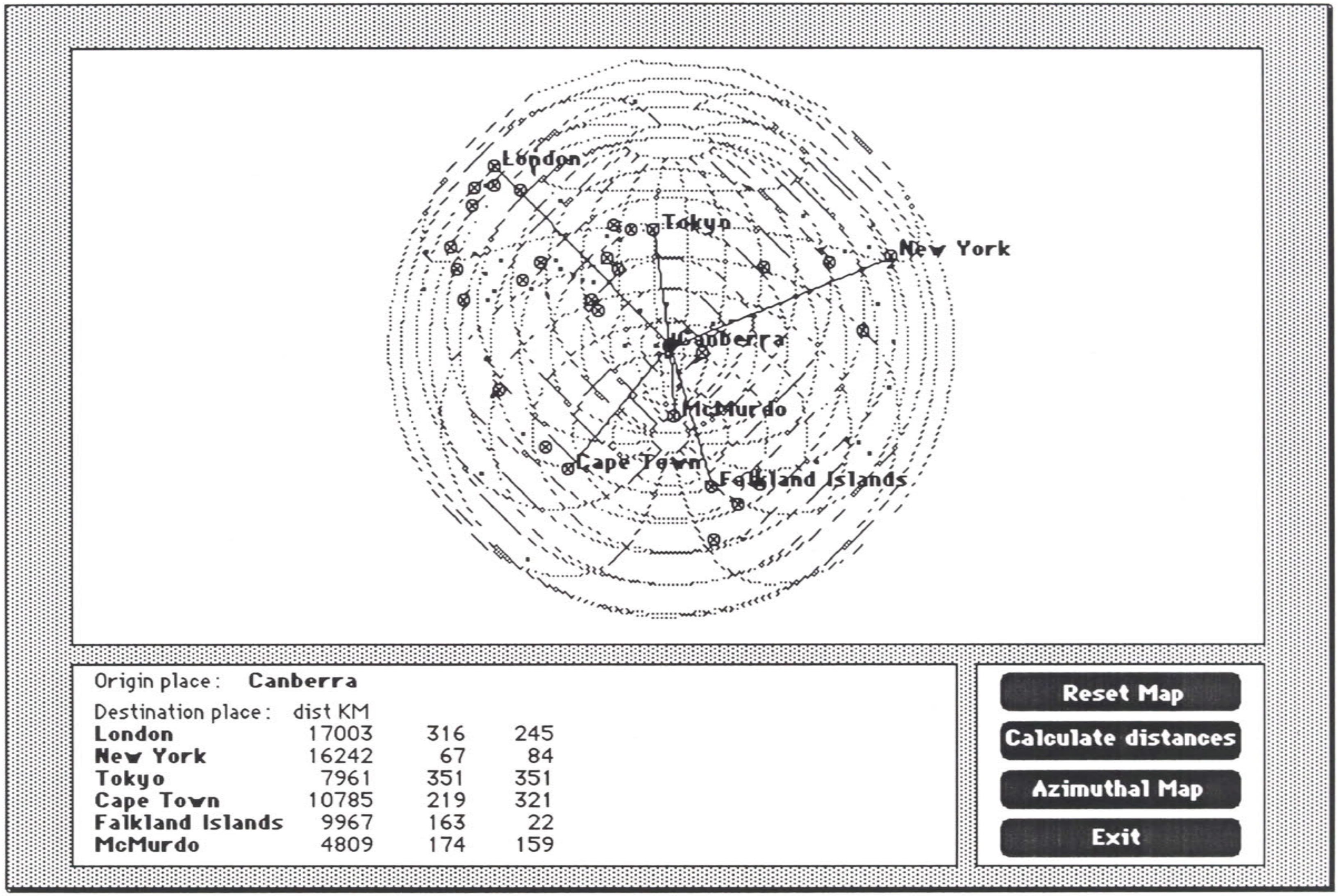


Figure 53: Azimuthal equidistant map

```
                    Algorithm air-path

enter terminal points
enter distance constraints
add departure node to active node list
repeat
   for    all active nodes
      if excessive progressive distance
      then
         deactivate node
      if destination node
      then
         deactivate node
      if distance to destination less than minimum range distance
      then
         deactivate node
      if node still active
      then
         generate nodes within range and arc to active node list
until all nodes on active node list are deactivated
report selected routes
```

Algorithm 4: Path planning in an *open* network

8.6 Terrain and Environmental analysis

The preceding sections addressed a selection of themes within the domain of geographic information and analytical and heuristic tools suitable for *decision-support systems*. The effective use of these tools, however, is influenced not only by the dominant theme but by many of the original background themes. As an example of integrating diverse information types, Steyaert (1989) suggests that geographic information system technology "is being examined in terms of the data base and analysis requirements for large area monitoring of land surface conditions in conjunction with process modeling and regional impact assessment". Steyaert's research is "based on quasi-operational analysis of satellite and surface-observed data" with the purpose of monitoring "current conditions associated with the surface environment, to isolate unusual patterns, to determine anomalies, to detect changes, and to search for associations between land surface data and various types of data associated with the climate and hydrologic systems."

Numerous researchers have integrated various terrain elements similar to that above. One such researcher, Laut (1987) of the Commonwealth Scientific and Industrial Research Organization (CSIRO), in assessing cross-country trafficability, asserts, however, that most trafficability models are algorithmic. Laut suggests that an algorithmic model "is a very powerful general-purpose model which can be used to predict landscape trafficability in very precise terms for a range of vehicles. Unfortunately, such models require a comprehensive set of engineering data inputs, both for the vehicle and the landscape. Whilst the vehicle inputs are readily available from design criteria, the landscape inputs are not, and they are very costly to obtain at the spatial resolution required by the model. If these data are obtained at a coarser resolution, the resulting imprecision of model predictions renders these predictions useless in practice."

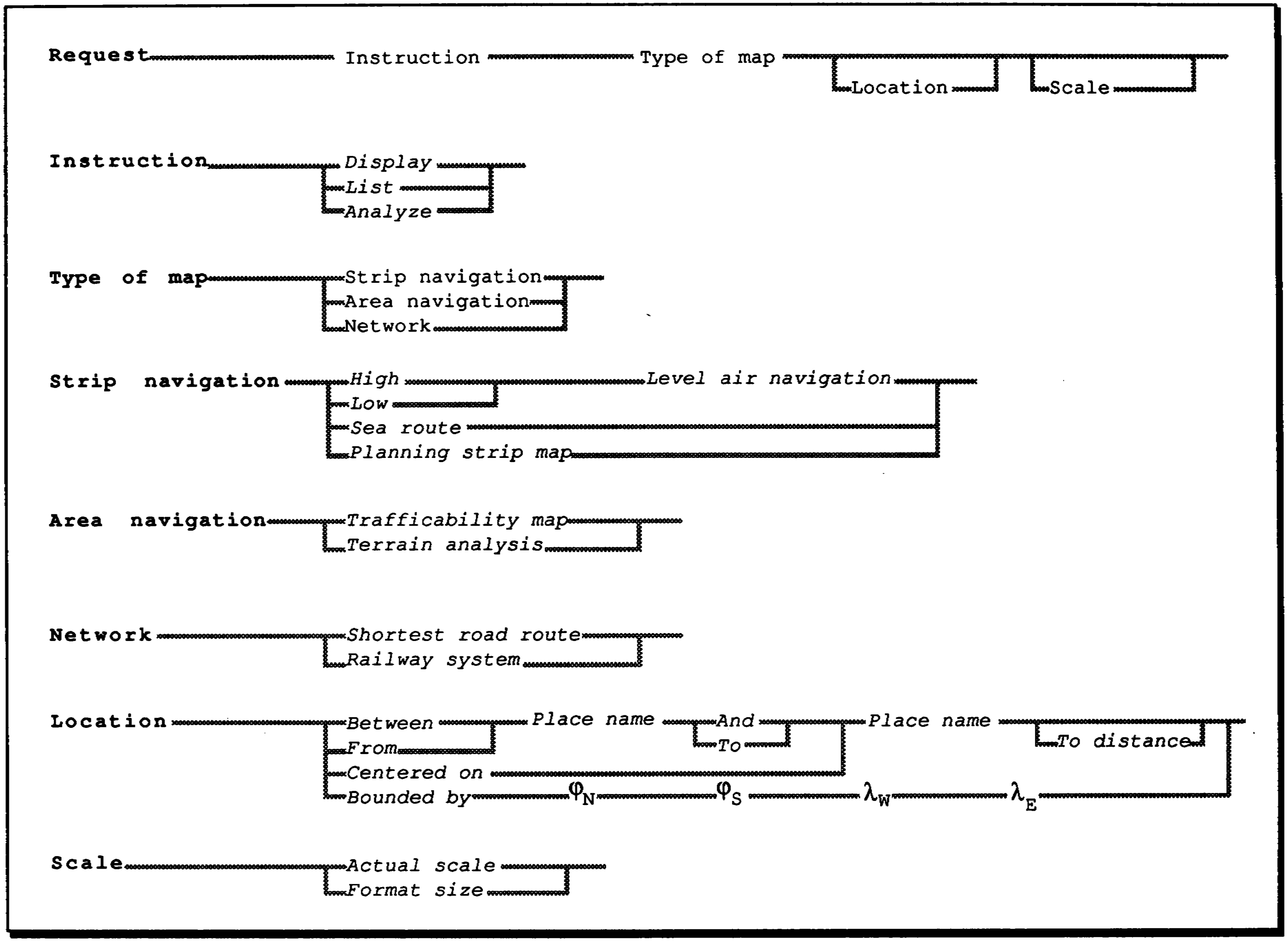


Figure 54: Product definition using 'railroad' form

In response to this situation, Laut proposes heuristic approaches. Laut's approach is based on two decades of research in describing landscape units (Laut et al, 1977), and on research into *expert systems* techniques in evaluating north Australian landscapes for livestock mustering. This latter research depended upon reliable information from individuals within the industry rather than mathematical models. Owners and managers of northern pastoral properties and contract musterers were consulted to provide opinions as to how landscape elements hindered or assisted cattle mustering. Laut notes that expert system techniques can be used for many terrain analysis applications and itemizes the estimation of the effects of fire on vegetation to be but one. Figure 55 is a decision tree (from Laut, 1987) showing cross-country trafficability ratings and demonstrating heuristic techniques.

In addition to applications involving analysis, whether by algorithmic or heuristic techniques, expert system technology offers tools for simulation and predictive analysis including the superimposition of images on cartographic data (such as architectural montages). Nakamae et al (1986) observe that in order to assess the potential impact of a new construction on local environments, it is important to understand the effects of viewing angles, local lighting and shadows, while U.S. Army Corps of Engineers Engineer Topographic Laboraties (ETL, 1985) comment that 'computer image generation' technology can combine information from digital feature files, digital photographs, elevation data and satellite imagery to create views that are shaded, three-dimensional and perspectively correct. ETL suggest that resulting scenes depict natural features of the terrain as well as man-made objects as bridges and buildings, and along with simulations of clouds, fog and other weather effects provide added realism, and one day may assist commanders plan battlefield maneuvers.

Further, McLaren (1989) summarizes that "traditionally, landscape visualization techniques have involved the building of physical models or the creation of artist's impressions. However, these are time consuming to create, and are inherently

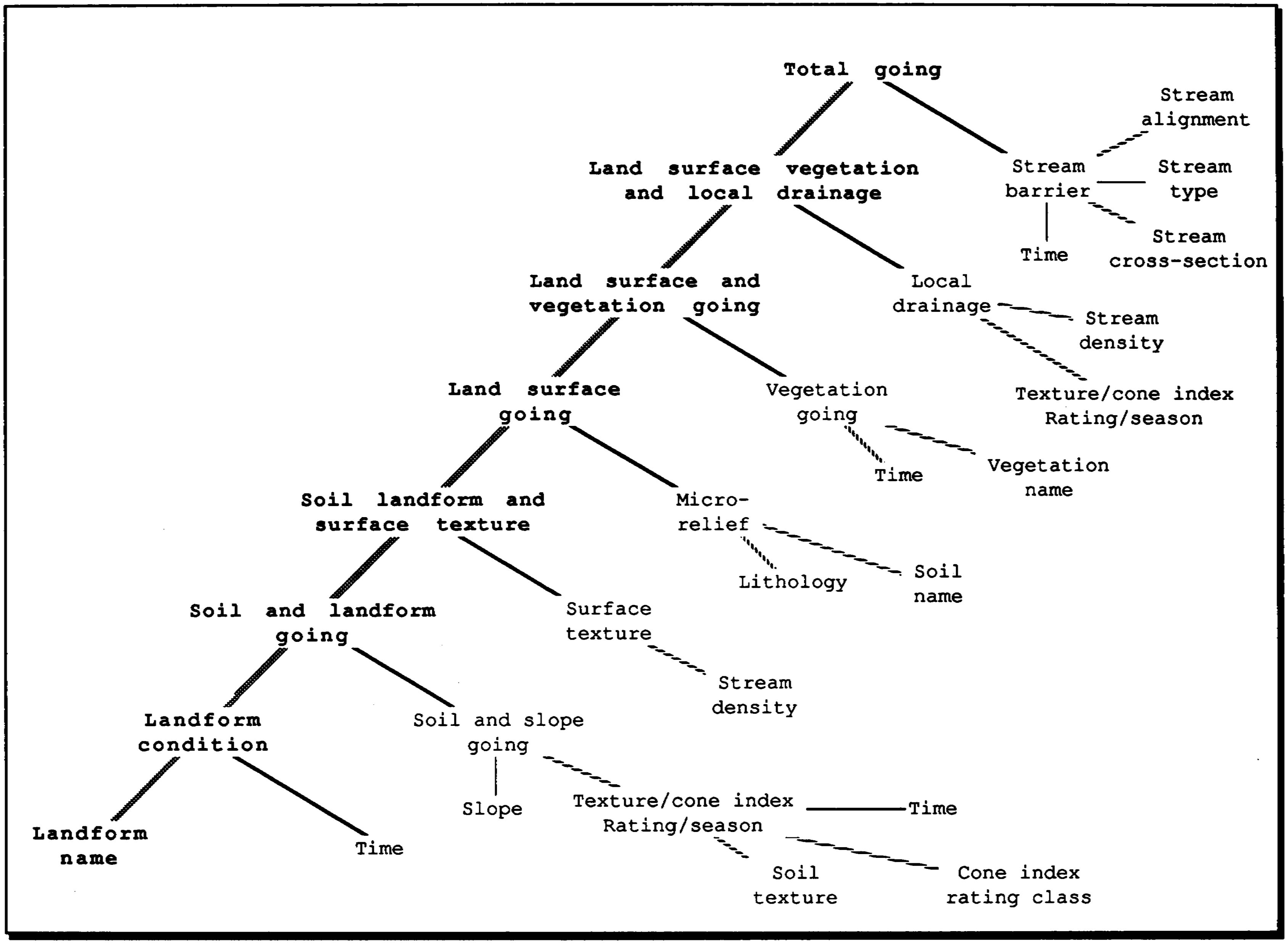


Figure 55: Decision tree for cross-country trafficability rating

and inflexible once created. In order to more accurately quantify the level of visual intrusion, computer graphic modeling and visualization techniques are increasingly being used in the planning and design of landscape projects". McLaren states that rendering processes are well established. These processes include geometric transformation, depth cueing (techniques to match 3-D interpretability in a 2-D space), hidden surface removal (edges and surfaces that are obscured by other surfaces), anti-aliasing (elimination of image distortion due to improper sampling), shading and shadows, surface texture detail, and atmospheric attenuation. McLaren concludes that "in the geographic information system environment, visualisation techniques are recognized as an invaluable system component, aiding in the interpretation of spatially related phenomena and complex data analyses that takes the technology a step beyond two dimensional polygonal overlay analysis".

8.7 Conclusion

Discussion in the preceding section has not examined any particular technique in detail, but has recognized that effective *decision support* depends on analysis and integration of a diversity of geographic information themes and evolving algorithmic and heuristic techniques. These techniques will have the potential to complement accepted heuristic techniques, such as described in the 'Case study - Road Network Analysis', and information search techniques, as discussed in the 'Case study - the Roper Corridor'. The result will be powerful *decision-support systems* operating on *operational databases* and *expertise databases* created as the result of previous heuristic analyses.

Until such *decision-support systems* are developed, a subset of the *subject databases* and sets of *product construction* rules offer the ability to produce *standard map and database products*.

Chapter 9
SUMMARY

9.1 Trends in cartographic theory

Computers have been used to process geographic data for up to two and a half decades. Major technological advances occurred when scientists at the Experimental Cartographic Unit (UK) developed the first digitizing tables (Bickmore, 1964); academic researchers realized the potential for applying analytical techniques to three dimensional models of the terrain (Yoelli, 1959) and managing natural and man-made resources (Tomlinson, 1972); and photogrammetrists first began using analytical techniques for photogrammetric mensuration and adjustment (Friedman *et al*, 1980, p.703).

However, because of different emphases placed on the management and use of geographic data by mapping agencies and resource management organizations, two distinct trends occurred in the evolution and development of digital cartography (Figure 56). The trend followed by the mapping organizations has become known as *computer-assisted mapping* (or *computer-assisted cartography*). This trend has emphasized graphic representation of data, classification and categorization of geographic features, and is characterized by the importance placed on coordinate referencing and positional accuracies. The second trend, generally known or associated with *geographic information systems*, has been favoured by resource and some utility managers. This second primary trend, in turn, consists of three definite sub-trends. These sub-trends are:

a. Terrain modeling, which has featured three dimensional representation of terrain data and analytical tools associated with slope, aspect, viewsheds, volumes, and so on, being of particular benefit to engineering applications;

b. Remote sensing (particularly satellite imagery) which has particular application in monitoring the earth's environment; and

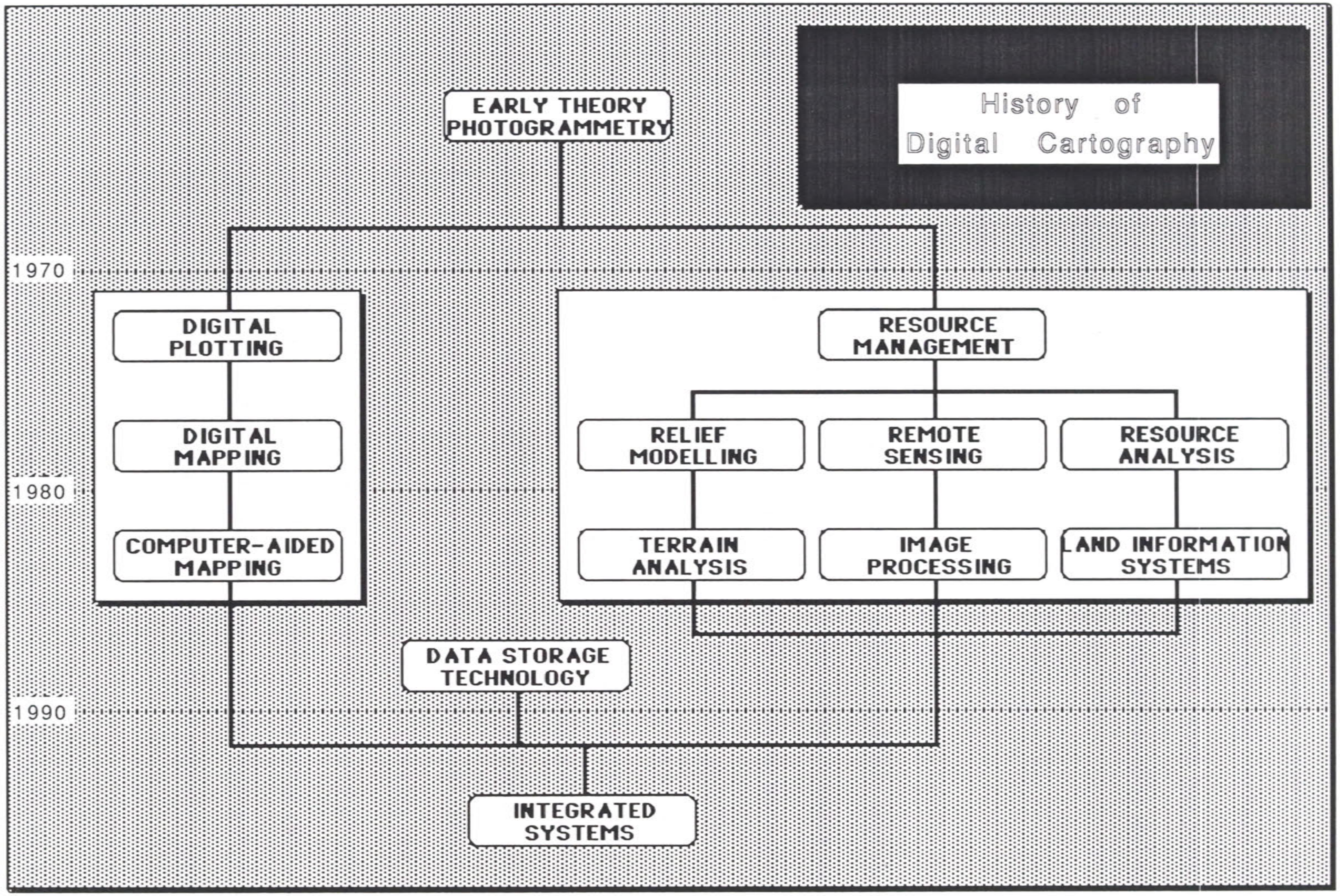


Figure 56: History of digital cartography

c. Land information systems (or multipurpose cadastre systems) whose development has been characterized in recent years by the emphasis placed on topological structuring of cartographic data, and which has particular reference to local and regional resource and property managers and utility organizations.

9.2 Thesis review

Until recently, these trends were often viewed as non-compatible approaches designed for different markets. But today's mapping market and resource managers are seeing a shift toward integrated and decision-support systems and operations management. Chapter 2, 3 and 4 reviewed these trends by discussing 'Traditional Approaches in Managing Digital Geographic Data' (Chapter 2), 'Traditional Techniques in Structuring Digital Geographic Data' (Chapter 3), and 'Trends in Digital Cartography and Geographic Information System Development' (Chapter 4). Chapter 4, also, included discussion on *intelligent and expert systems* and noted that intelligence can be achieved via two fundamental, but integrated sources. These sources are those of data relationships and structure; and techniques and procedures for manipulating and analyzing the data relationships. These characteristics were subsequently equated to the notions of *geographic knowledge bases* and *geographic knowledge rules*; the former notion being concerned with the organization and structuring of geographic phenomena while the latter notion was concerned with analyzing and interpreting aspects and relationships (or cognitive aspects) of the geographic reality.

Chapter 5 examined 'Aspects of Phenomenology' by examining fundamental definitions of geography, discussing contemporary research into data models, and proposing methodologies for describing and organizing the geographic phenomena. These methodologies included the definition of the domain of geographic features into *world views*; recognition of the importance of geographic location and referencing; knowledge of data lineage; and inclusion of geophysical and temporal considerations. The chapter concluded by observing that under the *expert system* approach, aspects of data reality corresponded to a formal definition of public knowledge and constituted a *geographic knowledge base.*

Chapter 6 examined 'Aspects of Cognition', noting that "cognition refers to awareness, attitudes, impressions, images, and beliefs that people have about their environments". The chapter reviewed definitions of *cartography* from the literature, noting that, as well as conventional maps, *cognitive* or *mental* maps were considered to be a part of cartography. Discussion then addressed cognition from an application and analysis viewpoint, and introduced non-conventional techniques for communicating geographic images; techniques that included the use of *fuzzy* (or locational) topology, pictures and sound. The chapter concluded by noting that the chapter was concerned with geographical images of the environment and argued that conventional cartography and present geographic information systems were concerned only with a subset of geographic reality and that future systems should be more innovative by addressing more complex geographic problems and the communication of the results using a variety of methods, particularly as "public awareness of environmental issues has strengthened in recent times".

Chapters 7 and 8 were consistent with the concepts discussed in chapters 5 and 6 respectively. Chapter 7, titled 'Geographic Knowledge-Bases', emphasized that the structure of geographic information from a phenomenological viewpoint is concerned with finding out *what* things are. To address this aim, the chapter examined knowledge representation, particularly non-traditional representation and meta-knowledge. The domain of geographic features was discussed in greater detail than preceding chapters and listed themes based on *world views.* This list of themes may appear to be logical and obvious but are, indeed, non-traditional in that mapping organizations have often organized data related to map production requirements while resource managers have organized data biased towards their particular application with background data being compiled in general overlays. The chapter then introduced two *identifiable concepts* - a *cognitive concept* and a *product concept*; the former corresponding to mental and dynamic interpretations of the domain of geographic features and the latter corresponding to formalized and symbolized representations of the domain, such maps and database products. *Meta-knowledge* was then described as the description of information about an identifiable concept and consisted of identification, general description, locational description, resolution, geographic extent, role and functional descriptions, relationships with higher level features, and directories of available theme-oriented information. The chapter then analyzed object structures, object representation, object relationships, the representation of objects and features within themes, and concluded by noting certain conflicts between *identifiable concepts* and *world view* representations of data. The conclusion to the chapter proposed the establishment of a database strategy which consisted of *subject databases* that had data organized and managed independent of any one application but best replicating its *real world* structure; and *product* or *operational databases* configured for specialist purposes, the latter possibly including *expertise databases* that contained results of previous analyses thereby establishing a 'learning system'.

Chapter 8, 'Geographic Knowledge-Rules', commenced by defining *expert* and *decision-support systems*. Discussion followed on rules and techniques to construct standard series map products, derived standard series map products, operational charts and standardized database products. The chapter then examined phenomenon-based information systems, including algorithms, formulae and heuristic techniques applicable to infrastructure-related applications, and concluded by suggesting that effective *decision-support systems* depend on analysis and integration of a diversity of geographic information along with evolving algorithmic and heuristic techniques. Resultant *decision-support systems* will operate on *operational databases* and, possibly, *expertise databases* created as the result of previous heuristic analyses.

This research has challenged existing digital cartographic theory and has introduced a number of significant concepts.

9.3 Significant aspects of the research

Fundamental to this research is the emphasis placed on modeling the 'real world' as opposed to modeling geometric abstractions of the world. Further, the entire domain of geographic themes has been discussed to greater or lesser degree. In adopting such a methodology, relationships, structures and analyses were discussed according to 'real world' perspectives. As an example, the topology of the road network is a specific form of a graph structure as well as being layered to transportation management guidelines. Under such a viewpoint, full (or total) integration of topology with all other features, such as vegetation boundaries, is irrelevant. If that particular relationship is required, then it should be obtained via analyses.

9.3.1 Identifiable concepts. The notion of 'identifiable concepts' requires that information be organized and managed in modules related to identifiable regions, places, and so on, as opposed to being organized in regular tiles or other abstract partitioning systems. Such an approach facilitates the management of information from a 'variable' perspective with respect to aspects of resolution (or scale) and geographic extent (or area of coverage), and that these characteristics are achieved to the quality that the concept (and inclusive features) warrant.

9.3.2 Meta-knowledge. Meta-knowledge is concerned with the definition of 'identifiable concepts'. Such a knowledge structure permits high-level querying of information, thus minimizing information retrieval time thereby enables decision-support to be offered more efficiently than through current techniques.

9.3.3 Product construction. In any production environment it is desirable to replicate products consistently and efficiently. To this end, sets of rules and production techniques need to be formalized and implemented in an automated manner. Standard series products and operational databases lend themselves to this methodology.

9.4 Comparison with contemporary research

This research differs from contemporary research agendas in a number of significant ways. Apart from the characteristics identified above, there are several aspects that are conceptually opposite to current trends.

9.4.1 *Top-down* approach. The entire design of the geographic model and support software to demonstrate and confirm research direction has been implemented in a 'top-down' technique. [The software, written by the author, consisting of 4 separate programs totalling over 14,000 lines of *LightSpeed PASCAL* and compiling 3Mb of executable code written for an *Apple Macintosh IIx* computer, has not been included with this thesis. The programs interrogate 99 files and directories]

This 'top-down' structure is apparent from the notion of identifiable concepts, which in turn own, or are composed of, objects and features - each in turn, of which may be identifiable concepts. Figures 27, 28, 29, 30, 36, 38, 39, 45, 46, 47, 48, 50, 51, 52, 53, and 56 have been produced by author written software. (Some Figures are composites of a number of displays.)

A 'top-down' model implies a logically continuous data model with increasing levels of detail being achieved through new concepts and managed through meta-knowledge. A 'top-down' approach also *orders* features hierarchically. This implies *dependency* amongst features, an example being a bridge which is dependent on a higher order feature such as a road. This approach also reverses current descriptive techniques as implemented in relational database systems. For example, most contemporary systems and current research would represent a 'building' as a feature (say) of type 'residence' in place

'Canberra'. This 'top down' model, on the other hand, defines the example as the populated place, or city, of 'Canberra ' [from the Habitation and Population theme] which is composed of objects and features from the domain of themes including 'residential areas', or 'suburbs' [from the Habitation and Population theme]. These features are, in turn, composed of objects and features from the domain of themes including 'buildings' [again from the Habitation and Population theme].

9.4.2 Object-orientation. Although recent literature identifies 'object-oriented' techniques as being desirable forms of representing geographic information, the literature is, in many instances, unclear as to what 'objects' are. For example, a square with a cross on top might well be considered an object designed to represent a church, or (say) a transportation system consisting of artificial transportation links (highways and channels) and natural transportation links (say navigable rivers). Nevertheless, object-oriented data models are composed of the concepts of abstraction, classification, generalization, association, and aggregation. This thesis considers objects to be related to complex features and associated features within the world view themes; as a water storage complex plus associated distribution network in the water resources theme.

9.4.3 Cognitive approach. This research has continually referred to world view themes and cognitive approaches implying phenomenological structuring of information as opposed to geometric structuring of cartographic data.

9.4.4 Subject and operational databases. Historically, definitions of Geographic Information Systems have included data input, data processing, and data output as fundamental requirements of any Geographic Information System. These basic functions have been needed (in the one system) because users (and researchers) generally have needed to input there own data. Because of the requirements at the data input stage, particularly for data validation, data structures have often been influenced by these requirements to the detriment of structures suitable for subsequent applications.

Additionally, database design (note that most *computer-assisted mapping* systems do not have databases) has often been influenced by a compromise between requirements of input functions and data, and products, which in some instances includes processed and generalized data, as is the case in the generalization of a group of houses.

This research proposes the establishment of *subject databases* that are application independent and are characterized by integrity and positional (or plan) characteristics, these being established and maintained by 'data gathering' organizations (such as the major mapping organizations). It also proposes the establishment of *operational databases* that are the results of some form of specialized analysis and configured for use by 'decision-makers' and analysts.

9.4.5 Logical continuity and consistency. The use of 'top-down' structures, identifiable concepts, meta-knowledge, and world view themes provides the model to process geographic information that is logically consistent and continuous; properties that are supported in recent literature. The most recent comment (or speculation) on continuous databases, both from scaleless and seamless perspectives, is that by Guptill (1989) who states that "the seamless requirement to traverse the entire data base and retrieve various elements implies that the Data Base Management System must support abstract data types and user-defined indexes. The scaleless requirement to vary data base resolution implies that the Data Base Management System supports multiple representations, user-defined operators, and rules. Spatial data users are the driving force toward seamless, scaleless spatial data bases. Data producers would have difficulty justifying such capabilities unless they were needed to satisfy their own internal use. GIS users, on the other hand, would probably prefer to view their study area in total, not arbitrarily partitioned by map sheet edges or affected by varying resolution data within the area. With extensible DBMS's, the technology to handle seamless, scaleless data bases is almost at hand. The burden is, therefore, placed on data producers to create future data-base designs that do not preclude users from creating seamless, scaleless versions.

Toward this end, the adoption by many mapping agencies of a feature-based, object-oriented data model is a positive step."

9.5 A model based on phenomenology and cognition

In summary, this research recognizes differences between knowledge bases oriented towards the requirements of 'real world' structures and knowledge bases oriented towards specific applications. As such, it concludes that two major forms of geographic knowledge base are desirable. One is a *subject database* consisting of information from the domain of geographic features containing meta-knowledge and object structures relevant to management of the information as it appears in the 'real world'. The other is an *operational database* being configured for specific applications and containing meta-knowledge and object structures relevant to the identifiable concepts and analysis requirements of the application.

Standard products, maps and digital products, as well as operational databases, could be produced using 'product construction' techniques from the subject databases. Information systems and decision-support systems could then be designed using appropriate algorithms and heuristic techniques and accessing the operational database. A 'learning ability' could be obtained by creating an expertise database which organizes the results of previous or confirmed and validated analyses (Figure 57).

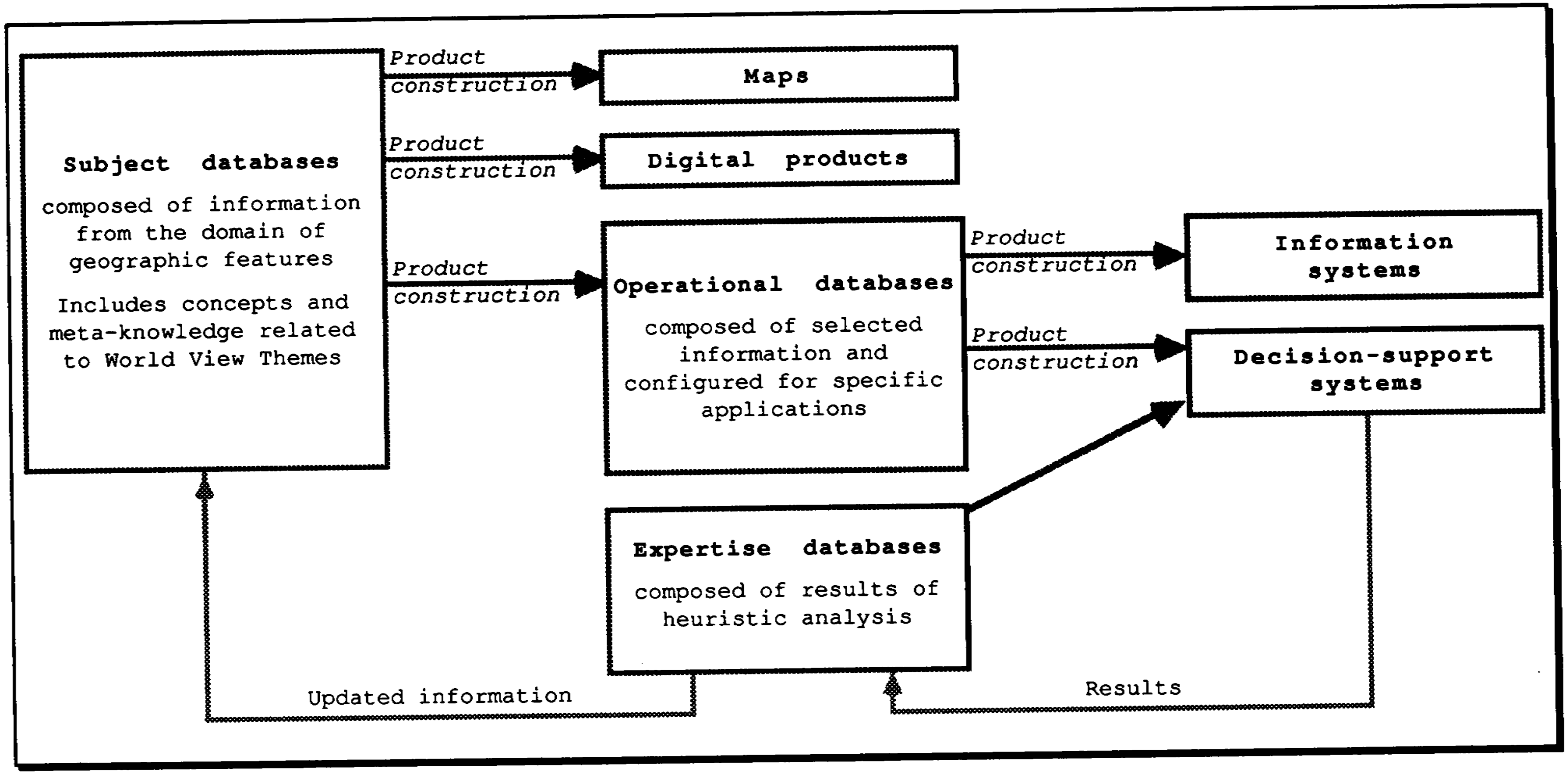


Figure 57: A model based on phenomenology and cognition

Chapter 10
CONCLUSION

10.1 Cartographic theory

The approach taken in this thesis has been to investigate the representation and analysis of geographic information from *phenomenological* and *cognitive* viewpoints. This approach implies that structural relationships have been investigated based on their occurrence in the 'real world' and the way in which features are managed and processed in the 'real world'. This approach differs from most other research which essentially investigates geographic data based on cartographic representations of features, thereby commencing with an abstraction and symbolic representation of data.

This *phenomenological* and *cognitive* approach has emphasized high level formalization and the importance of knowledge of general properties, significant properties, inter-relations and regularities of 'real world' geographic data. In expounding this methodology, the theory has been presented in a more abstract logical form than most other contemporary research in geographic data structures and automated cartography. Shiryaev (1987, p.34) states that "those dealing with the applications of automation and computer technology know very well that without the formalization of theory there can be no progress in science. [Pure] theory presents itself in an abstract logical form; it does not reflect the mapped content in concrete manifestations of objects or phenomena, but covers their most general and significant properties which they have in common with other objects and phenomena".

The view that communication and formalization play a decisive role in the development of cartographic theory is shared by an overwhelming majority of specialists. Cartographic theory can be considered as a derivative of geographical analysis, Shiryaev however regards the development of cartographic theory as totally dependent on the concrete content. From this view it follows that there can be no theory free of concrete content, there can only be a semi-theory - semi-practice, focused specifically on concrete objectives, constituting in fact a technique tied up with concrete content (geomorphology, demography, etc). Shiryaev further believes that "consequently all attempts to visualize the boundaries of a unified theory are futile, and it is impossible to arrive at a general theory of cartography that would incorporate the most general properties, categories, and principles inherent in a large number of objects and phenomena (geomorphological, tectonic, pedological, etc) at a more generalized, formal logical level, since it will be divorced from concrete content".

Although the emphasis of this thesis has been on high-level formalization of geographic information, the thesis still addresses only a semi-theory, and, indeed, the notion - *phenomenology* - which has been used throughout this thesis, does not assert the existence of an absolute knowledge. Boland (1986) suggests that "in the end, a phenomenological study cannot claim to have proof of its findings, only a reliance on its method and the hope that others will 'see' its descriptions as true and accurate".

10.2 Concluding remarks

In addition to the methodology outlined above, emphasis has been placed on society's need for information and knowledge of the environment in general, and decision makers and geographic information analysts in particular. This implies that geographic data base design and the construction of management tools need to reflect 'real world' structures and requirements as opposed to abstract geometric structures and relatively simple analyses.

Indeed, much research with respect to the analysis of geographic spatial data and cartography, in recent times, has been *reactive* ; that is, research has tended to follow applications and low-level techniques and production methodologies. In fact, many of the existing research papers often commence with discussion on low-level geometric topology, and the like, and tend to develop from that base. This research, however, has accepted that theory and considers such details as primitives, albeit mandatory primitives, and has taken the conceptually opposite approach by attempting to describe information and processes using high-level structures. Indeed, in concluding, the definition of **cartography** could well be presented from a high-level viewpoint as:

Cartography is the

"representation and communication of geographic phenomena".

This high-level definition is surprisingly little different from the first known definition published in *Geógraphica of Claudius Ptolemy - English Translation. 2nd Century AD* (the term *chorography* was used instead of the modern term *cartography*) from McCarthy (1988):

"A representation in picture of the whole known world together with the phenomena which are contained therein"

REFERENCES

AS-2482 (1984). "Interchange of Feature Coded Digital Mapping Data", **Australian Standard (AS 2482-1984).**

ASP (1980). **Manual of Photogrammetry**, Ed 4, Editor-in-Chief Chester C. Slama, American Society for Photogrammetry , Falls Church, VA.

Austin, M.P. and K.D.Cocks, eds. (1978). "Land use on the South Coast of New South Wales: A study in method of acquiring and using information to analyze regional land use options", Vol 1: General Report CSIRO, Melbourne.

Australasian Advisory Committee on Land Information (AACLI) (1987). **Recent developments in land information systems, Australasia**, Australian Government Publishing Service, Canberra.

Ayers, E. H. (1984). "Implementation of modern land records systems: Politics and institutional reform", Paper presented to **Seminar on the Multipurpose Cadastre: Modernizing Land Information Systems in North America**, The Institute for Environmental Studies, University of Wisconsin-Madison.

Baker, G. J. (1984). "Computer-assisted cartography in the Royal Australian Survey Corps: AUTOMAP 2", **Proceedings - Austra Carto One**, Australian Institute of Cartographers, Perth.

Ball, D. (1988). "Geographic Information Systems and the Defence of Australia: Introduction", in **Geographic Information in the Defence of Australia**, Australian Defence Force Academy, Canberra.

Ballard, D.H. (1981). "Strip trees: A hierarchical representation for curves", **Communications of the ACM**, Vol. 24, No. 5, May 81.

Bernstein, R. (1983). "Image geometry and rectification", **Manual of Remote Sensing**, 2 Ed, Vol 1, Ed Robert N.Colwell, American Society of Photogrammetry, Falls Church, VA.

Berry, J.K. (1987). "Fundamental operations in computer-assisted map analysis", **International Journal Geographical Information Systems**, Vol. 1, No. 2, Taylor and Francis, London.

Berry, J.K. and K.L. Reed (1987). "Computer-assisted map analysis: A set of primitive operators for a flexible approach", **Proceedings - 1987 ASPRS-ACSM Annual Convention**, Vol 1, American Society for Photogrammetry and Remote Sensing and American Congress on Surveying and Mapping, Falls Church, VA.

Bickmore, D.P. (1964). "An automatic system of cartography", Paper presented to **International Cartographic Association** meeting held at Imperial College London, 31 July 1964.

Boland, R.J. Jr (1986). "Phenomenology: A preferred Approach to Research on Information Systems" in **Trends in Information Systems**, eds. B.Langefors, A.A.Verrign-Stuart, G.Bracchi, North-Holland, Amsterdam.

Bomford, G. (1971). **Geodesy**, 3rd Ed, Clarendon Press, Oxford.

Bouillé, F. (1978). "Structuring cartographic data and spatial processes with the Hypergraph-Based Data Structure", **Harvard Papers on Geographic Information Systems,** Ed G. Dutton, Vol 5, Laboratory for Computer Graphics and Spatial Analysis, Harvard University, Cambridge, MA.

Bouillé, F. (1986). "Interfacing cartographic knowledge structures and robotics", **Proceedings - Auto Carto London,** Vol 2, Ed Michael Blakemore, International cartographic Association.

Boyle, A.R., J.Dangermond, D. Marble, D.S.Simonett and R.Tomlinson (1983). "Review and synthesis of problems and directions for large-scale geographic information systems", **NASA Contract NAS2-11346,** Environmental Systems Research Institute, Redlands, CA.

Brassel, K.E. (1978). "A topological data structure for multi-level map processing", **Harvard Papers on Geographic Information Systems,** Ed G. Dutton, Vol 4, Laboratory for Computer Graphics and Spatial Analysis, Harvard University, Cambridge, MA.

Bruegger, B.P. and A.U.Frank (1989). "Hierarchies over topological data structures", **Technical Papers 1989 ASPRS/ACSM Annual Convention - GIS/LIS,** Volume 4, American Society for Photogrammetry and Remote Sensing and American Congress on Surveying and Mapping, Falls Church, VA.

Bryant, N.A. and A.L.Zobrist (1978). "An image-based information system: Architecture for correlating satellite and topological data bases", **Harvard Papers on Geographic Information Systems,** Ed G. Dutton, Vol 4, Laboratory for Computer Graphics and Spatial Analysis, Harvard University, Cambridge, MA.

Bullard, Sir E. (1972). "The Earth's Magnetic Field and its Origin" in **Understanding the Earth: A Reader in the Earth Sciences**, eds. I.G.Gass P.J.Smith and R.C.L.Wilson, 2nd Edition, The Open University Press, Sussex, UK.

Calkins, H.M. (1977). "Information system developments in North America" in **Proceeding of the Commission on Geographic Data Sensing and Processing Moscow 1976**, Ed. R.F.Tomlinson,Commission on Geographical Data Sensing and Processing, International Geographical Union.

Chorley, Lord (1987). **Handling Geographic Information**, Report to the Secretary of State for the Environment of the Committee of Enquiry into the Handling of Geographic Information, Her Majesty's Stationery Office, London, UK.

Chrisman, N.R. (1978) "Concepts of space as a guide to cartographic data structures", **Harvard Papers on Geographic Information Systems**, Ed G. Dutton, Vol 7, Laboratory for Computer Graphics and Spatial Analysis, Harvard University, Cambridge, MA.

Chrisman, N.R. (1982). "A theory of cartographic error and its measurement in digital data bases", **Proceeding - Auto-Carto 5**, American Society for Photogrammetry and Remote Sensing and American Congress on Surveying and Mapping, Falls Church, VA.

Chrisman, N.R. (1983). "The role of quality information in the long-term functioning of a geographic information system", **Proceeding - Auto-Carto Six**, Vol 1, Sixth International Symposium on Automated Cartography, Ottawa, Canada.

Chrisman, N.R. (1987) "Fundamental Principles of Geographic Information Systems", **Proceedings - Auto-Carto 8,** American Society for Photogrammetry and Remote Sensing and American Congress on Surveying and Mapping, Falls Church, VA.

Chrisman, N.R. (1987b). "The accuracy of map overlays: A reassessment", **Landscape and Urban Planning,** Elsevier Science Publishers, Amsterdam.

Chrisman, N.R. and B.J.Niemann,Jr (1985). "Alternative Routes to a Multipurpose Cadastre: Merging Institutional and Technical Reasoning", **Proceedings - Auto-Carto 7,** American Society for Photogrammetry and Remote Sensing and American Congress on Surveying and Mapping, Falls Church, VA.

Clark, David (1969). **Plane and Geodetic Surveying: For Engineers,** Vol 2, 6th Edn, Constable, London,UK.

Cocks, K.D.(1979). "Experiences with the South Coast Data Bank / Mapping System", Paper presented to **Workshop/Seminar on Geographic Information Systems,** 5-7 December 1979, School of Pacific Studies, Australian National University, Canberra.

Cook, B.G. (1978). "The structural and algorithmic basis of a geographic data base", **Harvard Papers on Geographic Information Systems,** Ed G. Dutton, Vol 4, Laboratory for Computer Graphics and Spatial Analysis, Harvard University, Cambridge, MA.

Domaratz, M.A. and H. Moellering (1986). "The encoding of cartographic objects using HBDS concepts", **Proceedings - Auto Carto London,** Vol 1, Ed M. Blakemore, International Cartographic Association.

Dangermond, J. (1982). "Software components commonly used in Geographic Information Systems", Paper presented at **Harvard Computer Graphics Week**, Laboratory for Computer Graphics and Spatial Analysis, Harvard University, Cambridge, MA.

Dueker, K.J. (1985). "Geographic information systems: Toward a geo-relational structure", **Proceedings - Auto-Carto 7**, American Society for Photogrammetry and Remote Sensing and American Congress on Surveying and Mapping, Falls Church, VA.

Dutton, G., Ed. (1978). "First International Advanced Study Symposium on Topological Data Structures for Geographic Information Systems", **Harvard Papers on Geographic Information Systems**, 8 volumes, Laboratory for Computer Graphics and Spatial Analysis, Harvard University, Cambridge, MA.

Egenhofer, M.J. and A.U.Frank (1989). "Object-Oriented Modeling in GIS: Inheritance and Propagation", **Proceedings - Auto-Carto 9**, American Society for Photogrammetry and Remote Sensing and American Congress on Surveying and Mapping, Falls Church, VA.

Ehlert, von D. (1978). "Numerisch stabile Berechnung spärischer Dreiecke" in **Zeitschrift für Vermessungswesen**.

ETL (1985). **Organizational Activities**, U.S. Engineer Topographic Laboratories, Fort Belvoir, VA.

Fegeas, R.G. (1982). "Modularization of digital cartographic data capture", **Proceedings - Auto-Carto 5**, American Society for Photogrammetry and Remote Sensing and American Congress on Surveying and Mapping, Falls Church, VA.

Franklin, D.P. (1986). "Digital mapping: Fact or fiction", **Proceedings - Auto Carto London**, Vol 2, Ed Michael Blakemore, International cartographic Association.

Freeman, H (1974). "Computer processing of line drawing images", **Computing Surveys**, 6,57.

Friedman, S.J., J.B.Case, U.V.Helava, G.Konechny, H.M.Allam (1980). "Automation of the photogrammetric process", **Manual of Photogrammetry**, Fourth Edition, Editor-in-Chief C.C.Slama, American Society of Photogrammetry, Falls Church, VA.

Gass, I.G., P.J.Smith and R.C.LWilson (eds) (1972). **Understanding the Earth: A Reader in the Earth Sciences**, 2nd Edition, The Open University Press, Sussex, UK.

Gilbert, G. and D.Rooke (1987). "Computerised screening and stippling using the Royal Australian Survey Corps Automap 2 system", **Cartography**, Vol 16, No 2, The Australian Institute of Cartographers.

Goodchild, M.F. (1978). "Statistical aspects of the polygon overlay problem", **Harvard Papers on Geographic Information Systems**, Ed G. Dutton, Vol 6, Laboratory for Computer Graphics and Spatial Analysis, Harvard University, Cambridge, MA.

Grady, R.K. (1986). "New-age cartography", **Computer Graphics World**, 9, 10.

Guptill, S.C. and L.E.Starr (1984). "The future of cartography in the information age", **Computer-Assisted Cartography Research and Development Report**, International Cartographic Association, Commission C.

Guptill, S.C., K.J. Boyko, M.A. Domaratz, R.G. Fegeas and D.E. Hair (1987). "An Enhanced Digital Line Graph Design", Internal Paper of the National Mapping Division, United States Geological Survey, Washington, DC.

Guptill, S.C. (1989). "Speculations on Seamless, Scaleless Cartographic Data Bases", **Proceedings - Auto-Carto 9**, American Society for Photogrammetry and Remote Sensing and American Congress on Surveying and Mapping, Falls Church, VA.

Haggett, P. (1972). **Geography: A Modern Synthesis**, Harper and Row, New York, NY.

Hayes-Roth, F, D.A.Waterman and D.B.Lenat (1983). **Building Expert Systems**, Addison-Wesley Publishing Company, Reading, MA.

Huxhold, W.E., Allen, R.K. and Gshwind, R.A. (1982). "An Evaluation of the City of Milwaukee Automated Geographic Information and Cartographic System in Retrospect", Paper presented at **Harvard Computer Graphics Week**.

International Cartographic Association (1973). **Multilingual Dictionary of Technical Terms in Cartography**, Franz Steiner Verlag, Weisbaden, Germany.

Kennedy-Smith, G.M. (1986). "Data quality - A management philosophy", **Proceedings - Auto Carto London**, Vol 1, Ed Michael Blakemore, International Cartographic Association.

Klinger, A. (1971). "Patterns and search statistics", in **Optimizing Methods in Statistics**, J.S.Rustagi, ed., Academic Press, New York, NY.

Laut, P., P.C.Heyligers, G. Keig, E.Löffler, C.Margules and R.M.Scott (1977). **Environments of South Australia**, Handbook and 7 volumes, Commonwealth Scientific and Industrial Research Organization, Canberra.

Laut, P. and R. Davis (1987). "Landscape data and evaluation of cross-country trafficability for Cape York Peninsula", Paper presented to **Strategic and Defence Studies Centre Workshop on Geographic Information Systems and Australian Defence Force Requirements**, The Research School of Pacific Studies, The Australian National University, Canberra.

Lee, R.M. (1986). "Epistemological Aspects of Knowledge-Based DSS", in **Trends in Information Systems**, eds. B.Langefors, A.A.Verrign-Stuart, G.Bracchi, North-Holland, Amsterdam.

Lupien, A.E. and W.H. Moreland (1987). "A general approach to map conflation", **Proceedings - Auto-Carto 8**, American Society for Photogrammetry and Remote Sensing and American Congress on Surveying and Mapping, Falls Church, VA.

Lynch, M. and A. Saalfeld (1985). "Conflation: Automated map compilation, a video game approach", **Proceedings - Auto-Carto 7**, American Society for Photogrammetry and Remote Sensing and American Congress on Surveying and Mapping, Falls Church, VA.

Macomber, M.M. and D. Franklin (1984). "Development of a digital mapping program at the Defense Mapping Agency", Paper presented to **Seminar on the Multipurpose Cadastre: Modernizing Land Information Systems in North America**, The Institute for Environmental Studies, University of Wisconsin-Madison, WI.

Males, R.M. (1978). "ADAPT - A spatial data structure for use with planning and design models", **Harvard Papers on Geographic Information Systems**, Ed G. Dutton, Vol 3, Laboratory for Computer Graphics and Spatial Analysis, Harvard University, Cambridge, MA.

Maling, D.H. (1973). **Coordinate Systems and Map Projections**, George Philip and Son Limited, London, UK.

Marble, D.F. and D.J. Peuquet (1983) "Geographic information systems", **Manual of Remote Sensing**, 2 Ed, Vol 2, Ed R.N. Colwell, American Society of Photogrammetry, Falls Church, VA.

Mark, D.M. (1987). "On giving and receiving directions: Cartographic and cognitive issues", **Proceedings - Auto-Carto 8**, American Society for Photogrammetry and Remote Sensing and American Congress on Surveying and Mapping, Falls Church, VA.

McCarthy, J.E. (1988). **Mapmakers of Australia: The History of the Australian Institute of Cartographers**, The Australian Institute of Cartographers, Canberra.

McEwan, R.B. and H.W. Calkins (1982). "Digital cartography in the USGS National Mapping Division: A comparison of current and future mapping processes", **Cartographica: Perspectives in the alternative cartography**, Vol 19, No 2, Monograph 28, Ed David P.Bickmore, University of Toronto Press, Toronto, Canada.

McKenna, D.G. (1987). "The inward spiral method: An improved TIN generation technique and data structure for land planning applications", **Proceedings - Auto-Carto 8**, American Society for Photogrammetry and Remote Sensing and American Congress on Surveying and Mapping, Falls Church, VA.

McKeown, D.M. Jr (1983). "Concept Maps", Technical Report CMU-CS-83-117, Carnegie-Mellon University, Pittsburgh, PA.

McKeown, D.M.Jr (1987). "The Role of Artificial Intelligence in the Integration of Remotely Sensed Data with Geographic Information Systems", **IEEE Transactions on Geoscience and Remote Sensing**, Vol GE-25, No.3, May 1987.

McLaren, R.A. (1989). "Visualisation techniques and applications within GIS". **Proceedings - Auto-Carto 9**, American Society for Photogrammetry and Remote Sensing and American Congress on Surveying and Mapping, Falls Church, VA.

McLaughlin, J. (1984). "The multipurpose cadastre concept: Current status, future prospects", Paper presented to **Seminar on the Multipurpose Cadastre: Modernizing Land Information Systems in North America**, The Institute for Environmental Studies, University of Wisconsin-Madison, WI.

Moellering, H. (1983). "Designing Interactive Cartographic Systems Using the Concepts of Real and Virtual Maps", **Proceedings - Auto Carto Six**, Vol II, the Steering Committee for the Sixth International Symposium on Automated Cartography, Ottawa, Canada.

Moellering, H. Ed. (1986). **Issues in Digital Cartographic Data Standards**, Report #7, National Committee for Digital Cartographic Data Standards [US], The Ohio State University, Columbus, OH.

Moellering, H. Ed. (1987). **Issues in Digital Cartographic Data Standards**, Report #8, National Committee for Digital Cartographic Data Standards [US], The Ohio State University, Columbus, OH.

Moore, G.T and R.G.Golledge (eds) (1976). **Environmental Knowing: Theories, Research, and Methods**, Dowden, Hutchinson and Ross, Stroudsberg,PA.

Morehouse, S. (1985). "ARC/INFO: A geo-relational model for spatial information", **Proceedings - Auto-Carto 7**, American Society for Photogrammetry and Remote Sensing and American Congress on Surveying and Mapping, Falls Church, VA.

Morrison, J.L. (1986). "Cartography: A milestone and its Future", **Proceedings - Auto Carto London**, Vol 1, Ed Michael Blakemore, International Cartographic Association.

Morrison, J.L. (1988). "Digital cartographic data standards: The U.S. experience", **Proceedings - 7th Australian Cartographic Conference**, Volume 1, The Australian Institute of Cartographers, Sydney.

Mounsey, H.M. (1988). "Cartography and interactive video: Developments and applications in Britain", **Proceedings - 7th Australian Cartographic Conference**, Volume 1, The Australian Institute of Cartographers, Sydney.

Muehrcke, Phillip C. (1978). **Map Use: Reading, Analysis, and Interpretation**, JP Publications, Madison,WI.

Murdick, Robert G. (1980). **MIS: Concepts and Design**, Prentice-Hall, Englewood Cliffs, New Jersey, NJ.

Nakamae, E., K. Harada, T. Ishizaki and T.Nishita (1986). "A montage method: The overlaying of the computer generated images onto a background photograph", **Computer Graphics - SIGGRAPH '86 Conference Proceedings**, Volume 20, Number 4, August 1986.

National Research Council (1983). Panel on a Multipurpose Cadastre, **Procedures and Standards for a Multipurpose Cadastre**, National Academy Press, Washington, DC.

NCDCDS [US] (1987). "Proposed standard for digital cartographic data", National Committee for Digital Cartographic Data Standards, U.S.Geological Survey, Washington, DC.

NCDCDS 2 (1986). Working Group II on Data Set Quality, "Testing the Interim Proposed Standard for Digital Cartographic Data Quality", in Moellering, H. Ed. (1986). **Issues in Digital Cartographic Data Standards**, Report #7, National Committee for Digital Cartographic Data Standards [US], The Ohio State University, Columbus, OH.

Nyerges, T.L. (1980). **Modeling the Structure of Cartographic Information for Query Processing**, Unpublished PhD Dissertation, The Ohio State University, Columbus, OH.

Nyerges, T.L. (1989). "Design considerations for a transportation GIS", submitted to **ITE Journal** (Institute of Transportation Engineers - US).

Nyerges, T.L. and K.J.Dueker (1988). "Geographic information systems in transportation", submitted to **Transportation Research Record**, Transportation Research Board, Washington, DC.

Oxburgh, E.R. (1972). "Plate Tectonics" in **Understanding the Earth: A Reader in the Earth Sciences**, eds. I.G.Gass, P.J.Smith and R.C.L.Wilson, 2nd Edition, The Open University Press, Sussex, UK.

Petchenik, B.B. (1979). "From place to space: the psychological achievement of thematic mapping", **American Cartographer**, Vol 6, No 1.

Peucker, T.K. (1972). **Computer Cartography**, Commission on College Geography, Resource Paper No 17, Association of American Geographers, Washington, DC.

Peucker, T.K. and N.R.Chrisman (1975). "Cartographic data structures", **American Cartographer**, Vol 2, No 1.

Peuquet, D. (1979). "Raster processing: An alternative approach to automated cartographic data handling", **American Cartographer**, Vol 6.

Portner, J. (1982). **Beliefs Regarding Issues Relating to Land Records**, M.S. Thesis, Department of Landscape Architecture, University of Wisconsin-Madison, WI.

Portner, J. and Niemann, B.J. (1983). "Belief Differences among Land Records Officials and Users: Implications for Lands Records Modernization", Paper presented at **URISA**, Atlanta, GA.

Puniard, D. (1987). "The Australian Defence Force requirements for land related information", Paper presented to **Strategic and Defence Studies Centre Workshop on Geographic Information Systems and Australian Defence Force Requirements**, The Research School of Pacific Studies, The Australian National University, Canberra.

Raphael, B. (1976). **The Thinking Computer: Mind Inside Matter**, W.H.Freeman and Company, San Francisco, CA.

RASvy (1983). **An Introduction to the AUTOMAP 2 System**, Royal Australian Survey Corps.

Rhind, D. (1988). "A GIS Research Agenda", **International Journal of Geographic Information Systems**, Ed. J.T.Coppock and K.E.Anderson, Vol.2, No.1, January-March 1988, Taylor and Francis, London, UK.

Richardus, P. and R.K. Adler (1972). **Map Projections: For Geodesists, Cartographers and Geographers**, North-Holland, Amsterdam.

Robinson, A., R. Sale and J.L. Morrison (1978). **Elements of Cartography**, Ed. 4, John Wiley and Sons, New York, NY.

Rosen, B. and A. Saalfeld (1985). "Match criteria for automatic alignment". **Proceedings - Auto-Carto 7**, American Society for Photogrammetry and Remote Sensing and American Congress on Surveying and Mapping, Falls Church, VA.

Rossmeissl, H., M.Domaratz, J. List, L. Usery (1987). "Proposed Definition of Cartographic Features for Digital Line Graph-Enhanced (DLG-E)", Report of Committee Investigating Cartographic Entities, Definitions and Standards (CICAEDAS), National Mapping Division, United States Geological Survey, Washington, DC.

Rugg, R.D. (1983). "Building a Hypergraph-Based Data Structure: The examples of census geography and the road system", **Proceedings - Auto Carto Six**, Vol II, the Steering Committee for the Sixth International Symposium on Automated Cartography, Ottawa, Canada.

Salomonson, V.V. (1983). "Water resources assessment", **Manual of Remote Sensing**, 2 Ed, Vol 2, Ed R.N.Colwell, American Society of Photogrammetry, Falls Church, VA.

Samet, H. (1984). "The quadtree and related hierarchical data structures", **Computing Surveys**, Vol 16, No 2, June 1984.

Shea, K.S.and R.B. McMaster (1989). "Cartographic generalization in a digital environment: When and how to generalize". **Proceedings - Auto-Carto 9**, American Society for Photogrammetry and Remote Sensing and American Congress on Surveying and Mapping, Falls Church, VA.

Shiryaev, E.E. (1987). **Computers and the Representation of Geographical Data**, translated from the Russian by V.M.Divid, N.N.Protsenko and Yu.U.Rajabov, John Wiley and Sons, Chicester, UK.

Smith, A.G. (1972). "Continental Drift" in **Understanding the Earth: A Reader in the Earth Sciences**, eds. I.G.Gass, P.J.Smith and R.C.L.Wilson, 2nd Edition, The Open University Press, Sussex, UK.

Smith, T.R., S. Menon, J.L. Star and J.E. Estes (1987). "Requirements and principles for the implementation and construction of large-scale geographic information systems", **International Journal Geographical Information Systems**, Vol. 1, No. 1, Taylor and Francis, London.

Snyder, J.P. (1983). **Map Projections Used by the U.S. Geological Survey**, Geological Survey Bulletin 1532, Ed 2, United States Department of the Interior, Washington, DC.

Southard, R.B. (1984). "Automation of the national cartographic data base: Implications to state and local governments", Paper presented to **Seminar on the Multipurpose Cadastre: Modernizing Land Information Systems in North America**, The Institute for Environmental Studies, University of Wisconsin-Madison, WI.

Stamp, Sir D. (Ed) (1966). **A Glossary of Geographical Terms**, 2nd edn, Longmans, London, UK.

Starr, L.E. (1986). "MARK II: The next step in digital systems development at the U.S. geological Survey", **Proceedings - Auto Carto London**, Vol 2, Ed Michael Blakemore, International cartographic Association.

Steyaert, L.T. (1989). "Investigating the use of geographic information systems technology in the computer workstation environment for global change research". **Proceedings - GIS / LIS**, ASPRS / ACSM Annual Convention, American Society for Photogrammetry and Remote Sensing and American Congress on Surveying and Mapping, Falls Church, VA.

Thompson, C.N. (1986). "Managing the transition to supporting the production of digital geographic products in Military Survey", **Proceedings - Auto Carto London**, Vol 2, Ed Michael Blakemore, International cartographic Association.

Tomlin, C.D. (1983). "A Map Algebra", Paper presented to **Harvard Computer Graphics Conference**, Laboratory for Computer Graphics and Spatial Analysis, Harvard University, Cambridge, MA.

Tomlinson, R.F. (1968). "A geographic information system for regional planning", **Land Evaluation**, Ed G.A.Stewart, Macmillan of Australia, Melbourne.

Tomlinson, R.F. (1972). **Geographic Information Systems, Spatial Data Analysis, and Decision Making in Government**, Doctoral Dissertation, University College, London, UK.

Tomlinson, R.F. (1978). "Difficulties inherent in organizing earth data in storage form suitable for query", **Proceedings - Auto-Carto III**, American Society for Photogrammetry and Remote Sensing and American Congress on Surveying and Mapping, Falls Church, VA.

Tomlinson, R.F. (1987). "Current and potential uses of geographic information systems. The North American experience", **International Journal of Geographic Information Systems**, eds J.T.Coppock and K.E.Anderson, Vol 1, No 3, Taylor and Francis, London.

Trewartha, G.T., A.H. Robinson and E.H.Hammond (1967). **Elements of Geography**, Ed 5, McGraw-Hill, New York, NY.

Vonderohe, A.P. and N.R.Chrisman (1985). "Tests to establish the quality of digital cartographic data: Some examples from the Dane County Lands Records Project", **Proceedings - Auto-Carto 7**, American Society for Photogrammetry and Remote Sensing and American Congress on Surveying and Mapping, Falls Church, VA.

Walker, H. (1989). "Use of the 1:2,000,000 Digital Line Graph Data in Emergency Response", **Proceedings - Auto-Carto 9**, American Society for Photogrammetry and Remote Sensing and American Congress on Surveying and Mapping, Falls Church, VA.

Weisnet, D.R. and M. Matson (1983). "Remote sensing of weather and climate", **Manual of Remote Sensing**, 2 Ed, Vol 2, Ed R.N.Colwell, American Society of Photogrammetry, Falls Church, VA.

White,M. (1987). "Digital map requirements of vehicle navigation", **Proceedings - Auto-Carto 8**, American Society for Photogrammetry and Remote Sensing and American Congress on Surveying and Mapping, Falls Church, VA.

Williams, R.J. (1980). "Automated cartography with navigational applications", **Proceedings - 4th Australian Cartographic Conference**, The Australian Institute of Cartographers, Hobart.

Williams, R.J. (1984). "Who or what is DES?", **Cartography**, Vol 13, No 3, The Australian Institute of Cartographers.

Williams, R.J. (1985a) "Enquiry Systems for the Interrogation of Infrastructure", **Proceedings - AUTO-CARTO 7**, American Society for Photogrammetry and Remote Sensing and American Congress on Surveying and Mapping, Falls Church, VA.

Williams, R.J. (1985b). **Enquiry Systems for the Interrogation of Infrastructure in Areas of Large Geographic Extent**, Unpublished Masters Thesis, University of Wisconsin - Madison, WI.

Williams, R.J. (1986). "Automated cartography: The next development", **Proceedings - 6th Australian Cartographic Conference**, The Australian Institute of Cartographers, Melbourne.

Williams, R.J. (1987). "Evolution in cartography: data intelligence", **Cartography**, Vol 16, No 2, The Australian Institute of Cartographers.

Williams, R.J. (1988). "Analysis of the road transportation network", **Proceedings - 7th Australian Cartographic Conference**, Volume 2, The Australian Institute of Cartographers, Sydney.

Winograd, T. and F. Flores (1986). **Understanding Computers and Cognition: A New Foundation for Design**, Ablex Publishing, Norwood, New Jersey, NJ.

Wright, J.B. (1972). "Volcanism and the Earth's Crust" in **Understanding the Earth: A Reader in the Earth Sciences**, eds. I.G.Gass, P.J.Smith and R.C.L.Wilson, 2nd Edition, The Open University Press, Sussex, UK.

d'Ydewall, Géry and Patrick Delhaye (1988). "Artificial intelligence, knowledge extraction and the study of human intelligence", **Cognitive Science**, 115, February 1988.

Yoelli, P. (1959). "Relief shading", **Surveying and Mapping**, Vol 19.

Zarzycki, J.M. and Jiwani, Z. (1986). "Canadian Standards for Exchange of Digital Topographic Data", **The Canadian Surveyor**, Vol 40, No 4.

QUOTATION

Extract from *Sylvie and Bruno Concluded* from John Fisher (ed), **The Magic of Lewis Carroll**, Penguin Books.

BIOGRAPHICAL SKETCH

Robert Williams has twenty three years experience in the disciplines of surveying and mapping. After enlisting in the Australian Regular Army in 1965, he joined the Royal Australian Survey Corps. During the next nine years he attended a series of technical courses in geodesy, topographic surveying, photogrammetry and mapping topics, as well as working in technical and supervisory roles in the map production process. In 1976 he became the first supervisor of the photogrammetric and manual digitizer input sub-system of RASvy's AUTOMAP I computer-assisted mapping system.

During the period 1977-79 Robert studied for the award of BA Computing Studies majoring in cartography and undertaking his major project in oblique aspect map projections. Then followed managerial roles in aeronautical chart and topographic map production. In 1983-85 Robert undertook further studies, this time at the University of Wisconsin - Madison obtaining a MSc (Cartography) and specializing in computerized land information systems and contemporary cartography.

On return to Australia Robert has been employed as a research officer at the Army Survey Regiment at Bendigo, Victoria before undertaking this research at the Australian Defence Force Academy.

Robert specializes in contemporary cartography, the evolution in digital processing of geographic information and geographic data structures. He has presented five papers to conferences in Australia, two papers to conferences in the United States of America and has had a further four articles published in cartography journals.

Robert is married and two sons aged 17 and 14.